

DETERMINING OPTICAL CONSTANTS FOR ThO_2 THIN FILMS
SPUTTERED UNDER DIFFERENT BIAS VOLTAGES
FROM 1.2 TO 6.5 eV
BY SPECTROSCOPIC ELLIPSOMETRY

by

William Ray Evans

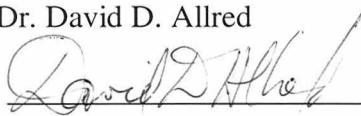
Submitted to Brigham Young University in partial fulfillment
of graduation requirements for University Honors

Department of Physics and Astronomy

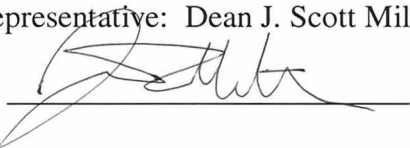
Brigham Young University

December 2005

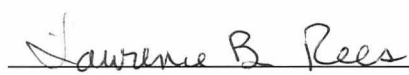
Advisor: Dr. David D. Allred

Signature: 

Honors Representative: Dean J. Scott Miller

Signature: 

Faculty Referee: Dr. Lawrence Rees

Signature: 

ABSTRACT

DETERMINING OPTICAL CONSTANTS FOR ThO₂ THIN FILMS
SPUTTERED UNDER DIFFERENT BIAS VOLTAGES
FROM 1.2 TO 6.5 eV
BY SPECTROSCOPIC ELLIPSOMETRY

William R. Evans

Department of Physics and Astronomy

Bachelor of Science

I report optical constants (n and k) between 1.24 and 6.5 eV of reactively sputtered ThO₂ thin films sputtered at bias voltages of 0, 50, 64, 65, 68 and 70 V. No significant dependences in refractive index (n) on bias voltage or film thickness were detected. We find n is dispersive over the full range, with values of 1.82 ± 0.06 , 1.85 ± 0.06 , 1.93 ± 0.06 , 2.24 ± 0.07 , at 1.2, 2.5, 4.0 and 6.0 eV respectively. An absorption feature at about 6.5 eV in ThO₂ is most likely a narrow absorption band with a full width at half maximum of about 0.4 eV.

ACKNOWLEDGEMENTS

First of all, I would like to thank my wife, Kristin, and the rest of my family, especially my parents Robert P. Evans and Loretta L. Evans, who have all been a never-ending source of help and support during this project. I would also like to thank my advisor, Dr. David Allred, who has made this project a real success. His guidance, expertise, and encouragement have made this entire project what it is. I would also like to thank all the members of the BYU thin film optics group, past and present, without whose help and training this would not have happened. I finally gratefully acknowledge the different sources of support and funding that have made all of this possible.

TABLE OF CONTENTS

Title and Signature Page	i
Abstract	ii
Acknowledgements	iii
Table of Contents	iv
List of Figures	vi
 1. Introduction	 1
1.1. The EUV and ThO ₂	1
1.1.1. Applications for EUV optics	1
1.1.2. ThO ₂ as a Potential Highly Reflective Coating	3
1.1.3. Biased Radio-Frequency Sputtering	5
1.1.4. Ellipsometry and Measuring in the Visible and Near UV	6
1.2. Optics and Theory	8
1.2.1. Basic Optics	8
1.2.2. The Effect of Film Density on Optical Properties	10
 2. Experimental Procedure	 12
2.1. Film Deposition	12
2.1.1. RF Magnetron Sputtering	12
2.1.2. Different Substrates used for Different Measurements	13
2.2. Film Characterization	15
2.2.1. XRD (X-Ray Diffraction) – Thickness	15
2.2.2. XPS (X-ray Photoelectron Spectroscopy) – Composition	17
2.2.3. AFM (Atomic Force Microscopy – Roughness	19
2.2.4. Ellipsometry	20
2.2.5. Fitting Optical Constants	22
 3. Reported data and discussion	 27
3.1. Index of Refraction as Compared to Bias Voltage, Thickness, and Literature	27
3.2. Relative Independence of n and k	31
3.3. Narrow Absorption Band	34
3.4. Low Energy Absorption	35
3.5. The Band Gap of ThO ₂	36
 4. Conclusions	 40

5. References	42
Appendices	
A. Detailed Experimental Procedure	44
A.1. Data Acquisition	44
A.2. Data Fitting	44
A.2.1. Building the Model	44
A.2.2. Fitting the Data	45
B. Tabulated Data	52
B.1. Heather Liddell's Data	52
B.2. n from Sellmeier Models	53
B.3. k fit with Oscillators	70
B.4. k fit Point-by-Point	89

LIST OF FIGURES

1.1: Calculated reflectances of various materials in the EUV plotted against photon energy.	3
2.1: The RF sputtering system "Joey."	12
2.2: X-ray diffraction.	15
2.3: X-ray diffraction crystallography graph of sample ThO ₂ 050604-2 on quartz.	16
2.4: Graph of composition as a function of sputtering time on sample ThO ₂ 050604-2 as measured by XPS.	18
2.5: Atomic Force Microscope.	19
2.6: AFM measurements made on sample ThO ₂ 050818 on silicon.	19
2.7: Showing k fit point by point, compared to n fit using a Sellmeier model and k modeled using a Tauc-Lorentz oscillator.	22

3.1: Fit values of n for different samples from 1.0 to 6.5 eV.	27
3.2: Fit values of n for different samples from 3.0 to 5.0 eV.	28
3.3: Average values of n and their standard deviations for all samples, biased samples vs. unbiased samples, and thick samples vs. thin samples.	29
3.4: Plots showing n vs. photon energy for selected samples of our data and for the optical constants published by Heather Liddell (1974).	31
3.5: Plots showing n and k fit for two different samples. Here different values of n were used, but the samples were accidentally fit to the same transmission data to obtain k	32
3.6: Plots showing n and k for two different samples where the different n s were used but the samples were accidentally fit to the same transmission data to obtain k	32
3.7: Plots showing n and k for two different fits on the same sample. The first fit of n was done assuming no absorption. The second fit of n was done after fitting the absorption.	33
3.8: Plots showing αd vs. E on several samples. Here α (or k) was fit point by point.	34
3.9: A plot of αd vs. E for samples ThO2 050520, sputtered at 68 V bias voltage to a thickness of 53 nm, and ThO2 050527, sputtered unbiased to a thickness of about 50 nm.	35
3.10: A plot of α^2 vs. E for sample ThO2 050818, sputtered at 65 V bias voltage to a thickness of 539 nm, with a linear fit.	37
3.11: A plot of $\alpha^{1/2}$ vs. E for sample ThO2 050604, sputtered at 64 V bias voltage to a thickness of 6.589 nm, with a linear fit.	38

A.1: First fit of n on sample ThO2 050526 on silicon.	45
A.2: A first fit of k (point by point) to sample ThO2 050526 on quartz.	47
A.3: Values of n and k obtained after the first fit of k (point by point).	48
A.4: Fit parameters window showing the point-by-point fit of k and the smooth oscillator curve used to model it.	48
A.5: A second fit of k using oscillators.	49
A.6: A final fit of n including the absorption from the last fit.	50
A.7: Plot showing the final, reported values of n and k after the final fit of n , taking into account absorption.	51

CHAPTER 1: INTRODUCTION

1.1. The EUV and ThO₂

The Extreme Ultraviolet (EUV) portion of the electromagnetic spectrum is that portion with photon energies from about 12 to 120 eV. (This corresponds to about 10 to 100 nm in wavelength or frequencies of 3 000 to 30 000 THz.) [1] The optical properties of many materials in the visible range of the electromagnetic spectrum have been well-known for years. However, lack of motivation and lack of technology have slowed progress in the EUV. Nonetheless, recent applications for EUV optics have motivated new research in this area.

1.1.1. Applications for EUV Optics

Lithography is the process by which integrated circuit components are etched onto wafers to make computer chips. The process functions similarly to traditional photography where an image is imprinted onto the film in a camera. In order to make faster and smaller computer chips, manufacturers must be able to etch smaller components onto these wafers. The size of components that can be formed by lithography is dependant on the wavelength of light used. With shorter wavelengths, smaller features may be created, thus producing smaller and faster computer chips. Intel has targeted EUV lithography for high-volume computer chip production by 2009. [2]

Biological applications of EUV optics such as soft x-ray microscopes, have also been developed. These have advantages over visible light microscopes in that they have much higher resolution. Soft x-ray microscopes also have advantages over electron

microscopes because with soft x-ray microscopes the specimen does not have to be dried nor stained, it can be imaged at atmospheric pressure, and the sample can be thicker than with electron microscopy. [3]

Astronomers have always been interested in studying the universe in any way possible. EUV astronomy has suffered because EUV light is absorbed by the atmosphere, so any EUV observations must be done by space-based telescopes. Recently, however, EUV astronomy has gained new interest due to the increase in the number of space-based telescopes. Members of the Brigham Young University (BYU) EUV research group helped to build optical systems on the IMAGE (Imager for Magnetopause-to-Aurora Global Exploration) satellite, launched 25 March 2000. [4] IMAGE uses ultraviolet and other imaging systems to observe the dynamics in the earth's magnetosphere. [5] More recently, the BYU EUV group also constructed a mirror for the European Space Agency's (ESA) Venus Express probe which is scheduled to be launched in October of 2005. The Venus Express is designed to study the clouds, atmosphere, and weather of Venus. [6]

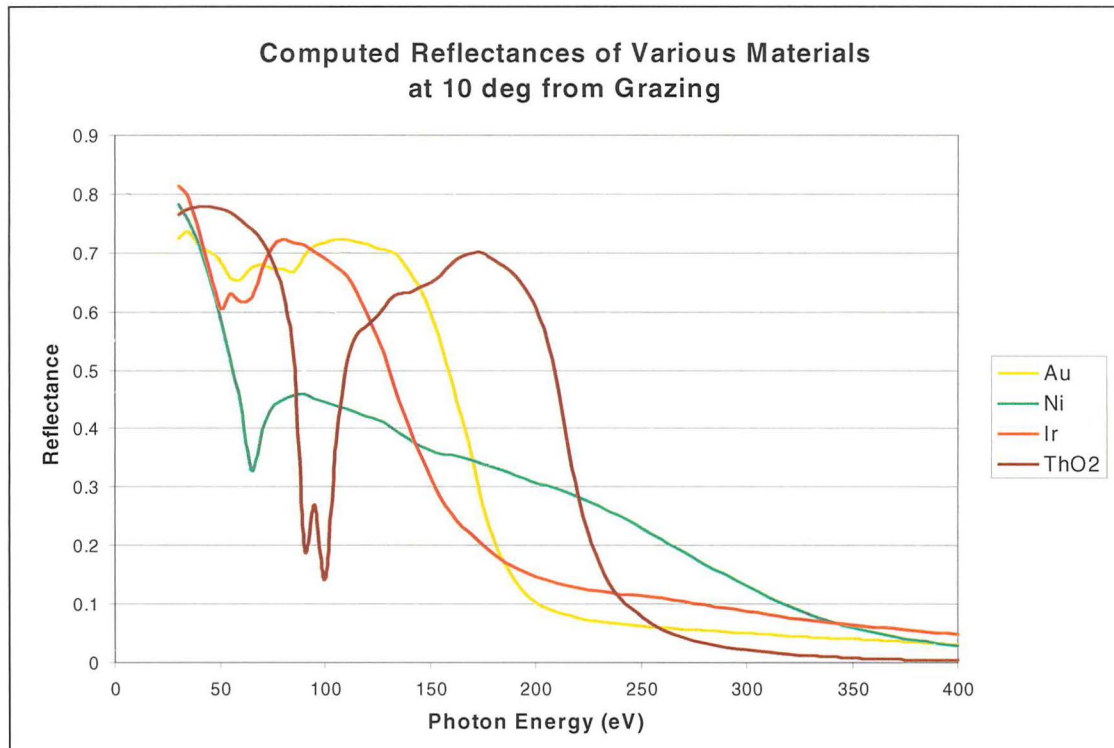


Figure 1.1: Calculated reflectances of various materials in the EUV plotted against photon energy. These reflectances were calculated using tabulated optical constants by the CXRO website. [7]

1.1.2. ThO₂ as a potential highly reflective coating

The BYU EUV thin film optics group has been studying the optical constants of various materials in the EUV for several years. One of the materials studied most recently is thorium (Th). As we can see from the calculated reflectances of thorium dioxide (ThO₂) in Figure 1.1, and according to published optical constants for Th and ThO₂ from the Center for X-Ray Optics (CXRO), it would appear that Th and ThO₂ are more reflective at certain energies of interest (eg. 200 eV) than many other monolayer coatings in common use today. Figure 1.1 shows the computed reflectances for various materials in the EUV. These reflectances have been computed using tabulated optical constants provided by CXRO. The materials included in the graph include thorium dioxide, which we are currently studying, also gold, nickel, and iridium. Gold, nickel and iridium are common reflector coatings in use in EUV optics. [8] Initial investigations by

our group also confirm that thorium and thorium dioxide are among the best monolayer reflectors known for specific regions of the spectrum. [9]

Most recently, we have been studying reactively sputtered thorium dioxide (as opposed to ThO_2 coming from thorium films that have been oxidized in air). Thorium dioxide has several advantages over regular thorium. First of all, the surfaces of thorium films naturally oxidize in air. This produces an effective bilayer of thorium dioxide on thorium. Since the precise thickness of the oxide layer is not always known, this can produce difficulties in modeling the data. However, with reactively sputtered thorium dioxide films, the entire film is already thorium dioxide and is stable against further oxidation. Also, thorium has only one stable oxidation state, ThO_2 . Therefore, with reactively sputtered thorium dioxide we know very well what we have. Also, the predicted reflectances of ThO_2 thin films are very similar to those of thorium thin films.

One thing to note, however, is that ThO_2 has the highest melting point of any oxide known, and one of the highest of any material known (3300 °C). [10] This indicates that the chemical bonds in ThO_2 are extremely strong, especially at room temperature (25 °C). Because of these exceptionally strong chemical bonds, as a ThO_2 film is sputtered, the atoms essentially stick where they land. This may produce films that are not fully dense (fully dense means that the atoms are in a close-packed lattice) on deposition. In the EUV, the density of a film is one of the most influential factors in determining that film's index of refraction, n . (Details regarding n and density will be covered in more detail later.) In general, materials that are more dense will have higher indices of refraction. One way to affect the density of a thin film is with the method of biased sputtering, which will be introduced in the next section.

1.1.3. Biased Radio-Frequency Sputtering

Radio-Frequency (RF) sputtering is the method by which we deposit our thin films. The exact details of this method will be covered in the next chapter, but we will give a brief overview of the method here for context. During sputtering, the material to be deposited (the “target”) is mounted on a sputter gun and installed inside a vacuum chamber. For our project, the target used was made of thorium metal. The substrates onto which the film is to be deposited (the “samples”) are also mounted on a sample holder in the chamber. The chamber is pumped down to a high vacuum. Argon is then introduced. The sputter gun, connected to a power supply, produces strong electromagnetic fields which ionize the argon, creating an argon plasma. This plasma is focused by these fields onto the target. The heavy argon ions knock off thorium atoms from the target. These atoms basically “spray paint” anything in the chamber, coating anything that isn’t obstructed, including the samples. If oxygen is introduced into the plasma, the oxide of the target material (in our case ThO_2) is reactively deposited.

Normally, the sample holder and the chamber are grounded. However, the sample holder can be set to a negative “bias voltage” (hence, “biased radio-frequency sputtering”). The idea behind biased sputtering is that this negative voltage will pull argon ions out of the plasma. These ions will then pound into the thin film. This is theorized to produce a smoother, denser film. The analogy is cold-working a piece of metal, pounding it to make it smoother and harder. A bias voltage system was installed on our sputter chamber for this project.

The purpose of this project was to determine if there would be a noticeable change in the optical constants of ThO_2 thin films sputtered under different bias voltages, and what that change would be.

1.1.4. Ellipsometry and Measuring in the Visible and Near UV

Although our research group is principally interested in the extreme ultraviolet, there are several concerns in measuring a large number of thin films in the EUV. First of all, the equipment required is not local. We usually go to the Advanced Light Source (ALS) at Lawrence Berkley Laboratory in Berkley, California, to measure the reflectances and transmittances of our films in the EUV. Naturally, this results in large costs and a large time commitment. Also, when measuring films in the EUV, cleanliness and roughness become more vital concerns. The light waves we use to measure in the EUV have wavelengths on the order of 10 – 20 nm (60 – 120 eV). At these sizes, even minute amounts of roughness or contamination can greatly affect the reflectance of a mirror. When attempting to measure the large number of samples that naturally come with testing a new preparation procedure, and doing so in a limited amount of time, the concerns with time, cost, cleanliness, and roughness make direct EUV measurements impractical.

We found that visible and near-ultraviolet spectroscopic ellipsometry could be a viable alternative for our purposes. The precise mechanics of spectroscopic ellipsometry will be covered in the next chapter. This section will briefly cover some of the advantages of using visible and near UV ellipsometry as opposed to direct EUV measurements. The spectroscopic ellipsometer at BYU that we used has the capability to reliably measure transmission and ellipsometric reflection between about 1.0 and 6.5 eV (about 200 – 1240 nm). For comparison, visible light is between about 1.5 and 3.5 eV (about 400 – 800 nm). Some advantages with visible and near UV ellipsometry are that the equipment is local, less costly, and less time-consuming. We can quickly measure

large numbers of samples and fit n (the index of refraction), k (the absorption constant), and thickness parametrically with a variety of different methods. Also, at these larger wavelengths, cleanliness and roughness are much less of an issue. We do not fail to notice, however, that while with spectroscopic ellipsometry we measure between 1.0 and 6.5 eV, the ALS measures between 50 and 600 eV, so we are really measuring a very different part of the spectrum. Also, in the EUV the correlation between density and the index of refraction is more pronounced, while in the visible and near UV, a host of other factors also affect the index of refraction. However, as we will discuss later, altering the density of a film should similarly affect its index of refraction at all energies, even though this effect may be more pronounced at some energies than at others.

1.2. Optics and Theory

1.2.1. Basic Optics

For purposes of introduction, we will briefly cover some basic optical theory. Some of the main purposes of our project involve finding the index of refraction of certain materials. The index of refraction is a complex number, $\tilde{N}$, where $\tilde{N} = n + i \cdot k$. $\tilde{N}$ is a function of the frequency of light. Often, the real part of the index of refraction, n , is referred to simply as the index of refraction, with $\tilde{N}$ being distinguished as the *complex* index of refraction. For simplicity, we will use this convention. The index of refraction, n , is also the ratio of the speed of light in vacuum and the speed of light in the material. The imaginary part of the complex index of refraction, k , is often referred to as the coefficient of absorption. This is because k governs how quickly light is absorbed when passing through a medium. In EUV work, it is customary to use δ and β , instead of n and k . These are given by $\delta = 1 - n$, and $\beta = k$. It is also customary to measure angles from grazing, rather than from the normal to the surface. However, since we are working primarily in the visible and near UV for this project, we will stick with n , k , and measuring angles from the normal to the surface in this thesis.

In matter, the electric field of a plane wave of light obeys equation 1.1 below. Note that in using complex numbers, the electric field is understood to be the real part of the expression.

$$\bar{E}(x, t) = \bar{E}_0 e^{i\left(\frac{\omega}{c} \tilde{N} \cdot x - \omega t\right)} = \bar{E}_0 e^{i\left(\frac{\omega}{c} (n + i \cdot k) \cdot x - \omega t\right)} = \bar{E}_0 e^{-\frac{\omega}{c} k \cdot x} \cos\left(\frac{\omega}{c} \cdot n \cdot x - \omega \cdot t\right) \quad (\text{eq. 1.1})$$

where

- $\bar{E}_0$ is the amplitude of the plane wave with phase information
- ω is the angular frequency
- t is time
- x is the distance in the direction of propagation
- c is the speed of light. [11]

Most often, we are interested in how light waves behave at interfaces between different materials. With equation 1.1 and boundary conditions given by Maxwell's equations, we can derive a number of relationships that help us describe such behavior:

$$\theta_i = \theta_r \quad (\text{eq. 1.2})$$

(The Reflectance Law)

$$\tilde{N}_i \sin \theta_i = \tilde{N}_t \sin \theta_t \quad (\text{eq. 1.3})$$

(Snell's Law of Refraction)

And the Fresnel Coefficients:

$$r_p \equiv \frac{E_p^{(r)}}{E_p^{(i)}} = \frac{\cos \theta_t \sin \theta_i - \cos \theta_i \sin \theta_t}{\cos \theta_t \sin \theta_i + \cos \theta_i \sin \theta_t} = -\frac{\tan(\theta_i - \theta_t)}{\tan(\theta_i + \theta_t)} = \frac{\tilde{N}_i \cos \theta_t - \tilde{N}_t \cos \theta_i}{\tilde{N}_i \cos \theta_t + \tilde{N}_t \cos \theta_i} \quad (\text{eq. 1.4})$$

$$t_p \equiv \frac{E_p^{(t)}}{E_p^{(i)}} = \frac{2 \cos \theta_i \sin \theta_t}{\cos \theta_t \sin \theta_i + \cos \theta_i \sin \theta_t} = \frac{2 \cos \theta_i \sin \theta_t}{\sin(\theta_i + \theta_t) \cos(\theta_i - \theta_t)} = \frac{2 \tilde{N}_i \cos \theta_t}{\tilde{N}_i \cos \theta_t + \tilde{N}_t \cos \theta_i} \quad (\text{eq. 1.5})$$

$$r_s \equiv \frac{E_s^{(r)}}{E_s^{(i)}} = \frac{\sin \theta_t \cos \theta_i - \sin \theta_i \cos \theta_t}{\sin \theta_t \cos \theta_i + \sin \theta_i \cos \theta_t} = -\frac{\sin(\theta_i - \theta_t)}{\sin(\theta_i + \theta_t)} = \frac{\tilde{N}_i \cos \theta_i - \tilde{N}_t \cos \theta_t}{\tilde{N}_i \cos \theta_i + \tilde{N}_t \cos \theta_t} \quad (\text{eq. 1.6})$$

$$t_s \equiv \frac{E_s^{(t)}}{E_s^{(i)}} = \frac{2 \sin \theta_t \cos \theta_i}{\sin \theta_t \cos \theta_i + \sin \theta_i \cos \theta_t} = \frac{2 \sin \theta_t \cos \theta_i}{\sin(\theta_i + \theta_t)} = \frac{2 \tilde{N}_i \cos \theta_i}{\tilde{N}_i \cos \theta_i + \tilde{N}_t \cos \theta_t} \quad (\text{eq. 1.7})$$

where

- $E_p^{(i)}, E_p^{(r)}, E_p^{(t)}, E_s^{(i)}, E_s^{(r)}, E_s^{(t)}$ are the amplitudes of the incident (*i*), reflected (*r*), and transmitted (*t*) plane waves in the plane of incidence (*p*), and perpendicular to that plane (*s*) at the point of incidence.
- θ_i, θ_t are the incident and transmitted angles, respectively
- $\tilde{N}_i, \tilde{N}_t$ are the indices of refraction for the mediums of the incident and transmitted light waves, respectively. [12]

The Fresnel coefficients, r_p , t_p , r_s , and t_s , are all simply complex numbers. They are most useful in calculating the amount of light that is transmitted and reflected at a

given interface. The effective Fresnel reflection coefficients, $\tilde{R}_p$ and $\tilde{R}_s$, for the entire stack can be calculated from the values of r_p , t_p , r_s , t_s , λ (the wavelength of the light in the layer), and d (the layer thickness) for each layer. [13]

1.2.2. The Effect of Film Density on Optical Properties

The index of refraction is different for each material. In the EUV, the index of refraction depends heavily on the density. It is often modeled with the atomic scattering factor, which, with some approximations, depends almost exclusively on the electron density of the material. [14] In the visible and near UV, the index of refraction depends on many things other than the density of the material, but the density still plays a large role. As we said before, in general, materials that are more dense will have higher values of n .

Mathematically, $(n - 1)$ should be directly proportional to N , the number density of atoms or molecules in the sample. In practice, n depends on many different factors, and often the direct dependence on density is masked by other factors like sample defects, chemical bonds, and minor resonances. However, with many different samples that are otherwise similar, correlation between density and n can be observed.

In his book, *Introduction to Electrodynamics*, Griffiths [15] derives a formula relating the index of refraction to the number density of atoms in a sample. He derives the index of refraction by deriving the complex dielectric constant and the complex permittivity of the material from the complex polarization of the material. He uses a simplified model that models electrons as driven damped harmonic oscillators, using the electric field of the light as the driving force. His derivation assumes a complex linear

dielectric, damping that is proportional to the velocity of an electron, and relatively low density of the sample. His final result is given below as equation 1.8:

$$n \cong 1 + \frac{Nq^2}{2m\epsilon_0} \sum_j \frac{f_j(\omega_j^2 - \omega^2)}{(\omega_j^2 - \omega^2)^2 + \gamma_j^2 \omega^2} \quad (\text{eq. 1.8})$$

where

- n is the index of refraction
- N is the number density of molecules
- q is the electron charge
- m is the effective electron mass
- f_j is the number of electrons with resonance frequency ω_j and damping γ_j in each molecule
- ω is the frequency of the light. [15]

This equation confirms that, for this model, $(n - 1)$ is directly proportional to N , the number density of atoms or molecules.

The basic property of films of higher density having higher indices of refraction allows us to test how biased sputtering is affecting the density of our thin films.

CHAPTER 2: EXPERIMENTAL PROCEDURE

2.1. Film Deposition

2.1.1. RF Magnetron Sputtering

The thorium dioxide thin films were deposited by RF magnetron sputtering. The films were created with the RF sputter system which was built at BYU by Joseph Choi in 2000. [16] Figure 2.1 shows the sputter system used to deposit our films. A four-inch target consisting of the material to be deposited (in this case, thorium metal) is mounted on the sputter gun. The sample, the substrate onto which the film is to be deposited, is mounted about 0.3 m above the target. A shutter separates the two so that we can control when the material is actually being deposited on the sample. The shutter can be removed or replaced by the use of an external knob.

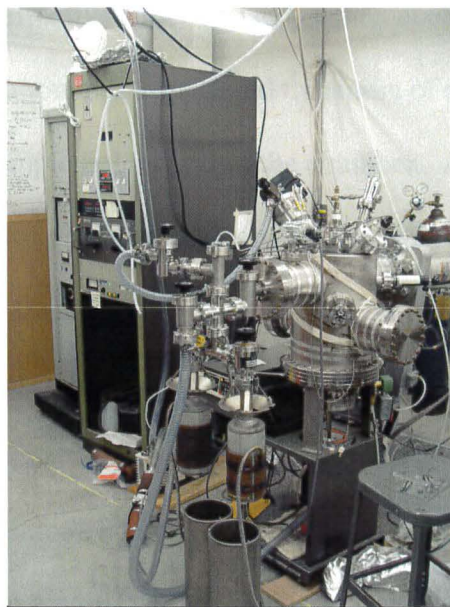


Figure 2.1: The RF sputtering system "Joey."

The chamber is evacuated down to about 10^{-6} torr (about 10^{-4} Pa, or about 10^{-9} atm). This is done with a small turbo pump backed with a mechanical roughing pump. A cryogenic pump can also be used in parallel with the turbo pump. Argon gas is then introduced. Since we are reactively sputtering ThO_2 , oxygen gas is also introduced. The pressure is then stabilized at about 7×10^{-3} torr.

An RF voltage is then applied to the target with the chamber housing grounded. The sample holder, which is electrically insulated from the rest of the sputter chamber, is

connected to a 200 V max DC power supply set to a pre-determined bias voltage. Note that this bias voltage, connected to the sample holder, is different than the RF voltage that drives the sputter gun. The RF voltage applied to the target ionizes the argon atoms and creates a plasma inside the chamber. The sputter gun creates strong electric and magnetic fields concentrated at the target. These fields confine the plasma principally to the space immediately above the target. Because of the potential difference, the positively-charged argon ions are accelerated into the target, dislodging the thorium atoms, which combine with the oxygen in the chamber. This creates an effective spray of ThO_2 which coats anything in its path (ie. straight "line of sight"), although the sputtered thickness of a sample varies depending on the position on the sample holder and in the chamber. As mentioned before, a shutter prevents the sample from being coated until the sputter rate is stabilized. The sputter rate and approximate total thickness deposited can be monitored by a crystal monitor inside the chamber. In our case, the crystal monitor only provides an approximate value for the thickness of the film deposited, due to the effects of bias voltage, tooling factors, and the placement of the samples in the sputter chamber. The crystal monitor can be calibrated if an independent measure of the film thickness is available. We use ellipsometry and low angle x-ray diffraction (XRD) for more precise thickness measurements. [17] The final determination of thickness was the ellipsometry fitting program.

2.1.2. Different Substrates

Both silicon wafers and quartz microscope slides were used as substrates for the deposition of ThO_2 films. The different substrates were used for different types of measurements. Silicon wafers were used primarily for ellipsometric reflectance

measurements and for low angle XRD. The quartz slides allowed us to make transmission measurements of our thin films, but we also used them to take ellipsometric reflectance measurements once we roughened the backs of the slides. The samples sputtered on quartz were also used for the crystallography XRD measurements, even though they gave us less signal, because the silicon samples also gave peaks corresponding to the silicon substrate. The quartz slides did not do so as much. The different substrates were sputtered together to make sure that the films deposited on each were as close to identical as possible.

In analyzing the optical constants on each of the substrates, we had to know the optical constants of the substrates. For the Si / SiO₂ wafers, we used the optical constants published by J. A. Woollam Company with their ellipsometry software [18], assuming a 2-nm thick native silicon oxide layer. For the quartz slides, we determined the optical properties ourselves. We measured the thickness of the quartz slides with a set of high precision calipers. Then we measured the transmission of the slides. We subsequently roughened the backs of the slides and measured the reflection ellipsometrically. We then fit the optical constants in the same way that we fit the optical constants for the ThO₂ thin films. This technique will be covered later. Once we had made satisfactory fits of the optical constants for our quartz slides, we used these constants in our models for fitting the ThO₂ films.

2.2. Film Characterization

Once the thin film samples were prepared, we needed to characterize them. Several different characterization techniques were used. These are outlined below.

2.2.1. XRD (X-Ray Diffraction)

XRD was used to give an initial estimate of the thickness of our samples. X-ray diffraction works by measuring interference peaks from x-rays as they are reflected off of the sample at different angles. Figure 2.2 illustrates how the constructive and destructive interference patterns

detected in the emerging x-rays can give information about the thickness of the films. Local maxima can be approximated with the

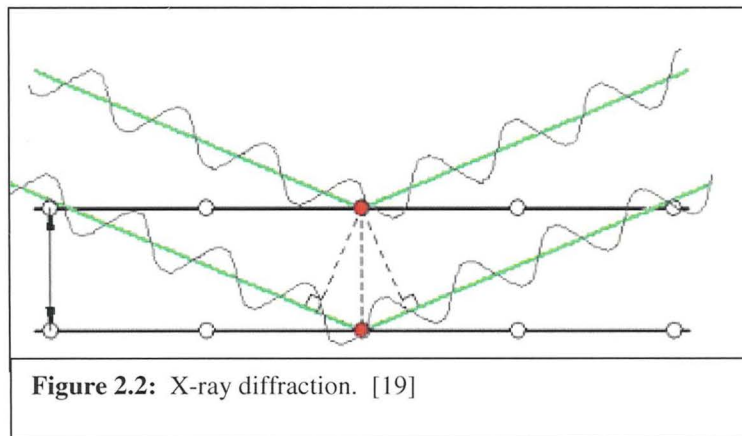
Bragg equation:

$$m\lambda = 2d \sin \theta \quad (\text{eq. 2.1})$$

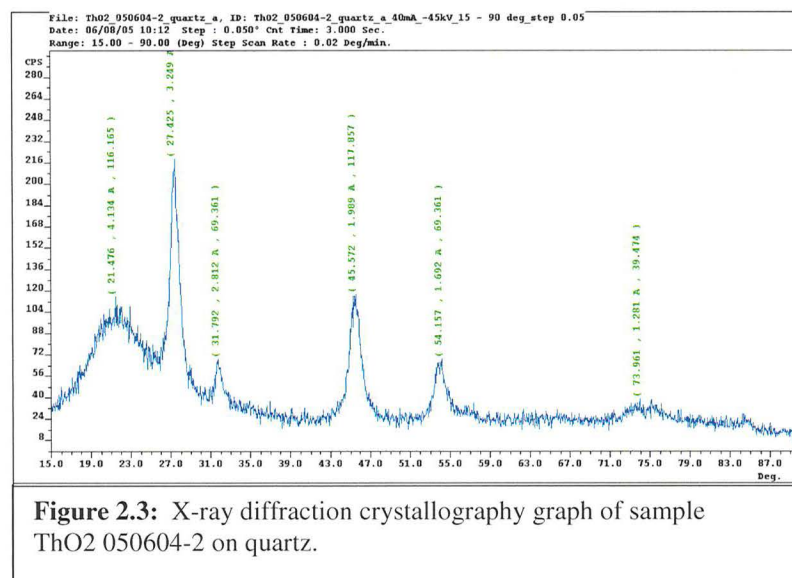
where

- m is an integer
- λ is the wavelength of light used
- d is the film thickness
- θ is the angle from grazing. [20]

This formula is presented to provide background. In our applications, more complex computer models were used to find the thickness from the known wavelengths and angles at which maxima occurred.



XRD can also be used to measure crystallographic structure of a sample. We made XRD crystallography measurements on our thickest sample sputtered on the quartz slide. We did this because the silicon samples gave us extra peaks (ones belonging to the silicon substrate). This made it harder to detect the thorium and thorium dioxide peaks. We made the extra-thick samples in part so that we would be able to make measurements of this type. Each of the different peaks in the XRD graph corresponds to a different crystal lattice configuration in the sample. In the XRD plot below (see Figure 2.3), we can see four sharp peaks, the first three of which correspond roughly to the (111), (200), and (220) configurations. The fourth sharp peak corresponds most closely to the (311) configuration. [21]



We did find that the layer thicknesses we obtained by XRD differed somewhat from the final thicknesses we reported and obtained by ellipsometry fitting. In the end, we used the thicknesses obtained by ellipsometry simply because we had a number of problems in the fitting program when we tried to force the optical constants to conform to the XRD thicknesses.

2.2.2. XPS (X-ray Photoelectron Spectroscopy)

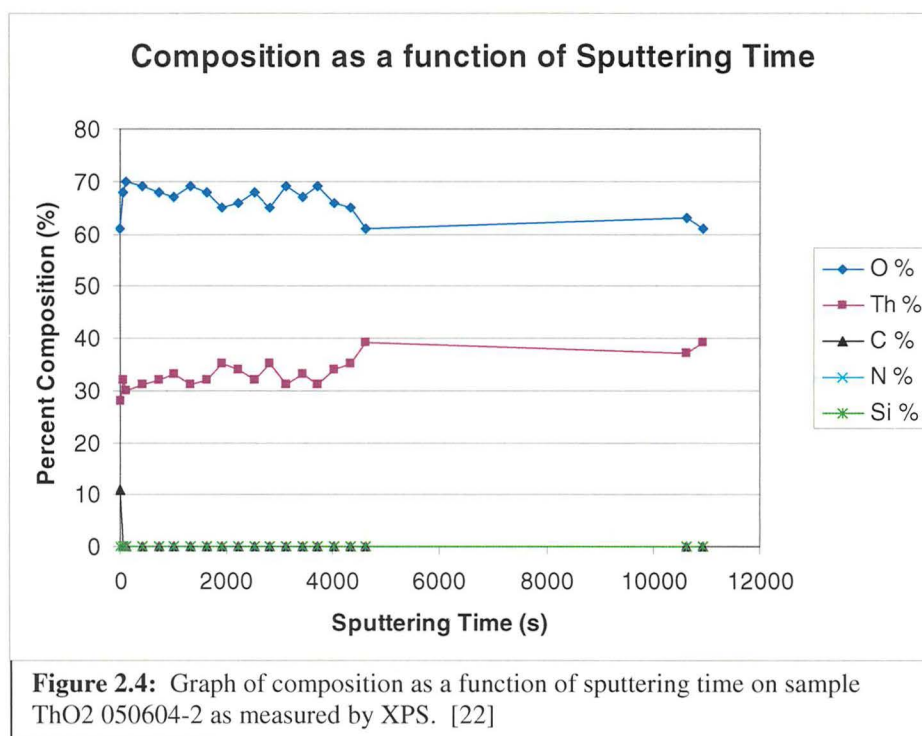
X-ray Photoelectron Spectroscopy is used to determine the composition of a sample's surface. XPS uses the photoelectric effect to determine film composition. The equation for the photoelectric effect is

$$KE_e = hf - \phi \quad (\text{eq. 2.2})$$

where

- h is Plank's constant
- f is the frequency of the incoming photon
- KE_e is the kinetic energy of the ejected electron
- ϕ is the work function of the material.

X-ray photons of a known frequency are shot at a sample surface and the kinetic energies of the ejected electrons are measured. As different materials have different work functions, the ejected electrons will have different energies depending on what material they came from. This is even sensitive to different oxidation states. With a known photon energy, the work function (and thereby the material), and relative abundances of the different materials can be determined. A small hole is then sputtered in the sample, and the composition of this surface, at a little deeper layer, is now measured. This process can be iterated as long as desired.



XPS was performed on selected silicon wafer samples. The graph in Figure 2.4 indicates percent composition as a function of sputtering time because precise translation from sputtering time to depth is not possible. For comparison, ellipsometric fitting placed the thickness of the ThO₂ layer on this sample to be about 3500 Å.

2.2.3. Atomic Force Microscopy (AFM)

Atomic Force Microscopy was used to determine the roughness of some of our samples. AFM works by dragging a record-needle-type tip to “feel” the roughness of a surface (see Figure 2.5). These data can then be analyzed to give a power spectral density, which gives a quantitative analysis of large-scale roughness vs. small-scale roughness.

AFM was performed on four of our samples.

Each showed an RMS (root mean squared) roughness of about 5 nm.

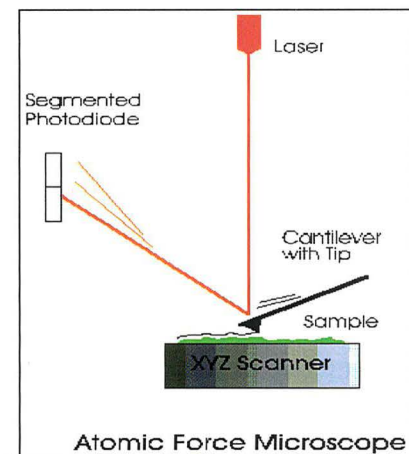


Figure 2.5: Atomic Force Microscope. [23]

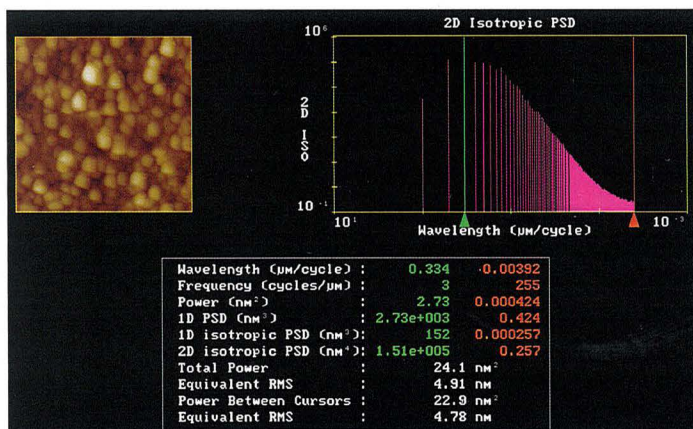


Figure 2.6: AFM measurements made on sample ThO2 050818 on silicon. [24]

Figure 2.6 shows AFM data taken on one of our thick thorium dioxide samples. The picture in the upper-left shows a visual representation of the area scanned. The graph in the upper-right shows a power spectral density, giving the amounts of roughness at

different size scales. The table at the bottom gives some numerical results about the sample, including the RMS roughness, which was later used in the sample modeling and data fitting.

2.2.4. Ellipsometry

The majority of our measurements were made using a John A. Woollam Company, M-2000 rotating analyzer spectroscopic ellipsometer at BYU. This system can measure transmission through a sample, and the polarization and intensity of light reflected off of a sample at different angles. Our system uses and measures light in the visible and near ultraviolet. The ellipsometer measures the intensity and ellipticity of polarized light reflected from a thin film's surface at various frequencies and angles. (The ellipticity of light consists of how circularly or linearly polarized it is, and in what direction its axis is pointing.) This gives information about the thickness and optical properties of the film. The equation for the ellipsometer is given by

$$\rho = \tan(\psi)e^{i\Delta} = \frac{\tilde{R}_p}{\tilde{R}_s} \quad (\text{eq. 2.3})$$

where

- ρ is the complex polarization
- ψ and Δ are parameters measured by the ellipsometer and are related to the orientation and ellipticity, respectively, of the elliptically polarized light
- $\tilde{R}_s$ and $\tilde{R}_p$ are the effective complex Fresnel reflection coefficients for all the layers in the stack, for s and p -polarized light, respectively.

$\tilde{R}_s$ and $\tilde{R}_p$ depend on the values of n , k , and the thickness for each of the different layers in the sample as given in Chapter 1. By analyzing the elliptical polarization of the detected light at different energies and at several different incident angles, we can (with a robust computer model) extract information about the thickness and index of refraction of the film. [13]

In order to gain the best information about the n of our films, we want a good “contrast” between the film and the substrate. In other words, we want the maximum

variation in ψ , which will give us a minimum of uncertainty. To obtain this, we want the Fresnel coefficients for the film-ambient and the film-substrate interfaces to be about equal. This is also the condition for an anti-reflection coating. Neglecting the effects from k (which is small), this works out to be the condition that n for the film should be about the geometric mean of the values of n for the substrate and the ambient. Since the index of refraction of silicon is about 3.5, vacuum is 1, and the index of refraction of ThO₂ is about 1.8, silicon is an ideal choice for a substrate for ThO₂ thin film measurements. ($\sqrt{3.5}=1.87....$)

Also, when making ellipsometric measurements, the best data are obtained when measuring close to the Brewster angle. This is where the difference between R_s and R_p (the reflectance of s -polarized and p -polarized light) is maximized, and where ellipsometry obtains the most precise data. [13] The Brewster angle is given by

$$\theta_B = \tan^{-1} \frac{n_t}{n_i} \quad (\text{eq. 2.4})$$

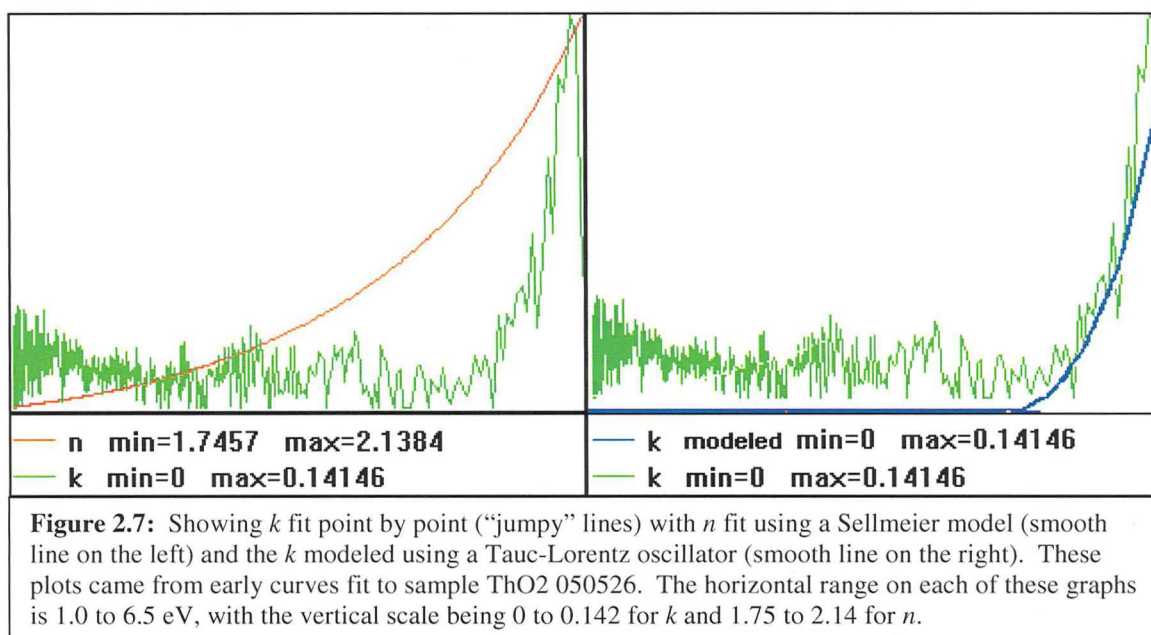
where

- n_i, n_t are the indices of refraction for the medium, and the material, respectively
- θ_B is the Brewster angle. [25]

Since the index of refraction of silicon is about 4.32 at 2.5 eV [26], and the index of refraction of air is close to 1, the Brewster angle for silicon is close to 77°. Therefore, for our measurements on silicon, data were taken every degree from 67° to 83°. For our reflection measurements on quartz slides, data were taken every degree from 53° to 63°. This was done because the index of refraction of our quartz was about 1.45, and therefore the Brewster angle for quartz would be about 56°. Also, the data were taken at 498 different photon energies between 1.253 and 6.509 eV (190.5 and 989.4 nm).

2.2.5. Fitting Optical Constants

The optical constants of our quartz slides and ThO₂ thin films were fit using the software provided with the J. A. Woollam ellipsometer. The software can fit n and k directly, or it can fit them using one of a number of different models. Although the direct fits can be useful from time to time, these usually produce very jumpy values of n and k due to statistical noise. In Figure 2.7, we can see what we mean by “jumpy” values of k , which we see in both graphs. We compare this to the smoother values of n fit from a Sellmeier model (smooth line in the left graph), and to the smoother values of k that we later used as modeled by a Tauc-Lorentz functional distribution (smooth line in the right graph).



For fitting n , the software uses a Sellmeier model, which fits n parametrically with different “poles.” Mathematically, these poles are discontinuities in the complex plane. However, the Sellmeier model does not account for k . That is, mathematically, the poles are on the real axis. Thus absorption is not included. The program does,

however, allow us to fit k by adding to the Sellmeier model additional “oscillators” of different types, which do include absorption. These model n and k using different functional types, including Gaussian, Lorentzian, and others. The parameters pertaining to each of these oscillators can be fit directly to the experimental data or to a reference material. Other types of oscillators can also be added to model n , expanding on the Sellmeier model. In addition, there are a number of other options that the software allows us which can account for specific optical phenomena, such as forbidden gaps.

In order to fit the constants for our ThO_2 thin films, we first needed a good understanding of the optical properties of the substrates on which they were deposited. For the silicon wafers with native silicon oxide layer, the optical constants are well-known and included with the fitting software. For the quartz slides, we had to measure our own constants. This was, in part, due to the fact that the optical properties of quartz slides are not uniform from batch to batch. Optically, there are many different types of quartz. So, we first fit the optical constants for our quartz slides.

In fitting the optical constants for our quartz slides, we first modeled the slides as a “general oscillator” material with a pre-determined thickness. We combined the transmission and reflection data taken on the uncoated quartz slides into a single data set. We then fit n and k directly, point by point, to the experimental data. This yielded a first fit. For the second fit, we started with these values and fit the experimental data using the Sellmeier model for n , and fitting k point by point. This yielded a smoothly varying $n(E)$, but $k(E)$ was not smooth. It was noisy, particularly at higher energies, moving up and down around a (presumed) smoothly varying $k(E)$.

The third and final stage was to try to find a suitable functional form for k . We used the optical constants obtained in the second fit as a “reference material” in the fitting software. We then modeled ϵ_2 (which yields k) with oscillators. This was done by first choosing an oscillator type, and then by fitting its parameters (including oscillator peak position, width, and amplitude) to best match the reference material’s optical constants. Finally, with these parameters governing n and k at reasonably good starting positions, we allowed the program to fit the different parameters to the set of experimental data. At every step we noted the MSE (Mean Squared Error) of our fits to make sure that it was satisfactorily small. In most cases the MSE was less than 3 and often less than 1. Also, each fit was analyzed visually to make sure that the forms of the generated data and the experimental data lined up well (peaks lined up with peaks, troughs with troughs).

In order to fit the optical constants of our ThO₂ thin films, we made the measurements and tried to fit them parametrically, similar to the method outlined above. We found, however, that for the ThO₂ samples, combining the reflection and transmission data sets on quartz produced unsatisfactory, often non-physical, results. And, because the silicon substrate is opaque, there is no transmission data for samples deposited on silicon wafers. Therefore, in fitting the ThO₂ samples, the data sets were kept separate, but the fitting procedure was similar.

For the first fit, we fit n with the Sellmeier model and k point by point to the reflection data from the samples deposited on silicon. For some samples, we were not able to get satisfactory values of k from the silicon samples, so we assumed k to be 0. Other times, we would use the values of k obtained from other, similar thorium samples as an initial guess. In the end, we found that the differences in initial guesses at this step

did not affect the final values of n or k . Afterwards, we fixed these values of n , and fit k again point by point to the transmission data from the quartz samples.

For the second fit, we used the values from the first fit as a reference material and modeled k (actually ϵ_2) with one or more oscillators. As in the case with the quartz substrate described above, the oscillator parameters were first fit to the reference material, and afterwards fit to the experimental data. We fit the absorption oscillator parameters to the transmission data taken on quartz samples and Sellmeier parameters to the reflection data taken on the silicon samples. The MSEs were kept similarly low in the ThO_2 fits.

In each of these steps, we allowed the program to fit the thicknesses of the films starting with the values we had obtained from XRD. We allowed the thicknesses of the ThO_2 films on the quartz and on the silicon to be different, even for samples sputtered in the same run. In most cases the thicknesses turned out to be somewhat different. If we forced both samples to have the same thickness, we found that the MSEs were not low, and the fits were visibly poor. We believe that this difference is possible, and might result from the different positions of the quartz and silicon samples in the sputter chamber during deposition. Specifically, we have found that due to the geometry of the sputter system, those samples and parts of samples that are nearer the center of the sample holder are often coated somewhat more thickly than the others. Another possibility might be the different electrical properties of the silicon and the quartz substrates. The quartz samples might have experienced some self-biasing during deposition, since the quartz is an insulator. Biasing (or inducing an electrical potential) can attract or repel the ionized part

of the incoming argon and thorium atoms. The fraction of the incoming atoms that are ionized is not known.

Finally, a roughness layer was added to the models for some of our samples. We constrained the roughness to be the RMS roughness found by AFM. We used this to obtain our final, reported optical constants.

From these fits we were able to obtain optical constants that generate data that agree very well with our experimental data. These values are presented in the next chapter.

We also were interested in information about the band gap of thorium dioxide. The energy of the band gap of a substance can be obtained by extrapolating a linear fit of α , α^2 , or $\alpha^{1/2}$ vs. energy to 0. [27] The value α is given by

$$\alpha = \frac{4 \cdot \pi \cdot k}{\lambda} = \frac{4 \cdot \pi \cdot E \cdot k}{h \cdot c} \quad (\text{eq. 2.5})$$

where

- k , which is also known as the coefficient of absorption, is the imaginary part of the complex index of refraction
- λ is the wavelength of light used
- E is the photon energy of the light used
- h is Planck's constant
- c is the speed of light.

To obtain values of α , we used the values of n from our final fits for each sample, and fit k point by point. These fit values of k were then translated into α , α^2 , and $\alpha^{1/2}$.

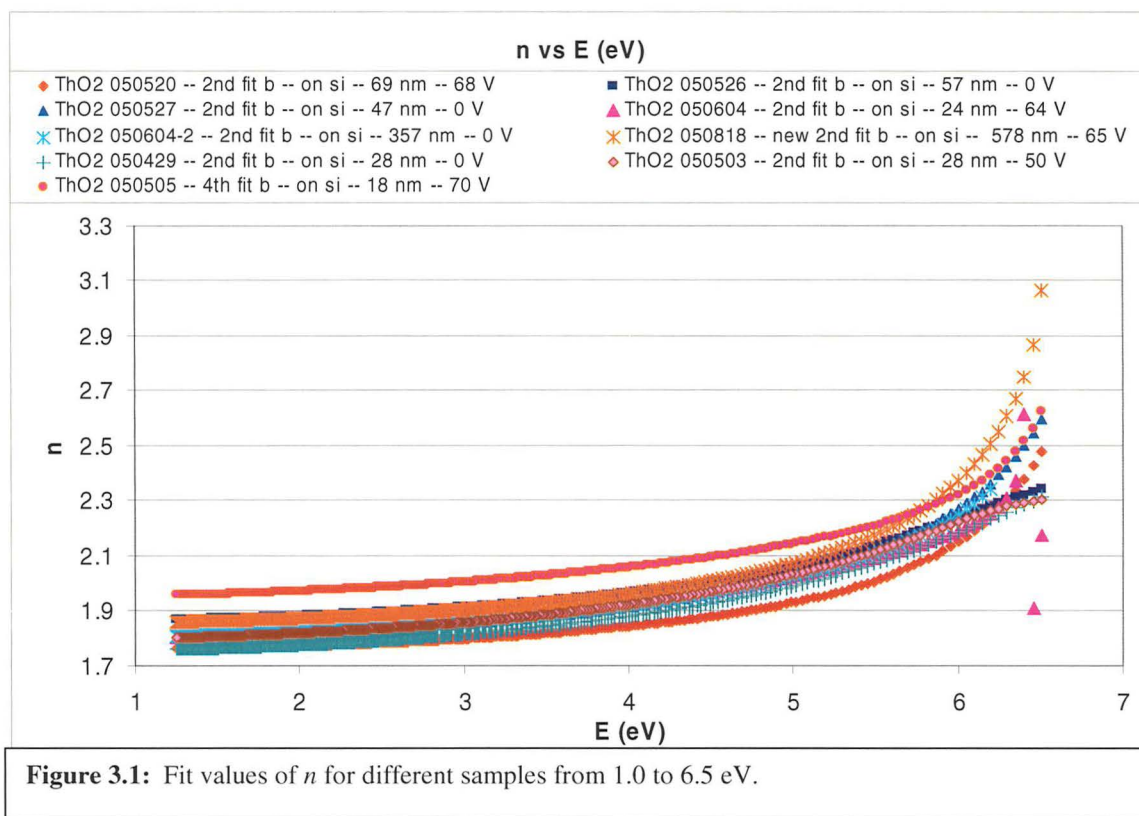
Appropriate linear fits were then obtained. We finally extrapolated the fits to $\alpha = 0$, and found the energy at which this occurred. We used the point-by-point fits for k , because we wanted values of k that did not rely on pre-made assumptions, as the oscillator models did.

CHAPTER 3: REPORTED DATA AND DISCUSSION

After parametrically fitting the experimental data, we found a number of interesting things.

3.1. Index of Refraction as Compared to Bias Voltage, Thickness, and Literature

First of all, as we can see in Figure 3.1, the values of n obtained for the nine samples line up very well below about 5.5 eV. Above about 5.5 eV, the curves diverge somewhat.



From Figure 3.1, we see that the general shapes of the different fits of n are essentially the same up until about 6.0 eV, where the equipment starts to lose sensitivity. We also notice that above about 5.5 eV, some curves climb more steeply than others. This was again primarily result of decreased instrument sensitivity above about 6.0 eV.

Figure 3.2 shows the same plot as above, but detailing the range from 3.0 to 5.0 eV. The fit values of n mostly lie in a narrow band around 1.85 at 3.0 eV. They have a spread of about 0.2, except for sample ThO2 050505, for which we believe we have faulty data. This sample was removed from consideration when making statistical calculations.

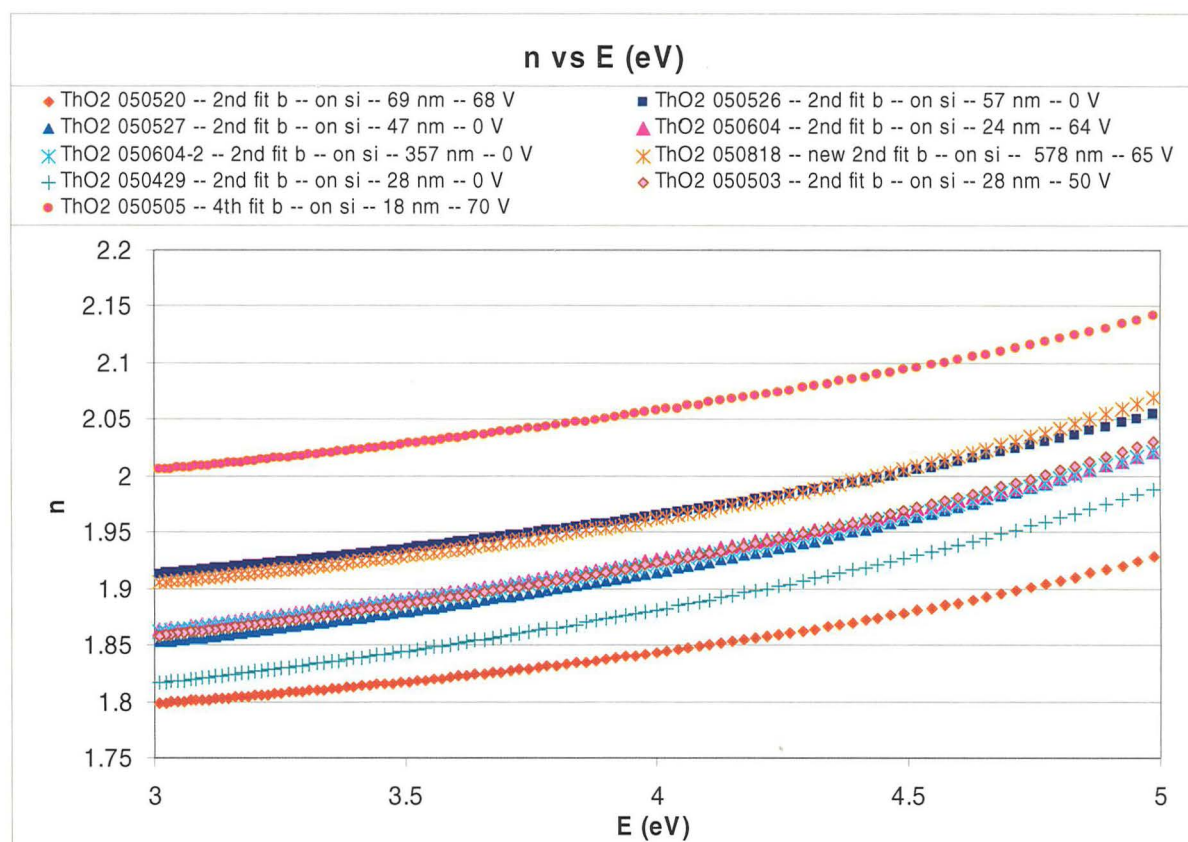
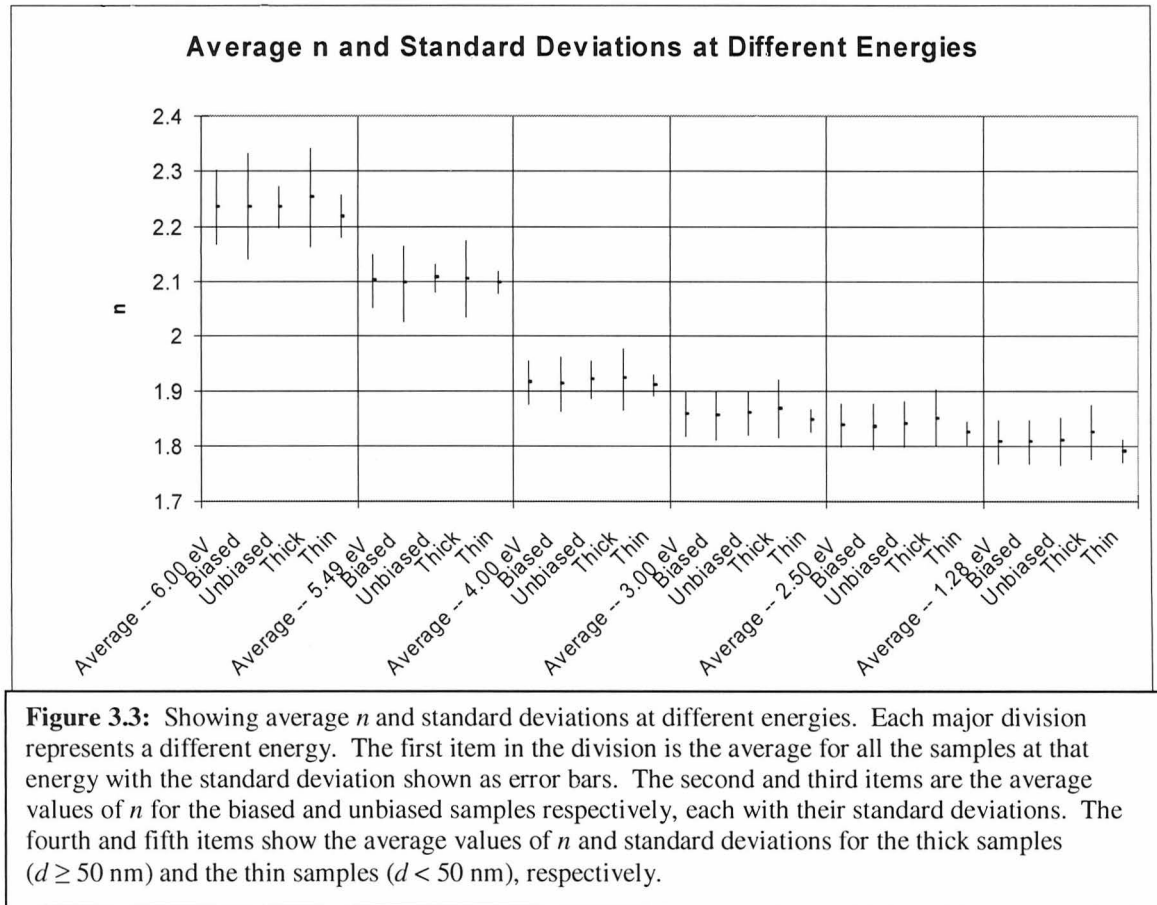


Figure 3.2: Fit values of n for different samples from 3.0 to 5.0 eV.

In Figure 3.2, we see the values of n fit for nine different samples plotted against photon energy. In the legend of the graph in Figure 3.2, we have listed the thickness to which each sample was sputtered and the bias voltage at which it was sputtered. Note that this graph only shows data between photon energies of 3 and 5 eV, which is only a partial range. Data are available from 1.2 to 6.5 eV. This graph uses a reduced range so

that we can better see a few different features. We see the values fall into several different bands. However, we do not see a correlation between which band a sample falls into and at what bias voltage the sample was sputtered. This independence of n with respect to bias voltage is better illustrated in Figure 3.3.



In Figure 3.3, we see that the average value of n at 3 eV for the unbiased samples was 1.86 with a standard deviation of 0.04. The average value of n at 3 eV for the biased samples was 1.88 with a standard deviation of 0.08. Also, we do not see a correlation between these bands and thickness. The average value of n at 3 eV for the thicker samples ($d \geq 50$ nm) was 1.87 with a standard deviation of 0.05. The average value of n at 3 eV for the thinner samples ($d \leq 50$ nm) was 1.88 with a standard deviation of 0.07.

Indeed we found no correlation with sputter pressure, deposition rate, or any other deposition parameter.

With our current fitting software, we cannot determine exactly what are the error bars associated with each of the $n(E)$ curves in Figure 3.2. The standard deviations across different samples as shown in Figure 3.3 give a good idea of the relative errors. The software gives standard deviations for each of the fit parameters for each curve. These include the positions and magnitudes of the different poles. However, translating these into uncertainties in the values for $n(E)$, which values are determined from these parameters, is not straightforward. Therefore we cannot say with certainty how significant these differences are. One method that we might use to determine the size of the uncertainties on $n(E)$ is a type of *Monte Carlo* method, which would consist of varying each of the parameters within the confidence interval and measuring the amount of variation in n . This, however, is outside the scope of this study.

Nonetheless, we can say that, within the bounds of our experiment, there does not seem to be a correlation between the sputtering bias voltage, and the value of n . Therefore, it appears that bias voltage cannot be reliably used to increase the index of refraction, and thus the density, of our thin films.

In comparing our data to the published literature, we find that they line up quite well. Heather M. Liddell studied the optical constants of several different oxides in the early 1970s. Her films were deposited using electron bombardment evaporation onto synthetic silica substrates (Spectrosil B). Her optical constants for ThO_2 were fit assuming a homogenous film of thickness 92.4 nm. We find that the optical constants she reports line up very well with those that we obtain. [28]

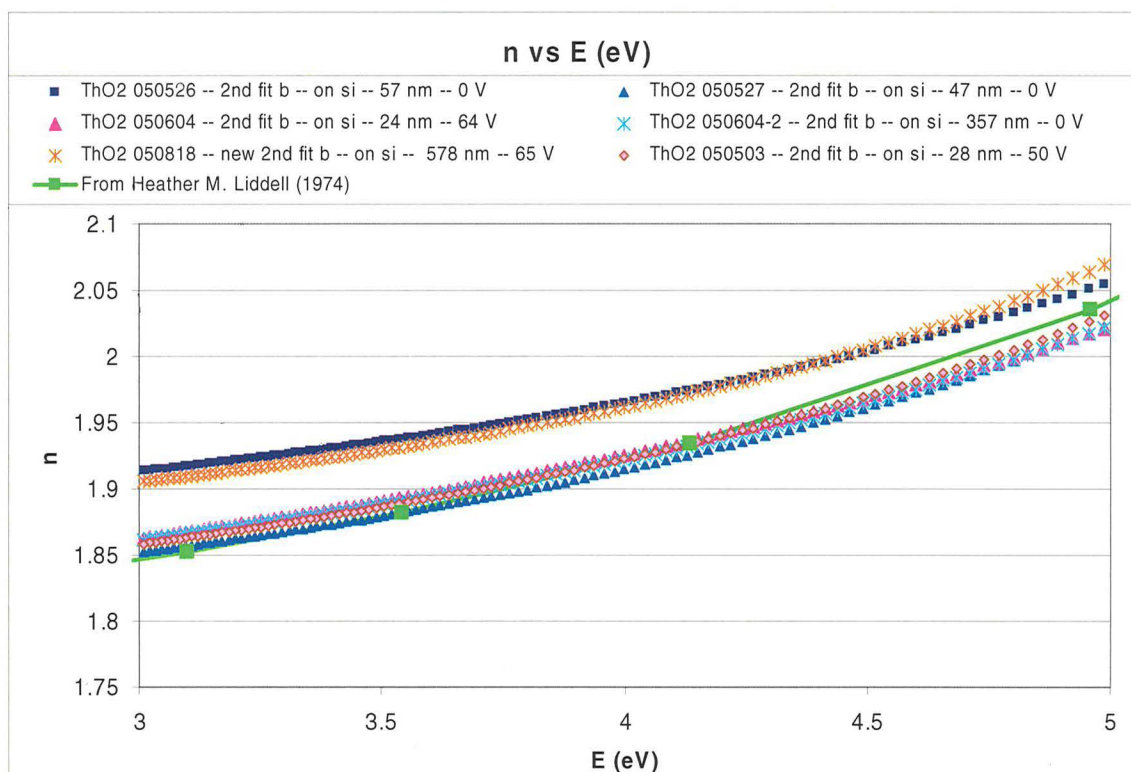


Figure 3.4: Plots showing n vs. photon energy for selected samples of our data and for the optical constants published by Heather Liddell (1974). We included only a few of our samples simply for clarity of the graph.

In Figure 3.4, we see that the published optical constants for ThO_2 line up well with the average of our optical constants.

3.2. Relative Independence of n and k

It appears that n and k are fairly independent in their forms. During the course of data fitting, we found that we had accidentally fit k for one sample to the transmission data from a different sample.

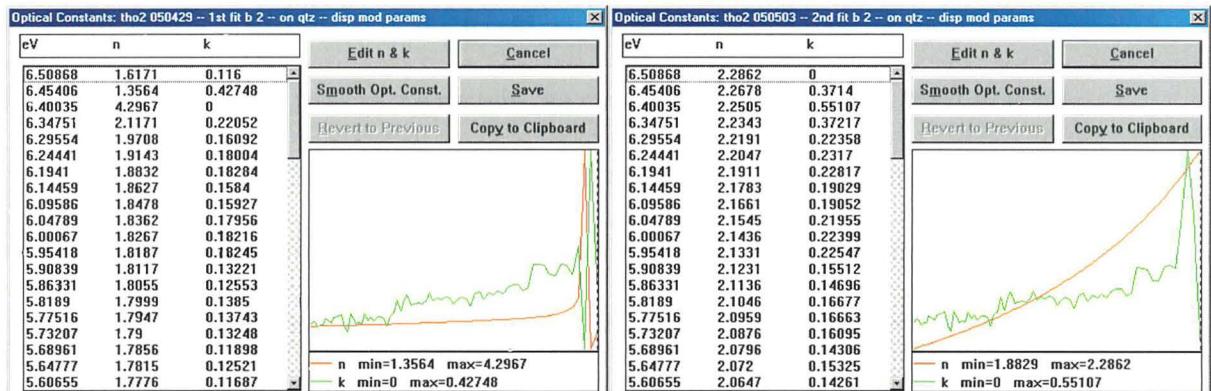


Figure 3.5: Plots showing n and k fit for two different samples. Here different values of n were used, but the samples were accidentally fit to the same transmission data to obtain k . Note the similarities in k .

In Figure 3.5, we note that the forms for k are very similar, despite the differences in n . The values of n for the two samples were very different. However, the values of k that we obtained using the two different sets of n were very similar.

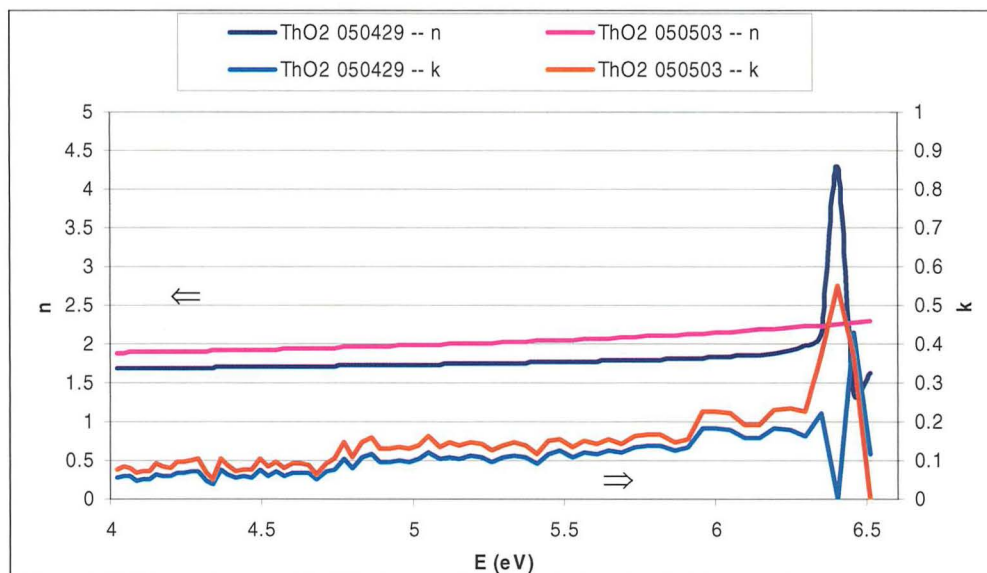


Figure 3.6: Plots showing n and k for two different samples where the different n s were used but the samples were accidentally fit to the same transmission data to obtain k . Note the similarities in k .

In Figure 3.6, we compare the two sets of curves from Figure 3.5 directly. The upper curves represent n for the two samples, with vertical scale on the left, while the lower curves represent k for the two samples, with vertical scale on the right. The values of n

differ by nearly 0.3 for most of the graph, while the values of k differ by at most about 0.04. One interesting feature we note in the curves for sample ThO2 050429 is the resonance that the oscillators go through at about 6.4 eV. This is characterized by the spike in n , with the delayed spike in k . This is very similar to what we would expect for a material as we scan past a resonance. [29] The curves do not look exactly as might be predicted, but it appears that we're just seeing the first part of the resonance, with the rest being a slightly higher energy, just outside of our range of view. We note that even with erroneous values of n , the values of k were quite similar. We therefore conclude that the form of k is not highly dependant on the values of n .

We also found that between different fits on the same sample, the values of n that we obtained did not change much when we added absorption.

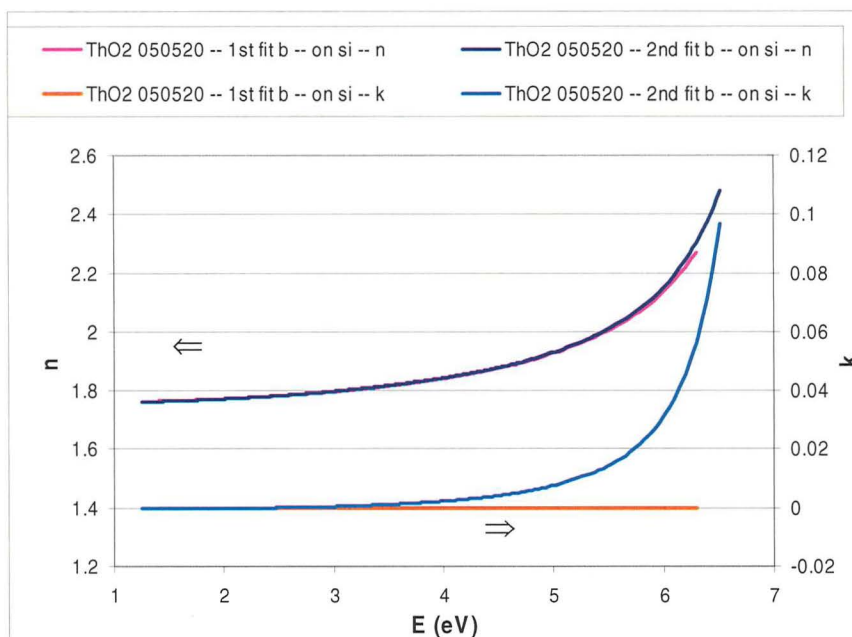


Figure 3.7: Plots showing n and k for two different fits on the same sample. The first fit of n was done assuming no absorption. The second fit of n was done after fitting the absorption. Note how n did not change much after adding absorption.

In Figure 3.7, we note that adding k between the first and second fits on silicon (the first fit on silicon for this sample assumed no absorption) did not change the values of n much

at all. Therefore, it appears that the values of n are not greatly dependant on the form of k . These indications give us confidence that our results for each of n and k are quite mutually independent.

3.3. Narrow Absorption Band

Analysis of k and $\alpha \left(\alpha = \frac{4 \cdot \pi \cdot k}{\lambda} \right)$ shows that the increase in absorption at about 6 eV does not appear to be the onset of a large absorption edge, but rather a narrow absorption band. In Figure 3.8, we plotted αd against photon energy because absorption goes as $e^{\alpha d}$, where d is the thickness of the sample. In this figure, one notes that the absorption drops again after about 6.2 eV. This is most clear in the thicker samples.

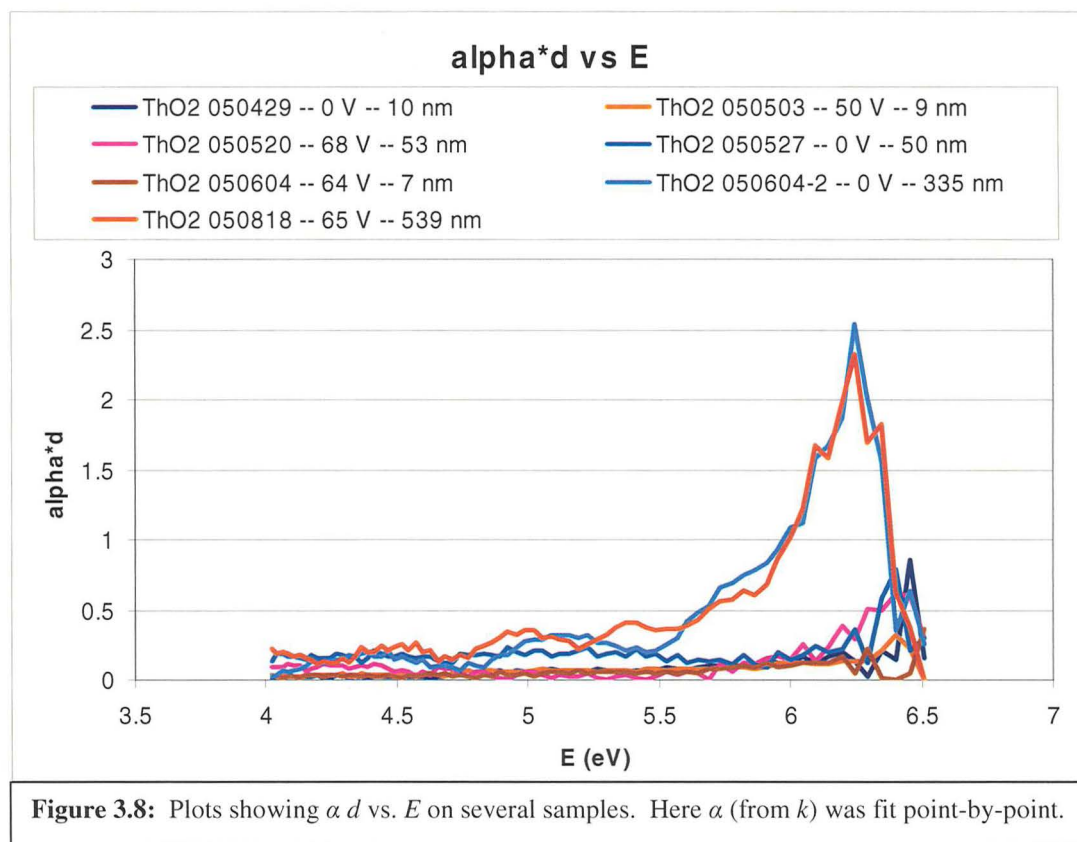


Figure 3.8: Plots showing αd vs. E on several samples. Here α (from k) was fit point-by-point.

Figure 3.8 shows, most clearly in the thick samples, that the absorption feature at about 6.3 eV in ThO_2 is not an absorption edge, but more likely a narrow absorption band (the

full width at half max is about 0.4 eV). We can also see that there is not a great deal of difference in the absorption of the biased samples and the unbiased samples. Note that the “waves” at low energy in the thick samples are due to interference fringes which the fitting program was not entirely able to remove. These were removed in later fits by using oscillator models.

3.4. Low Energy Absorption

There is also evidence in some samples of a significant amount of absorption at low energy.

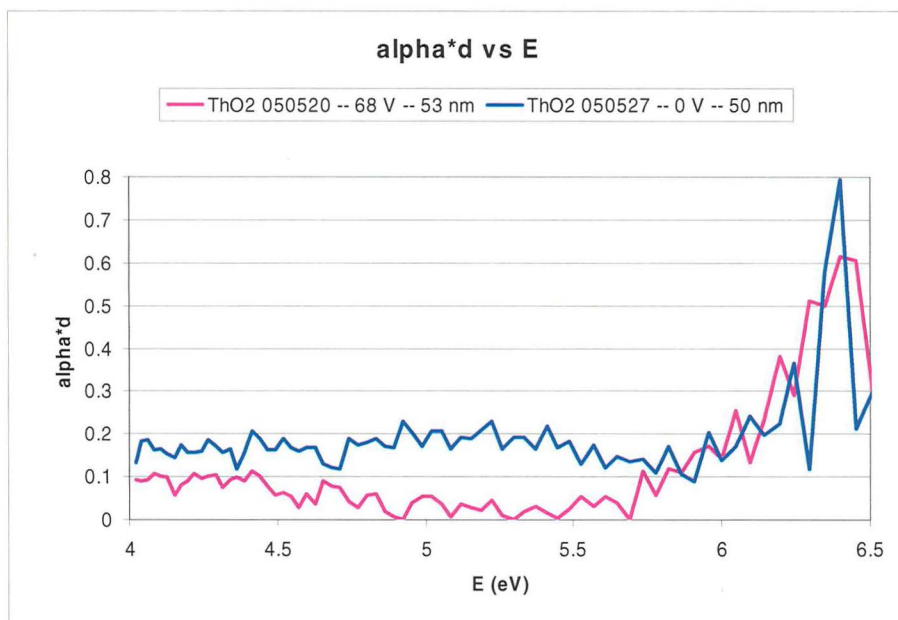


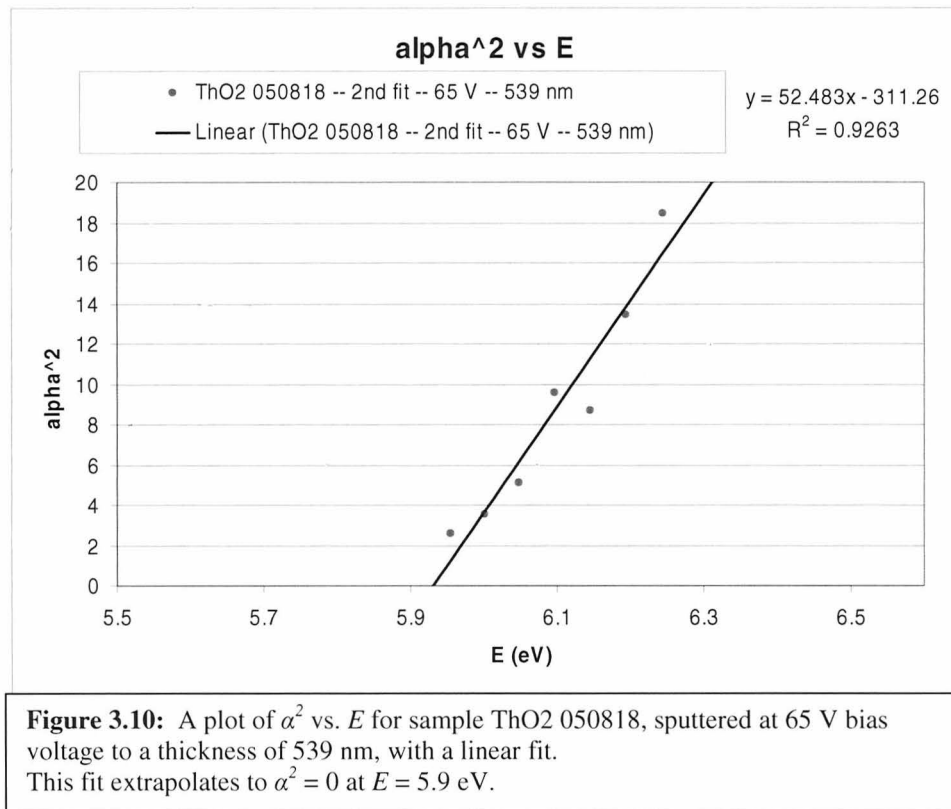
Figure 3.9: A plot of αd vs. E for samples ThO2 050520, sputtered at 68 V bias voltage to a thickness of 53 nm, and ThO2 050527, sputtered unbiased to a thickness of about 50 nm. Note the rise in absorption with decreasing energy after minima at about 5.3 or 5.8 eV.

In Figure 3.9, it appears that the absorptions of these samples each go through a minimum, one at about 5.3 eV, the other at about 5.8 eV, and then rise again at lower energy to a significant amount. A value of $\alpha d = 0.1$ represents an absorption of about 10%, which the instrument can easily detect.

3.5. The Band Gap of ThO₂

Another thing we are interested in is the location of the band gap of ThO₂ in thin film form. A band gap generally corresponds to a spike in the absorption of a material resulting from a transition from the valence band to the conduction band. These band gaps can be classified as *direct* or *indirect* band gaps, depending on whether or not the transition is forbidden (or how strongly forbidden it is). Indirect band gaps are also distinguished by the fact that they require the involvement (either by absorption or emission) of a phonon (a quantum of vibration). Many semi-conductors may have both types of band gaps. Fox [30] describes how direct band gap transitions are made by the absorption of a photon, while, again, indirect band gap transitions also require a phonon to be involved. He shows how we should expect that for a direct band gap absorption, we should expect $E - E_g \propto \alpha^2$, and for an indirect band gap absorption, $E - E_g \propto \sqrt{\alpha}$. A natural way to find E_g , therefore, is to plot α^2 and $\alpha^{1/2}$ vs. E , and extrapolate to find the value of E at which $\alpha = 0$.

From our calculated values of α , we plotted α^2 and $\alpha^{1/2}$ vs. E to find the band gaps for the different samples. As one can see from the shape of αd vs. E in Figure 3.8, there is only a narrow section of the complete graph that we can use to extrapolate α to 0.



In Figure 3.10, we see a representative linear fit to a plot of α^2 vs. E for sample ThO2 050818. In this case, the fit extrapolates to $\alpha^2 = 0$ at $E = 5.9$ eV. For each of our samples in plotting α^2 vs. E , the extrapolated band gap energy gave an average of $E_g = 6.1$ eV with a standard deviation of 0.15 eV.

Many of our samples also showed evidence of an indirect band gap. We found this by plotting $\alpha^{1/2}$ vs. E . We again restricted our domain to only use the range over which $\alpha^{1/2}$ was increasing approximately linearly with E .

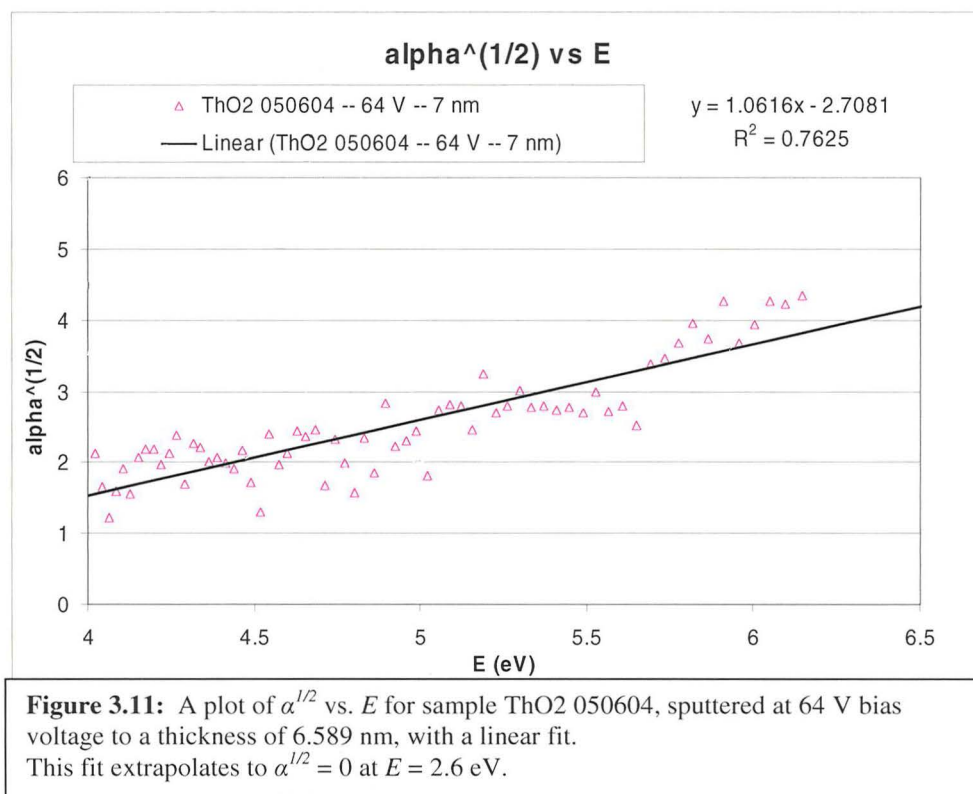


Figure 3.11 shows a representative fit for an indirect band gap. This linear fit was done on the data from sample ThO2 050604, and extrapolates to $\alpha^{1/2} = 0$ at $E = 2.6$ eV. Most of our samples showed similar behavior. Two of our samples, however, did not show evidence of an indirect band gap. Linear fits to $\alpha^{1/2}$ vs. E on those samples gave an extrapolated value of E_g which was less than 0. Neglecting those samples, the extrapolated band gap energy gave an average of $E_g = 2.8$ eV with a standard deviation of 0.45 eV.

These band gap energies differ somewhat from those values in the literature. Safwat Mahmoud reports a band gap energy of about 3.84 eV. [31] This difference could be due to a number of factors. First of all, the samples were deposited by different methods. Ours were deposited using reactive sputtering, while Mahmoud's were deposited using spray pyrolysis. In addition, the samples were deposited onto different

types of substrates. Our samples were deposited onto silicon wafers and quartz slides, while Mahmoud used amorphous glass. With different substrates, impurities in the substrate and the even the film material itself will interdiffuse differently. There might be other factors which also could play a role.

CHAPTER 4: CONCLUSIONS

Knowing the optical properties of different materials is very important for understanding and using them in optical devices. We have prepared and characterized nine samples of ThO₂ thin films on silicon and quartz, and in doing so we have significantly improved our knowledge of the optical properties of reactively sputtered ThO₂ thin films. We have also established that the optical properties of our thin films do not vary significantly with thickness (over the range considered), shown that applying a bias voltage during deposition cannot be expected to increase the density of our films, and obtained new data regarding the band gap of ThO₂ thin films.

Admittedly, we did not expect to find that increasing the bias voltage had no effect on n , but there are a couple of possible explanations as to why. First of all, it is possible that the thin films are being deposited fully dense, in which case it would not be possible to increase the density of the film any more. More likely, however, it is possible that our bias voltage was never high enough to greatly affect the film density. This makes sense especially when we consider how strongly ThO₂ is bonded together (as is reflected in its exceptionally high melting point). We were unable, with our system, to increase the bias voltage beyond 70 or 75 V, because above that voltage, the sample holder would discharge through the plasma during deposition. This resulted in a lot of sparking which damaged our samples.

Even though we have accomplished quite a bit, there is still a lot of work to be done. In light of what this project has uncovered, several areas of further research might be suggested. First of all, the optical constants of thorium dioxide thin films sputtered at

different bias voltages need to be studied in the EUV. This will allow more direct application of the constants we obtain to the applications we're interested in. Also, other techniques have been considered for variations on the sputtering method to possibly alter the index of refraction. One technique that should be studied is that of heating the sample substrate during deposition. This technique shows promise for increasing the density and smoothness of the films. However, given that ThO_2 has the highest melting point of any known oxide, studying this technique on ThO_2 might require some special considerations.

In summary, we have achieved new milestones in our understanding of the optical properties of reactively sputtered ThO_2 in thin film form, satisfactorily evaluated the deposition technique of biased RF magnetron sputtering, and established procedures for determining the optical constants of thin films in the visible by means of spectroscopic ellipsometry.

5: REFERENCES

- [1] J. E. J. Johnson, "Thorium Based Mirrors for High Reflectivity in the EUV," Undergraduate Thesis (Brigham Young University, Provo, UT, 2004), p. 1.
- [2] "Intel EUV Lithography Program Enters Development Phase," Intel Corporation, <http://www.intel.com/technology/silicon/si08041.htm>, 29 Dec 2004.
- [3] "X-Ray Microscope," ISA – Institute for Storage Ring Facilities, University of Aarhus, Denmark, <http://www.isa.au.dk/SR/XRM/xrm.html>, 30 Dec 2004.
- [4] J. E. J. Johnson, "Thorium Based Mirrors for High Reflectivity in the EUV," Undergraduate Thesis (Brigham Young University, Provo, UT, 2004), p. 1–2; "IMAGE Science Center," National Aeronautics and Space Administration (NASA), <http://image.gsfc.nasa.gov/>, 30 Dec 2004; Dr. David Allred (personal communication).
- [5] "IMAGE Science Center," National Aeronautics and Space Administration (NASA), <http://image.gsfc.nasa.gov/>, 30 Dec 2004.
- [6] "Venus Express Factsheet," European Space Agency (ESA), http://www.esa.int/export/esaSC/SEM2EE1A6BD_index_0.html, 30 Dec 2004.
- [7] "Layered Mirror Reflectivity," Center for X-Ray Optics (CXRO) – Lawrence Berkeley National Laboratory, http://www.cxro.lbl.gov/optical_constants/layer2.html.
- [8] See, for example: "Experimental Techniques at Light-Source Beamlines," U. S. Department of Energy Office of Basic Energy Sciences, http://www.sc.doe.gov/bes/synchrotron_techniques/BeamlineTechniques.pdf, 26 Sep 2005, p. 9;
R. L. Sandberg, "Optical Applications of Uranium Thin Film Compounds for the Extreme Ultraviolet and Soft X-Ray Region," Undergraduate Thesis (Brigham Young University, Provo, UT, 2004);
D. E. Graessle, et. al., "Feasibility study of the use of synchrotron radiation in the calibration of AXAF – Initial reflectivity results," *Proceedings of the Meeting of the SPIE, San Diego, California, July 22–24, 1991*, p. 13 – 25, (SPIE, Jan 1992).
- [9] See, for example: J. E. J. Johnson, "Thorium Based Mirrors for High Reflectivity in the EUV," Undergraduate Thesis (Brigham Young University, Provo, UT, 2004);
N. Farnsworth, "Thorium Based Mirrors in the Extreme Ultraviolet," Undergraduate Thesis (Brigham Young University, Provo, UT, 2005).
- [10] Wikipedia online encyclopedia, "Thorium dioxide," http://en.wikipedia.org/wiki/Thorium_oxide, 16 Aug 2005.
- [11] J. Peatross, M. Ware, *Physics of Light and Optics*, (Brigham Young University, Provo, UT, 2005), p. 34-36.
- [12] J. Peatross, M. Ware, *Physics of Light and Optics*, (Brigham Young University, Provo, UT, 2005), p. 59.
- [13] "Wollam Spectroscopic Ellipsometers and Thin Film Characterization," J. A. Wollam Co., Inc., http://www.jawoollam.com/Tutorial_1.html, 16 Aug 2005.
- [14] J. E. J. Johnson, "Thorium Based Mirrors for High Reflectivity in the EUV," Undergraduate Thesis (Brigham Young University, Provo, UT, 2004), p. 2–5.

- [15] D. J. Griffiths, *Introduction to Electrodynamics. Third Edition*. Prentice Hall, Upper Saddle River, NJ, 1999, p. 398 – 403.
- [16] See, for example: J. S. Choi, "In Situ Ellipsometry of Surfaces in an Ultrahigh Vacuum Thin Film Deposition Chamber," Undergraduate Thesis (Brigham Young University, Provo, UT, 2000).
- [17] J. E. J. Johnson, "Thorium Based Mirrors for High Reflectivity in the EUV," Undergraduate Thesis (Brigham Young University, Provo, UT, 2004), p. 13.
- [18] C. M. Herzinger, B. Johs, W. A. McGahan, J. A. Woollam, W. Paulson, "Ellipsometric Determination of Optical Constants for Silicon and Thermally Grown Silicon Dioxide via a Multi-sample, Multi-wavelength, Multi-angle Investigation," *Journal of Applied Physics*, Vol. 83. No. 6, (March 15, 1998,) pg. 3323.
- [19] "About X-ray Diffraction," Rigaku Corporation, <http://www.rigakumsc.com/xrd/about.html>, 31 Dec 2004.
- [20] J. E. J. Johnson, "Thorium Based Mirrors for High Reflectivity in the EUV," Undergraduate Thesis (Brigham Young University, Provo, UT, 2004), p. 14.
- [21] *Powder Diffraction File*, (Joint Committee on Powder Diffraction Standards, Philadelphia, PN, 1960), Inorganic, Sets 1-5, p. 527. Index number 4-0556.
- [22] Amy Baker (Personal Communication).
- [23] "Probing Biomolecules with the Atomic Force Microscope," The Lab of Helen Hansma, University of California, Santa Barbara, <http://www.physics.ucsb.edu/~hhansma/afm-ac news.htm>, 24 Sep 2005.
- [24] Mike Clemens (personal communication).
- [25] J. Peatross, M. Ware, *Physics of Light and Optics*, (Brigham Young University, Provo, UT, 2005), p. 61–62.
- [26] Edward D. Palik, ed. *Handbook of Optical Constants of Solids, Vol. 1*, (Academic Press, Inc., Orlando, FL, 1985), p. 569.
- [27] M. Fox, *Optical Properties of Solids*. (Oxford University Press, Oxford, UK, 2001), p. 58–59, 63–66.
- [28] H. M. Liddell, "Theoretical determination of the optical constants of weakly absorbing thin films." *J. Phys. D: Appl. Phys.*, Vol. 7. p. 1588 – 1596. (Great Britain, 1974).
- [29] See, for example: D. J. Griffiths, *Introduction to Electrodynamics. Third Edition*. Prentice Hall, Upper Saddle River, NJ, 1999, p. 403]
- [30] M. Fox, *Optical Properties of Solids*. Oxford University Press, Oxford, UK, 2001. p. 54-55, 58-59, 63-65.
- [31] S. A. Mahmoud, "Characterization of thorium dioxide thin films prepared by the spray pyrolysis technique." *Solid State Sciences* 4. p. 221 – 228. (2002).

APPENDIX A: DETAILED EXPERIMENTAL PROCEDURE

A.1. Data Acquisition

I took ellipsometric reflection data on each silicon sample for the full range of energies. I did this at every degree between 67° and 83° . I also took spectroscopic transmission data over the full range of energies on the quartz transmission samples. Finally, after roughening up the back of the quartz samples, ellipsometric reflection data were taken at every degree from 53° to 63° over the full range of energies.

A.2. Data Fitting

A.2.1. Building the Model

First, I built the model. For the silicon samples, the model had a 1 mm thick layer of Si (using the `si_jaw.mat` silicon data file) with a 2 nm layer of SiO_2 . I did not fit the thickness of this layer as we believed that that would include too large a level of freedom for the program to fit the data reliably. The top layer was a generalized oscillator layer (`genosc.mat`). I started the thickness of the oscillator layer as that thickness bound by XRD. Finally, for some samples, I added a layer of roughness (using the `srough.mat` data file). The thickness of this roughness layer was the rms roughness found by AFM on a representative sample. Usually this was about 5 nm. Again, I did not let it fit the amount of roughness because that would produce less reliable results. (Often it made the roughness go to 0.)

For the quartz samples, I used the `.mat` files that I had developed for our bare quartz. The optical constants for the quartz were obtained by a similar method to how we obtained to optical constants for the ThO_2 , but using data from the uncoated quartz. The

quartz layer was our substrate for the transmission samples' models. I used the .mat files described and a thickness that we obtained using high precision calipers on the quartz slides themselves. I then added our ThO₂ layer as a genosc.mat layer. Finally, I added a layer of roughness, again from the AFM measurements.

A.2.2. Fitting the Data

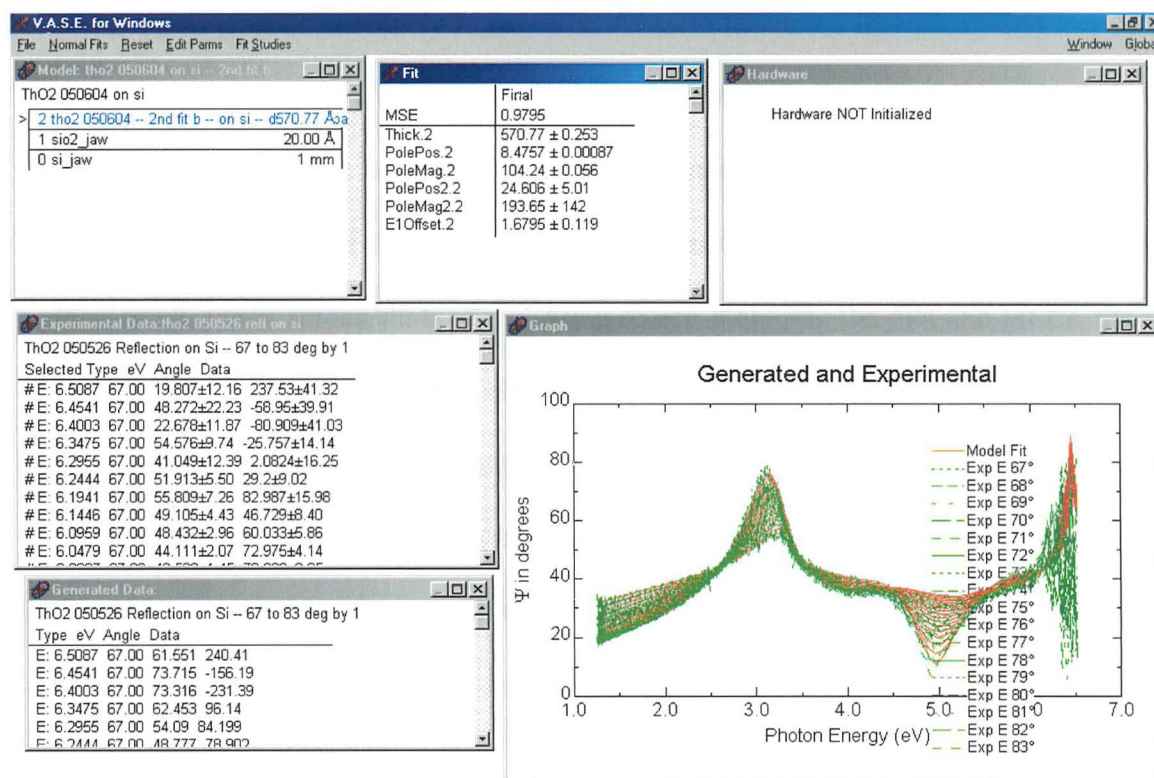


Figure A.1: First fit of n on sample ThO₂ 050526 on silicon, showing Psi (Ψ) (experimental in the green and generated in the red) vs. Energy, the model, the fit parameter values each with their relative uncertainties, and the fit MSE.

For the first fit, we fit n using the Sellmeier model, assuming no k . I fit n to the ellipsometric reflection data on silicon. I fit the pole positions and magnitudes in the layer parameters box. I often fit the thickness simultaneously. However, sometimes this would produce non-physical results (most often when fitting to transmission). In those cases, I fit the constants, while holding the thickness fixed, and then fit the thickness, while holding the constants fixed. I went back and forth like this several times. Also, we

usually fit the ε_1 offset. In general, a satisfactory fit would be one with an MSE less than about 3 and generated data that lined up visibly well with the experimental data on the plot. When I say “visibly well,” I mean all the major features lined up. Peaks lined up with peaks, troughs lined up with troughs, etc. I mention these two criteria separately because often they are not mutually implicative. Sometimes, a visibly good fit will inexplicably give an unusually high MSE. Also, sometimes a fit with a fairly low MSE will be obviously bad visibly. I have had fits with inexplicably low MSEs where the peaks and troughs were basically switched. You need to check both.

At each stage of the fits, I saved the information about the fits in several forms. First of all, I took screen shots of the fitting screen including the plot and MSEs, the parameters window, and the optical constants window. I saved these as .bmp files. I also saved the tabulated optical constants in a .txt file. I finally saved the model (as a .mod file) and the material parameters (as a .mat file). I saved the .mat file twice, once with the dispersion model parameters, and once as tabulated values of n and k . After each fit I used a different name which was representative of where I was in the fitting process.

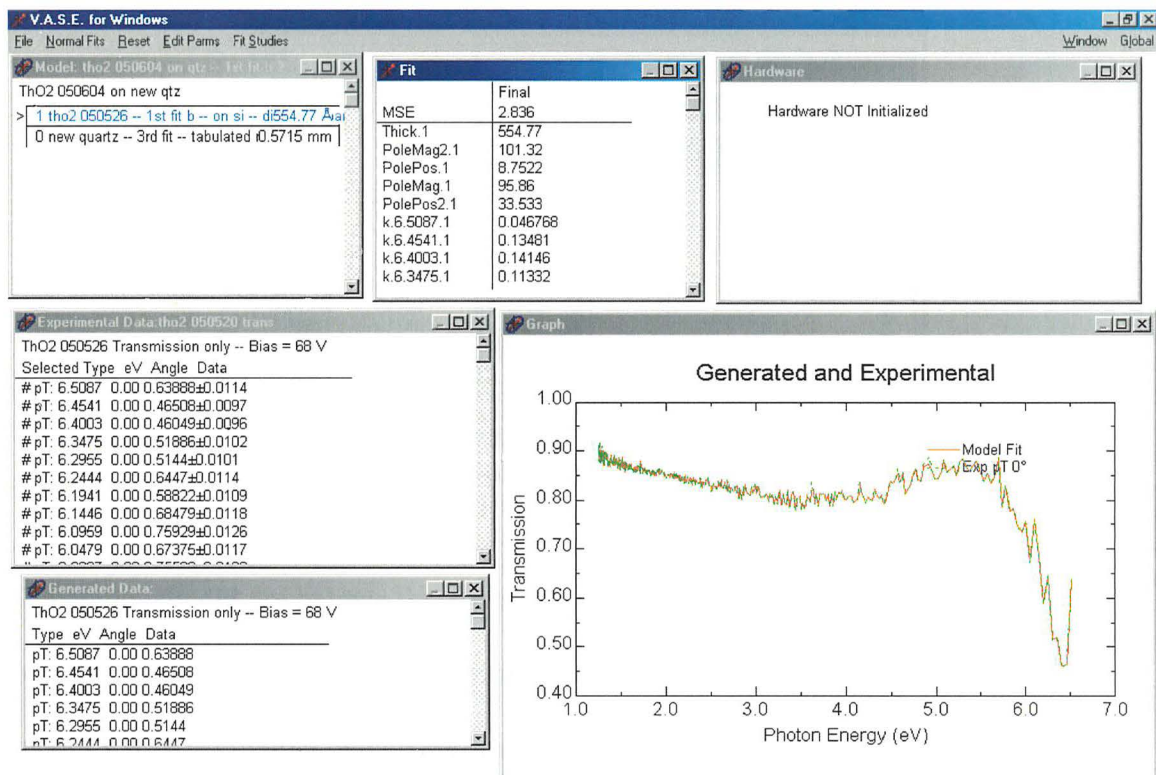


Figure A.2: A first fit of k to sample ThO2 050526 on quartz showing transmission and MSE. In this fit, k was fit point by point. Note how exactly the experimental data and generated data align.

For the first fit on k (which was the second fit), I loaded the .mat file from the first fit of n , and the data file from the transmission through quartz. Fixing the n s obtained from the first fit on silicon, we first fit the thickness of the sample. This was easier on the thicker samples, as they had a lot of interference fringes at low energies. Often I would fit thickness *only* to that low energy data with all the fringes, constraining that thickness for the rest of the fit. We then fit k point by point. This was done using the “optical constants fit” check box in the layer parameters window. After this fit, I again saved the information as before. This fit of k produced very “jumpy” values of k .

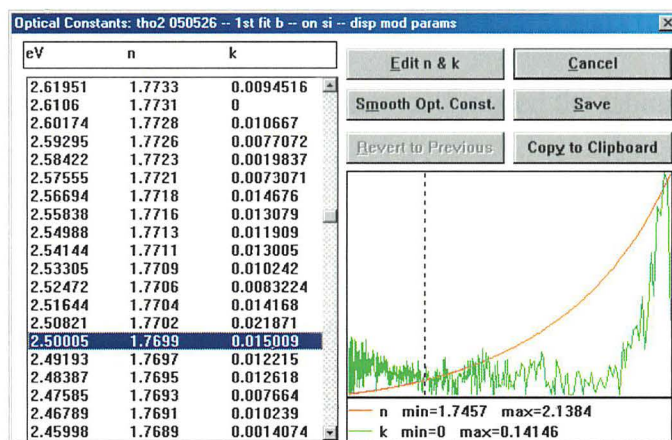


Figure A.3: Values of n and k obtained after the first fit of k (point by point).

We obviously did not believe these jumpy values of k to be the actual values of k , because k should be a smoothly varying function of E . For this reason, we needed to model k with oscillators, which are smooth functional distributions.

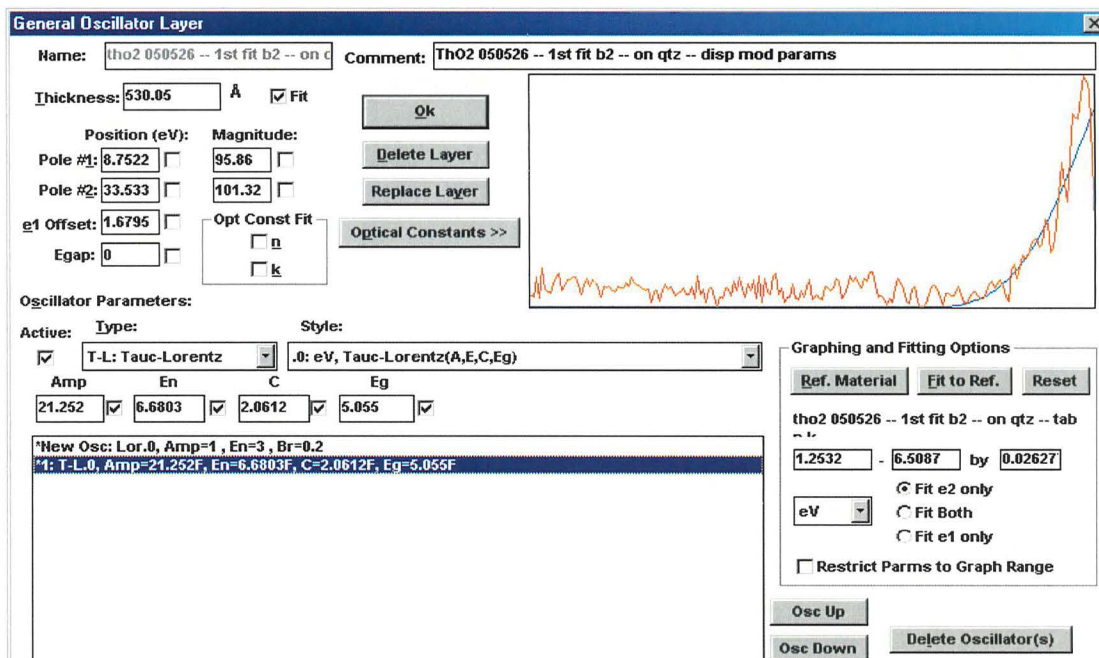


Figure A.4: Fit parameters window showing the point-by-point fit of k and the smooth oscillator curve used to model it.

The third fit was, in general, also to the quartz transmission samples. The software has the difficulty that I don't believe there is a way to use the k from a point-by-

point fit without *fitting* the k point by point on that fit. Therefore, I used the “reference material” option on the layer parameters window and loaded the tabulated n and k .mat file from the second fit. I then added an oscillator or two to model the form of k from the reference material. For ThO_2 , I found that I most often used Tauc-Lorentz type oscillators. Other times, Gaussian oscillators were most useful. (In general, I used the “fit ϵ_2 only” option.) First, I would position the oscillator by hand. Then I would check one or more of the oscillator parameters and use the “fit to reference” button. Finally, after again selecting which parameters I wanted the program to fit (remember, with parameters, you need to give the computer enough freedom to do its job, but don’t give it too much freedom, or it will often find non-physical minimizing solutions), I fit the oscillator parameters to the experimental data.

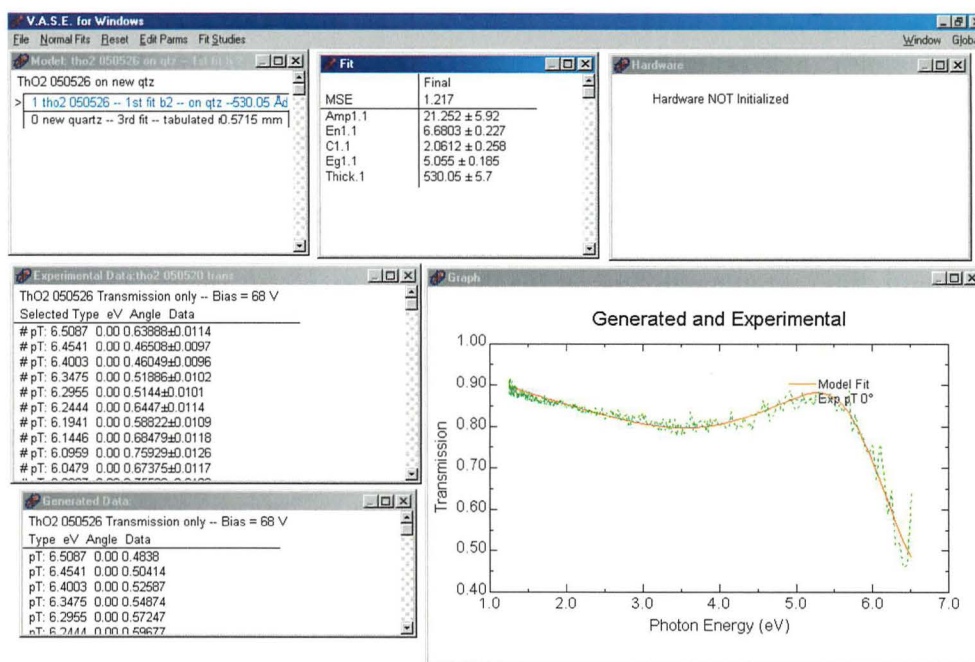


Figure A.5: A second fit of k using oscillators. This shows transmission (experimental and generated) and MSE. Note the smooth generated data line.

Often, with each fit, I would have to go back and forth fitting parameters and fixing thickness, and then fixing the parameters and fitting thickness.

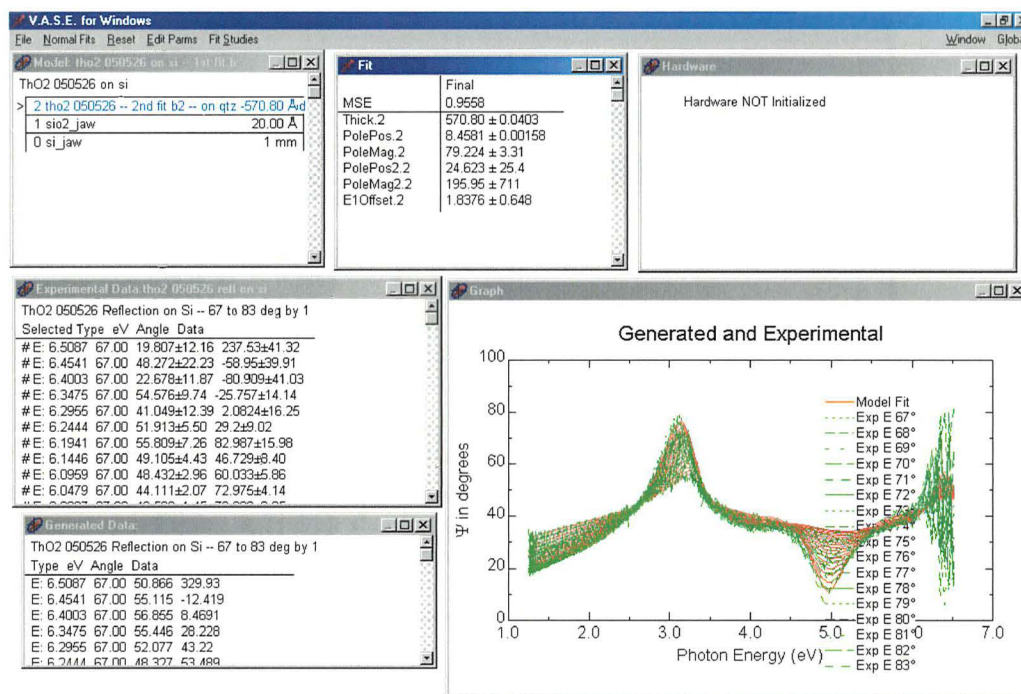


Figure A.6: A final fit of n including the absorption from the last fit. This shows Psi (experimental and generated) and MSE.

The fourth and final fit was again to the silicon reflection data. (Note that even though we took reflection data on the quartz samples we really didn't find it that useful for us to fit to it.) In this fit, we loaded the values of k from the oscillator parameters from the third fit, and re-fit n with the pole positions and magnitudes (and often the ϵ_1 offset). Again, we often had to fit thickness. We found that frequently, the values of n didn't change much. This was encouraging in that it meant that we had essentially reached a "stable equilibrium" of our parameter values.

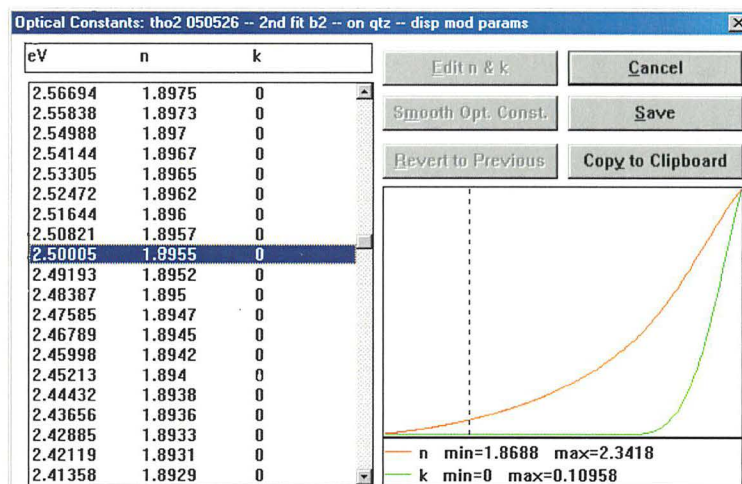


Figure A.7: Plot showing the final, reported values of n and k after the final fit of n , taking into account absorption.

This final fit, after saving everything, gave us the values we reported.

APPENDIX B: TABULATED DATA

B.1. Heather Liddell's Data [28]

From Heather M. Liddell (1974)		
From Liddell [Table 2]		
n -- Liddell -- ThO ₂ -- 1a		
Homogenous Film -- d = 92.4 nm		
λ (nm)	E (eV)	1a
215	5.76744186	2.186
225	5.511111111	2.131
250	4.96	2.035
300	4.133333333	1.934
350	3.542857143	1.882
400	3.1	1.852
450	2.755555556	1.833
502	2.470119522	1.819
546	2.271062271	1.81
633	1.95892575	1.799

B.2. Our Values of n from Sellmeier Models

(Note that we only included the most recent fit data.)

(Note also that the thicknesses listed (nm) are the thicknesses of the film as fit by ellipsometry, and the voltages listed (V) are the voltages at which each sample was sputtered.)

E (eV)	λ (nm)	ThO2 050429	ThO2 050503	ThO2 050505	ThO2 050520	ThO2 050526	ThO2 050527	ThO2 050604	ThO2 050604-2	ThO2 050818
		-- 27.726 nm -- 0 V	-- 27.725 nm -- 50 V	-- 17.861 nm -- 70 V	-- 69.202 nm -- 68 V	-- 57.080 nm -- 0 V	-- 46.896 nm -- 0 V	-- 24.145 nm -- 64 V	-- 356.9 nm -- 0 V	-- 578.432 nm -- 65 V
		n	n	n	n	n	n	n	n	n
6.50868	190.5148	2.3116	2.3011	2.6232	2.4795	2.3418	2.5953	2.1748		3.0631
6.45406	192.1271	2.2996	2.2962	2.5633	2.4247	2.3317	2.5434	1.9067		2.8675
6.40035	193.7394	2.2868	2.2913	2.5158	2.3774	2.3216	2.498	2.6104		2.747
6.34751	195.3522	2.2735	2.2858	2.477	2.3363	2.3114	2.458	2.3685		2.6676
6.29554	196.9648	2.2601	2.2793	2.4446	2.3002	2.3011	2.4224	2.3086		2.6056
6.24441	198.5776	2.2466	2.2718	2.417	2.2681	2.2907	2.3905	2.276		2.5533
6.1941	200.1905	2.2333	2.2633	2.3931	2.2396	2.2803	2.3615	2.253	2.3447	2.5079
6.14459	201.8035	2.2202	2.254	2.3721	2.2139	2.2699	2.3297	2.2346	2.3144	2.4679
6.09586	203.4167	2.2075	2.2442	2.3535	2.1908	2.2596	2.3133	2.2189	2.2887	2.4325
6.04789	205.0302	2.1951	2.2341	2.3368	2.1698	2.2492	2.2912	2.2051	2.2663	2.4009
6.00067	206.6436	2.1831	2.2237	2.3217	2.1506	2.239	2.2712	2.1926	2.2464	2.3725
5.95418	208.2571	2.1715	2.2133	2.3079	2.1331	2.229	2.2528	2.1811	2.2286	2.3468
5.90839	209.871	2.1604	2.2029	2.2953	2.117	2.2191	2.2357	2.1704	2.2125	2.3235
5.86331	211.4846	2.1496	2.1927	2.2837	2.1021	2.2094	2.2199	2.1604	2.1978	2.3023
5.8189	213.0987	2.1393	2.1828	2.273	2.0883	2.1999	2.2051	2.151	2.1842	2.2829
5.77516	214.7127	2.1293	2.173	2.263	2.0756	2.1907	2.1913	2.1421	2.1717	2.265
5.73207	216.3267	2.1197	2.1636	2.2537	2.0637	2.1817	2.1784	2.1337	2.16	2.2485
5.68961	217.9411	2.1105	2.1544	2.2449	2.0526	2.173	2.1663	2.1257	2.1491	2.2332
5.64777	219.5557	2.1017	2.1456	2.2367	2.0423	2.1645	2.1548	2.118	2.1389	2.219
5.60655	221.1699	2.0932	2.137	2.229	2.0326	2.1563	2.1441	2.1107	2.1293	2.2057

E (eV)	λ (nm)	ThO2 050429	ThO2 050503	ThO2 050505	ThO2 050520	ThO2 050526	ThO2 050527	ThO2 050604	ThO2 050604-2	ThO2 050818
		-- 27.726 nm	-- 27.725 nm	-- 17.861 nm	-- 69.202 nm	-- 57.080 nm	-- 46.896 nm	-- 24.145 nm	-- 356.9 nm	-- 578.432 nm
		-- 0 V	-- 50 V	-- 70 V	-- 68 V	-- 0 V	-- 0 V	-- 64 V	-- 0 V	-- 65 V
		n	n	n	n	n	n	n	n	n
5.56591	222.7848	2.085	2.1288	2.2217	2.0234	2.1484	2.1339	2.1037	2.1203	2.1934
5.52586	224.3995	2.0771	2.1208	2.2148	2.0149	2.1407	2.1242	2.097	2.1117	2.1819
5.48638	226.0142	2.0695	2.1131	2.2082	2.0068	2.1334	2.1151	2.0906	2.1036	2.1711
5.44746	227.629	2.0622	2.1057	2.202	1.9991	2.1262	2.1064	2.0844	2.0959	2.1609
5.40909	229.2437	2.0552	2.0986	2.196	1.9919	2.1194	2.0982	2.0785	2.0886	2.1513
5.37124	230.8592	2.0484	2.0917	2.1904	1.9851	2.1127	2.0903	2.0727	2.0817	2.1423
5.33393	232.474	2.0419	2.0851	2.185	1.9786	2.1063	2.0828	2.0672	2.075	2.1338
5.29712	234.0895	2.0356	2.0787	2.1798	1.9724	2.1002	2.0756	2.0619	2.0687	2.1257
5.26082	235.7047	2.0295	2.0726	2.1748	1.9665	2.0943	2.0688	2.0567	2.0626	2.1181
5.22501	237.3201	2.0237	2.0666	2.17	1.9609	2.0886	2.0622	2.0517	2.0567	2.1108
5.18968	238.9357	2.018	2.0609	2.1655	1.9556	2.0831	2.056	2.0469	2.0511	2.1039
5.15483	240.5511	2.0125	2.0553	2.1611	1.9505	2.0779	2.05	2.0422	2.0458	2.0974
5.12044	242.1667	2.0072	2.05	2.1568	1.9457	2.0729	2.0442	2.0377	2.0406	2.0911
5.0865	243.7826	2.0021	2.0448	2.1527	1.941	2.0681	2.0386	2.0333	2.0357	2.0852
5.05301	245.3983	1.9972	2.0398	2.1488	1.9366	2.0635	2.0333	2.0291	2.0309	2.0794
5.01996	247.0139	1.9924	2.0349	2.145	1.9323	2.0591	2.0281	2.025	2.0263	2.074
4.98733	248.63	1.9878	2.0302	2.1413	1.9282	2.0549	2.0232	2.021	2.0218	2.0688
4.95512	250.2462	1.9833	2.0257	2.1378	1.9243	2.0509	2.0184	2.0171	2.0175	2.0638
4.92333	251.8621	1.9789	2.0213	2.1344	1.9205	2.0471	2.0138	2.0133	2.0134	2.059
4.89194	253.4782	1.9747	2.017	2.131	1.9169	2.0434	2.0094	2.0097	2.0093	2.0544
4.86095	255.0942	1.9707	2.0129	2.1278	1.9134	2.0398	2.0051	2.0061	2.0055	2.0499
4.83034	256.7107	1.9667	2.0088	2.1247	1.9101	2.0364	2.001	2.0026	2.0017	2.0457
4.80012	258.3269	1.9628	2.005	2.1217	1.9068	2.0331	1.997	1.9993	1.9981	2.0416
4.77027	259.9434	1.9591	2.0012	2.1187	1.9037	2.0299	1.9931	1.996	1.9945	2.0377
4.74079	261.5598	1.9555	1.9975	2.1159	1.9007	2.0268	1.9893	1.9928	1.9911	2.0339
4.71168	263.1758	1.952	1.9939	2.1131	1.8978	2.0238	1.9857	1.9897	1.9878	2.0302
4.68291	264.7926	1.9485	1.9905	2.1104	1.895	2.0208	1.9822	1.9866	1.9846	2.0267
4.6545	266.4089	1.9452	1.9871	2.1078	1.8923	2.018	1.9788	1.9837	1.9815	2.0232
4.62642	268.0258	1.942	1.9838	2.1053	1.8897	2.0153	1.9755	1.9808	1.9784	2.0199
4.59869	269.642	1.9388	1.9807	2.1028	1.8871	2.0126	1.9723	1.978	1.9755	2.0167
4.57128	271.2588	1.9357	1.9776	2.1004	1.8847	2.0101	1.9691	1.9753	1.9726	2.0137

E (eV)	λ (nm)	ThO2 050429	ThO2 050503	ThO2 050505	ThO2 050520	ThO2 050526	ThO2 050527	ThO2 050604	ThO2 050604-2	ThO2 050818
		-- 27.726 nm	-- 27.725 nm	-- 17.861 nm	-- 69.202 nm	-- 57.080 nm	-- 46.896 nm	-- 24.145 nm	-- 356.9 nm	-- 578.432 nm
		-- 0 V	-- 50 V	-- 70 V	-- 68 V	-- 0 V	-- 0 V	-- 64 V	-- 0 V	-- 65 V
		n	n	n	n	n	n	n	n	n
4.54419	272.8759	1.9328	1.9745	2.0981	1.8823	2.0075	1.9661	1.9726	1.9698	2.0107
4.51743	274.4924	1.9299	1.9716	2.0958	1.88	2.0051	1.9632	1.97	1.9671	2.0078
4.49098	276.109	1.927	1.9688	2.0935	1.8778	2.0027	1.9603	1.9674	1.9645	2.005
4.46483	277.7261	1.9243	1.966	2.0914	1.8756	2.0004	1.9575	1.9649	1.9619	2.0023
4.43899	279.3428	1.9216	1.9633	2.0893	1.8735	1.9982	1.9548	1.9625	1.9594	1.9996
4.41344	280.96	1.9189	1.9606	2.0872	1.8715	1.996	1.9522	1.9601	1.9569	1.9971
4.38819	282.5766	1.9164	1.958	2.0852	1.8695	1.9939	1.9496	1.9578	1.9545	1.9946
4.36322	284.1938	1.9139	1.9555	2.0832	1.8675	1.9918	1.9471	1.9555	1.9522	1.9922
4.33853	285.8111	1.9115	1.9531	2.0813	1.8657	1.9898	1.9447	1.9533	1.9499	1.9898
4.31413	287.4276	1.9091	1.9507	2.0794	1.8639	1.9879	1.9423	1.9511	1.9477	1.9876
4.28999	289.045	1.9068	1.9483	2.0776	1.8621	1.986	1.94	1.949	1.9456	1.9854
4.26612	290.6622	1.9045	1.946	2.0758	1.8604	1.9841	1.9378	1.9469	1.9435	1.9832
4.24252	292.2791	1.9023	1.9438	2.0741	1.8587	1.9823	1.9356	1.9449	1.9414	1.9811
4.21918	293.896	1.9001	1.9416	2.0723	1.8571	1.9805	1.9334	1.9429	1.9394	1.9791
4.19609	295.5132	1.898	1.9395	2.0707	1.8555	1.9788	1.9313	1.9409	1.9374	1.9771
4.17325	297.1305	1.8959	1.9374	2.069	1.8539	1.9771	1.9293	1.939	1.9355	1.9751
4.15066	298.7477	1.8939	1.9354	2.0674	1.8524	1.9754	1.9273	1.9371	1.9336	1.9733
4.12831	300.365	1.8919	1.9334	2.0659	1.851	1.9738	1.9253	1.9353	1.9318	1.9714
4.1062	301.9824	1.89	1.9315	2.0643	1.8495	1.9722	1.9234	1.9335	1.93	1.9696
4.08433	303.5994	1.8881	1.9296	2.0628	1.8481	1.9707	1.9216	1.9318	1.9283	1.9679
4.06269	305.2165	1.8863	1.9277	2.0614	1.8468	1.9692	1.9198	1.93	1.9265	1.9662
4.04127	306.8342	1.8845	1.9259	2.0599	1.8454	1.9677	1.918	1.9283	1.9249	1.9645
4.02008	308.4516	1.8827	1.9241	2.0585	1.8442	1.9662	1.9162	1.9267	1.9232	1.9629
3.99911	310.069	1.881	1.9224	2.0571	1.8429	1.9648	1.9145	1.9251	1.9216	1.9613
3.97836	311.6862	1.8793	1.9207	2.0558	1.8416	1.9635	1.9129	1.9235	1.92	1.9598
3.95782	313.3038	1.8776	1.919	2.0545	1.8404	1.9621	1.9113	1.9219	1.9185	1.9583
3.9375	314.9206	1.876	1.9174	2.0532	1.8393	1.9608	1.9097	1.9204	1.917	1.9568
3.91738	316.5381	1.8744	1.9158	2.0519	1.8381	1.9595	1.9081	1.9189	1.9155	1.9554
3.89746	318.1559	1.8728	1.9142	2.0506	1.837	1.9582	1.9066	1.9174	1.914	1.9539
3.87775	319.7731	1.8713	1.9127	2.0494	1.8359	1.957	1.9051	1.9159	1.9126	1.9526
3.85824	321.3901	1.8698	1.9111	2.0482	1.8348	1.9558	1.9036	1.9145	1.9112	1.9512

E (eV)	λ (nm)	ThO2 050429	ThO2 050503	ThO2 050505	ThO2 050520	ThO2 050526	ThO2 050527	ThO2 050604	ThO2 050604-2	ThO2 050818
		-- 27.726 nm	-- 27.725 nm	-- 17.861 nm	-- 69.202 nm	-- 57.080 nm	-- 46.896 nm	-- 24.145 nm	-- 356.9 nm	-- 578.432 nm
		-- 0 V	-- 50 V	-- 70 V	-- 68 V	-- 0 V	-- 0 V	-- 64 V	-- 0 V	-- 65 V
		n	n	n	n	n	n	n	n	n
3.83892	323.0075	1.8683	1.9097	2.047	1.8337	1.9546	1.9022	1.9131	1.9098	1.9499
3.81979	324.6252	1.8668	1.9082	2.0459	1.8327	1.9534	1.9008	1.9117	1.9085	1.9486
3.80085	326.2428	1.8654	1.9068	2.0447	1.8317	1.9523	1.8994	1.9104	1.9072	1.9473
3.7821	327.8602	1.864	1.9054	2.0436	1.8307	1.9511	1.8981	1.9091	1.9059	1.9461
3.76354	329.477	1.8627	1.904	2.0425	1.8297	1.95	1.8967	1.9078	1.9046	1.9449
3.74515	331.0949	1.8613	1.9027	2.0414	1.8288	1.949	1.8954	1.9065	1.9034	1.9437
3.72694	332.7126	1.86	1.9014	2.0404	1.8279	1.9479	1.8942	1.9052	1.9022	1.9426
3.70891	334.33	1.8587	1.9001	2.0393	1.827	1.9469	1.8929	1.904	1.901	1.9414
3.69106	335.9469	1.8575	1.8988	2.0383	1.8261	1.9458	1.8917	1.9028	1.8998	1.9403
3.67337	337.5647	1.8562	1.8976	2.0373	1.8252	1.9448	1.8905	1.9016	1.8986	1.9392
3.65586	339.1815	1.855	1.8964	2.0363	1.8243	1.9439	1.8893	1.9004	1.8975	1.9381
3.63851	340.7988	1.8538	1.8952	2.0354	1.8235	1.9429	1.8881	1.8993	1.8964	1.9371
3.62132	342.4166	1.8526	1.894	2.0344	1.8227	1.942	1.887	1.8981	1.8953	1.9361
3.6043	344.0335	1.8514	1.8928	2.0335	1.8219	1.941	1.8859	1.897	1.8942	1.935
3.58743	345.6513	1.8503	1.8917	2.0326	1.8211	1.9401	1.8848	1.8959	1.8932	1.9341
3.57072	347.2689	1.8492	1.8906	2.0316	1.8203	1.9392	1.8837	1.8948	1.8921	1.9331
3.55417	348.886	1.8481	1.8895	2.0308	1.8195	1.9383	1.8827	1.8938	1.8911	1.9321
3.53777	350.5033	1.847	1.8884	2.0299	1.8188	1.9375	1.8816	1.8927	1.8901	1.9312
3.52152	352.1207	1.8459	1.8873	2.029	1.8181	1.9366	1.8806	1.8917	1.8891	1.9303
3.50542	353.7379	1.8449	1.8863	2.0282	1.8173	1.9358	1.8796	1.8907	1.8882	1.9294
3.48946	355.3558	1.8439	1.8853	2.0273	1.8166	1.935	1.8786	1.8897	1.8872	1.9285
3.47365	356.9732	1.8429	1.8843	2.0265	1.8159	1.9342	1.8776	1.8887	1.8863	1.9276
3.45799	358.5898	1.8419	1.8833	2.0257	1.8153	1.9334	1.8767	1.8878	1.8853	1.9268
3.44246	360.2075	1.8409	1.8823	2.0249	1.8146	1.9326	1.8758	1.8868	1.8844	1.9259
3.42707	361.8251	1.8399	1.8814	2.0241	1.8139	1.9319	1.8748	1.8859	1.8835	1.9251
3.41182	363.4424	1.839	1.8804	2.0234	1.8133	1.9311	1.8739	1.885	1.8827	1.9243
3.39671	365.0591	1.8381	1.8795	2.0226	1.8126	1.9304	1.873	1.884	1.8818	1.9235
3.38173	366.6762	1.8371	1.8786	2.0219	1.812	1.9296	1.8722	1.8832	1.881	1.9227
3.36688	368.2935	1.8362	1.8777	2.0211	1.8114	1.9289	1.8713	1.8823	1.8801	1.922
3.35216	369.9107	1.8353	1.8768	2.0204	1.8108	1.9282	1.8705	1.8814	1.8793	1.9212
3.33757	371.5278	1.8345	1.8759	2.0197	1.8102	1.9275	1.8696	1.8806	1.8785	1.9205

E (eV)	λ (nm)	ThO2 050429	ThO2 050503	ThO2 050505	ThO2 050520	ThO2 050526	ThO2 050527	ThO2 050604	ThO2 050604-2	ThO2 050818
		-- 27.726 nm	-- 27.725 nm	-- 17.861 nm	-- 69.202 nm	-- 57.080 nm	-- 46.896 nm	-- 24.145 nm	-- 356.9 nm	-- 578.432 nm
		-- 0 V	-- 50 V	-- 70 V	-- 68 V	-- 0 V	-- 0 V	-- 64 V	-- 0 V	-- 65 V
		n	n	n	n	n	n	n	n	n
3.3231	373.1456	1.8336	1.8751	2.019	1.8096	1.9268	1.8688	1.8797	1.8777	1.9197
3.30876	374.7628	1.8328	1.8743	2.0183	1.8091	1.9262	1.868	1.8789	1.8769	1.919
3.29454	376.3803	1.8319	1.8734	2.0176	1.8085	1.9255	1.8672	1.8781	1.8761	1.9183
3.28045	377.9969	1.8311	1.8726	2.017	1.8079	1.9249	1.8664	1.8773	1.8754	1.9176
3.26647	379.6147	1.8303	1.8718	2.0163	1.8074	1.9242	1.8656	1.8765	1.8746	1.917
3.25262	381.2311	1.8295	1.871	2.0157	1.8069	1.9236	1.8649	1.8757	1.8739	1.9163
3.23888	382.8484	1.8287	1.8702	2.015	1.8063	1.923	1.8641	1.8749	1.8732	1.9156
3.22526	384.4651	1.8279	1.8695	2.0144	1.8058	1.9224	1.8634	1.8742	1.8724	1.915
3.21175	386.0824	1.8272	1.8687	2.0138	1.8053	1.9218	1.8627	1.8734	1.8717	1.9143
3.19835	387.6999	1.8264	1.868	2.0132	1.8048	1.9212	1.862	1.8727	1.871	1.9137
3.18507	389.3164	1.8257	1.8673	2.0126	1.8043	1.9206	1.8613	1.872	1.8704	1.9131
3.17189	390.9341	1.825	1.8665	2.012	1.8038	1.92	1.8606	1.8713	1.8697	1.9125
3.15883	392.5504	1.8242	1.8658	2.0114	1.8033	1.9195	1.8599	1.8706	1.869	1.9119
3.14587	394.1676	1.8235	1.8651	2.0108	1.8029	1.9189	1.8592	1.8699	1.8684	1.9113
3.13302	395.7843	1.8228	1.8644	2.0102	1.8024	1.9184	1.8586	1.8692	1.8677	1.9107
3.12027	397.4015	1.8221	1.8638	2.0097	1.802	1.9178	1.8579	1.8685	1.8671	1.9101
3.10763	399.0179	1.8215	1.8631	2.0091	1.8015	1.9173	1.8573	1.8678	1.8665	1.9096
3.09508	400.6358	1.8208	1.8624	2.0086	1.8011	1.9168	1.8566	1.8672	1.8658	1.909
3.08265	402.2513	1.8201	1.8618	2.008	1.8006	1.9162	1.856	1.8665	1.8652	1.9085
3.0703	403.8693	1.8195	1.8611	2.0075	1.8002	1.9157	1.8554	1.8659	1.8646	1.9079
3.05806	405.4858	1.8188	1.8605	2.007	1.7998	1.9152	1.8548	1.8653	1.864	1.9074
3.04592	407.102	1.8182	1.8599	2.0065	1.7994	1.9147	1.8542	1.8646	1.8634	1.9069
3.03387	408.7189	1.8176	1.8593	2.0059	1.7989	1.9143	1.8536	1.864	1.8629	1.9064
3.02191	410.3365	1.817	1.8587	2.0054	1.7985	1.9138	1.853	1.8634	1.8623	1.9059
3.01005	411.9533	1.8164	1.8581	2.0049	1.7981	1.9133	1.8524	1.8628	1.8617	1.9054
2.99829	413.5691	1.8158	1.8575	2.0045	1.7977	1.9128	1.8519	1.8622	1.8612	1.9049
2.98661	415.1864	1.8152	1.8569	2.004	1.7974	1.9124	1.8513	1.8616	1.8606	1.9044
2.97503	416.8025	1.8146	1.8563	2.0035	1.797	1.9119	1.8508	1.8611	1.8601	1.9039
2.96353	418.4199	1.814	1.8558	2.003	1.7966	1.9115	1.8502	1.8605	1.8596	1.9034
2.95213	420.0357	1.8134	1.8552	2.0026	1.7962	1.911	1.8497	1.8599	1.859	1.903
2.94081	421.6525	1.8129	1.8546	2.0021	1.7959	1.9106	1.8492	1.8594	1.8585	1.9025

E (eV)	λ (nm)	ThO2 050429	ThO2 050503	ThO2 050505	ThO2 050520	ThO2 050526	ThO2 050527	ThO2 050604	ThO2 050604-2	ThO2 050818
		-- 27.726 nm	-- 27.725 nm	-- 17.861 nm	-- 69.202 nm	-- 57.080 nm	-- 46.896 nm	-- 24.145 nm	-- 356.9 nm	-- 578.432 nm
		-- 0 V	-- 50 V	-- 70 V	-- 68 V	-- 0 V	-- 0 V	-- 64 V	-- 0 V	-- 65 V
		n	n	n	n	n	n	n	n	n
2.92958	423.2689	1.8123	1.8541	2.0016	1.7955	1.9102	1.8486	1.8588	1.858	1.902
2.91843	424.886	1.8118	1.8536	2.0012	1.7951	1.9097	1.8481	1.8583	1.8575	1.9016
2.90737	426.5023	1.8112	1.853	2.0007	1.7948	1.9093	1.8476	1.8577	1.857	1.9012
2.89639	428.1191	1.8107	1.8525	2.0003	1.7944	1.9089	1.8471	1.8572	1.8565	1.9007
2.8855	429.7349	1.8102	1.852	1.9999	1.7941	1.9085	1.8466	1.8567	1.856	1.9003
2.87468	431.3524	1.8097	1.8515	1.9995	1.7938	1.9081	1.8461	1.8562	1.8555	1.8999
2.86395	432.9685	1.8091	1.851	1.999	1.7934	1.9077	1.8457	1.8557	1.8551	1.8994
2.8533	434.5845	1.8086	1.8505	1.9986	1.7931	1.9073	1.8452	1.8552	1.8546	1.899
2.84273	436.2004	1.8081	1.85	1.9982	1.7928	1.9069	1.8447	1.8547	1.8541	1.8986
2.83223	437.8176	1.8076	1.8495	1.9978	1.7924	1.9065	1.8443	1.8542	1.8537	1.8982
2.82181	439.4343	1.8072	1.849	1.9974	1.7921	1.9061	1.8438	1.8537	1.8532	1.8978
2.81147	441.0504	1.8067	1.8486	1.997	1.7918	1.9058	1.8433	1.8532	1.8528	1.8974
2.80121	442.6658	1.8062	1.8481	1.9966	1.7915	1.9054	1.8429	1.8528	1.8523	1.8971
2.79102	444.282	1.8057	1.8477	1.9962	1.7912	1.905	1.8425	1.8523	1.8519	1.8967
2.7809	445.8988	1.8053	1.8472	1.9958	1.7909	1.9047	1.842	1.8518	1.8515	1.8963
2.77086	447.5145	1.8048	1.8467	1.9955	1.7906	1.9043	1.8416	1.8514	1.8511	1.8959
2.76088	449.1322	1.8044	1.8463	1.9951	1.7903	1.904	1.8412	1.8509	1.8506	1.8956
2.75099	450.7468	1.8039	1.8459	1.9947	1.79	1.9036	1.8408	1.8505	1.8502	1.8952
2.74116	452.3632	1.8035	1.8454	1.9944	1.7897	1.9033	1.8403	1.85	1.8498	1.8948
2.7314	453.9796	1.803	1.845	1.994	1.7895	1.903	1.8399	1.8496	1.8494	1.8945
2.72171	455.5959	1.8026	1.8446	1.9936	1.7892	1.9026	1.8395	1.8492	1.849	1.8941
2.71209	457.212	1.8022	1.8442	1.9933	1.7889	1.9023	1.8391	1.8488	1.8486	1.8938
2.70254	458.8276	1.8017	1.8438	1.993	1.7886	1.902	1.8387	1.8483	1.8482	1.8935
2.69305	460.4445	1.8013	1.8434	1.9926	1.7884	1.9016	1.8383	1.8479	1.8479	1.8931
2.68363	462.0607	1.8009	1.843	1.9923	1.7881	1.9013	1.838	1.8475	1.8475	1.8928
2.67428	463.6762	1.8005	1.8426	1.9919	1.7879	1.901	1.8376	1.8471	1.8471	1.8925
2.66499	465.2926	1.8001	1.8422	1.9916	1.7876	1.9007	1.8372	1.8467	1.8467	1.8921
2.65577	466.9079	1.7997	1.8418	1.9913	1.7873	1.9004	1.8368	1.8463	1.8464	1.8918
2.64661	468.5239	1.7993	1.8414	1.991	1.7871	1.9001	1.8365	1.8459	1.846	1.8915
2.63751	470.1404	1.7989	1.841	1.9906	1.7868	1.8998	1.8361	1.8455	1.8456	1.8912
2.62848	471.7555	1.7985	1.8406	1.9903	1.7866	1.8995	1.8357	1.8452	1.8453	1.8909

E (eV)	λ (nm)	ThO2 050429	ThO2 050503	ThO2 050505	ThO2 050520	ThO2 050526	ThO2 050527	ThO2 050604	ThO2 050604-2	ThO2 050818
		-- 27.726 nm	-- 27.725 nm	-- 17.861 nm	-- 69.202 nm	-- 57.080 nm	-- 46.896 nm	-- 24.145 nm	-- 356.9 nm	-- 578.432 nm
		-- 0 V	-- 50 V	-- 70 V	-- 68 V	-- 0 V	-- 0 V	-- 64 V	-- 0 V	-- 65 V
		n	n	n	n	n	n	n	n	n
2.61951	473.371	1.7982	1.8403	1.99	1.7863	1.8992	1.8354	1.8448	1.8449	1.8906
2.6106	474.9866	1.7978	1.8399	1.9897	1.7861	1.8989	1.835	1.8444	1.8446	1.8903
2.60174	476.6041	1.7974	1.8395	1.9894	1.7859	1.8986	1.8347	1.844	1.8442	1.89
2.59295	478.2198	1.797	1.8392	1.9891	1.7856	1.8984	1.8343	1.8437	1.8439	1.8897
2.58422	479.8353	1.7967	1.8388	1.9888	1.7854	1.8981	1.834	1.8433	1.8436	1.8894
2.57555	481.4506	1.7963	1.8385	1.9885	1.7852	1.8978	1.8337	1.8429	1.8432	1.8891
2.56694	483.0654	1.796	1.8381	1.9882	1.785	1.8975	1.8333	1.8426	1.8429	1.8888
2.55838	484.6817	1.7956	1.8378	1.9879	1.7847	1.8973	1.833	1.8422	1.8426	1.8886
2.54988	486.2974	1.7953	1.8375	1.9876	1.7845	1.897	1.8327	1.8419	1.8423	1.8883
2.54144	487.9124	1.7949	1.8371	1.9873	1.7843	1.8967	1.8324	1.8415	1.8419	1.888
2.53305	489.5284	1.7946	1.8368	1.9871	1.7841	1.8965	1.8321	1.8412	1.8416	1.8877
2.52472	491.1436	1.7943	1.8365	1.9868	1.7839	1.8962	1.8317	1.8409	1.8413	1.8875
2.51644	492.7596	1.7939	1.8361	1.9865	1.7836	1.896	1.8314	1.8405	1.841	1.8872
2.50821	494.3765	1.7936	1.8358	1.9862	1.7834	1.8957	1.8311	1.8402	1.8407	1.8869
2.50005	495.9901	1.7933	1.8355	1.986	1.7832	1.8955	1.8308	1.8399	1.8404	1.8867
2.49193	497.6063	1.793	1.8352	1.9857	1.783	1.8952	1.8305	1.8396	1.8401	1.8864
2.48387	499.221	1.7926	1.8349	1.9854	1.7828	1.895	1.8302	1.8392	1.8398	1.8862
2.47585	500.8381	1.7923	1.8346	1.9852	1.7826	1.8947	1.8299	1.8389	1.8395	1.8859
2.46789	502.4535	1.792	1.8343	1.9849	1.7824	1.8945	1.8296	1.8386	1.8392	1.8857
2.45998	504.0691	1.7917	1.834	1.9847	1.7822	1.8942	1.8294	1.8383	1.8389	1.8854
2.45213	505.6828	1.7914	1.8337	1.9844	1.782	1.894	1.8291	1.838	1.8387	1.8852
2.44432	507.2986	1.7911	1.8334	1.9842	1.7818	1.8938	1.8288	1.8377	1.8384	1.8849
2.43656	508.9142	1.7908	1.8331	1.9839	1.7817	1.8936	1.8285	1.8374	1.8381	1.8847
2.42885	510.5297	1.7905	1.8328	1.9837	1.7815	1.8933	1.8282	1.8371	1.8378	1.8845
2.42119	512.1449	1.7902	1.8325	1.9834	1.7813	1.8931	1.828	1.8368	1.8376	1.8842
2.41358	513.7596	1.7899	1.8322	1.9832	1.7811	1.8929	1.8277	1.8365	1.8373	1.884
2.40601	515.3761	1.7897	1.832	1.9829	1.7809	1.8927	1.8274	1.8362	1.837	1.8838
2.39849	516.9919	1.7894	1.8317	1.9827	1.7807	1.8924	1.8272	1.8359	1.8368	1.8836
2.39102	518.6071	1.7891	1.8314	1.9825	1.7806	1.8922	1.8269	1.8357	1.8365	1.8833
2.3836	520.2215	1.7888	1.8311	1.9822	1.7804	1.892	1.8266	1.8354	1.8363	1.8831
2.37622	521.8372	1.7885	1.8309	1.982	1.7802	1.8918	1.8264	1.8351	1.836	1.8829

E (eV)	λ (nm)	ThO2 050429	ThO2 050503	ThO2 050505	ThO2 050520	ThO2 050526	ThO2 050527	ThO2 050604	ThO2 050604-2	ThO2 050818
		-- 27.726 nm	-- 27.725 nm	-- 17.861 nm	-- 69.202 nm	-- 57.080 nm	-- 46.896 nm	-- 24.145 nm	-- 356.9 nm	-- 578.432 nm
		-- 0 V	-- 50 V	-- 70 V	-- 68 V	-- 0 V	-- 0 V	-- 64 V	-- 0 V	-- 65 V
		n	n	n	n	n	n	n	n	n
2.36889	523.4519	1.7883	1.8306	1.9818	1.78	1.8916	1.8261	1.8348	1.8357	1.8827
2.3616	525.0678	1.788	1.8303	1.9816	1.7799	1.8914	1.8259	1.8346	1.8355	1.8825
2.35436	526.6824	1.7877	1.8301	1.9813	1.7797	1.8912	1.8256	1.8343	1.8352	1.8823
2.34716	528.298	1.7875	1.8298	1.9811	1.7795	1.891	1.8254	1.834	1.835	1.882
2.34001	529.9123	1.7872	1.8296	1.9809	1.7794	1.8908	1.8252	1.8338	1.8348	1.8818
2.3329	531.5273	1.787	1.8293	1.9807	1.7792	1.8906	1.8249	1.8335	1.8345	1.8816
2.32583	533.143	1.7867	1.8291	1.9805	1.7791	1.8904	1.8247	1.8332	1.8343	1.8814
2.31881	534.7571	1.7865	1.8288	1.9803	1.7789	1.8902	1.8244	1.833	1.834	1.8812
2.31183	536.3716	1.7862	1.8286	1.9801	1.7787	1.89	1.8242	1.8327	1.8338	1.881
2.30489	537.9866	1.786	1.8283	1.9799	1.7786	1.8898	1.824	1.8325	1.8336	1.8808
2.29799	539.602	1.7858	1.8281	1.9796	1.7784	1.8896	1.8238	1.8322	1.8334	1.8806
2.29113	541.2177	1.7855	1.8279	1.9794	1.7783	1.8894	1.8235	1.832	1.8331	1.8805
2.28432	542.8311	1.7853	1.8276	1.9792	1.7781	1.8893	1.8233	1.8317	1.8329	1.8803
2.27754	544.4471	1.7851	1.8274	1.979	1.778	1.8891	1.8231	1.8315	1.8327	1.8801
2.27081	546.0607	1.7848	1.8272	1.9788	1.7778	1.8889	1.8229	1.8313	1.8325	1.8799
2.26411	547.6766	1.7846	1.8269	1.9787	1.7777	1.8887	1.8226	1.831	1.8322	1.8797
2.25746	549.2899	1.7844	1.8267	1.9785	1.7775	1.8885	1.8224	1.8308	1.832	1.8795
2.25084	550.9054	1.7842	1.8265	1.9783	1.7774	1.8884	1.8222	1.8306	1.8318	1.8793
2.24426	552.5207	1.7839	1.8263	1.9781	1.7772	1.8882	1.822	1.8303	1.8316	1.8792
2.23772	554.1355	1.7837	1.826	1.9779	1.7771	1.888	1.8218	1.8301	1.8314	1.879
2.23122	555.7498	1.7835	1.8258	1.9777	1.777	1.8879	1.8216	1.8299	1.8312	1.8788
2.22475	557.366	1.7833	1.8256	1.9775	1.7768	1.8877	1.8214	1.8297	1.831	1.8786
2.21833	558.9791	1.7831	1.8254	1.9773	1.7767	1.8875	1.8212	1.8294	1.8308	1.8785
2.21194	560.5939	1.7829	1.8252	1.9772	1.7765	1.8874	1.821	1.8292	1.8306	1.8783
2.20558	562.2104	1.7827	1.825	1.977	1.7764	1.8872	1.8208	1.829	1.8304	1.8781
2.19927	563.8235	1.7825	1.8248	1.9768	1.7763	1.887	1.8206	1.8288	1.8302	1.8779
2.19299	565.4381	1.7823	1.8246	1.9766	1.7761	1.8869	1.8204	1.8286	1.83	1.8778
2.18674	567.0542	1.7821	1.8244	1.9764	1.776	1.8867	1.8202	1.8284	1.8298	1.8776
2.18054	568.6665	1.7819	1.8242	1.9763	1.7759	1.8865	1.82	1.8281	1.8296	1.8775
2.17436	570.2827	1.7817	1.824	1.9761	1.7758	1.8864	1.8198	1.8279	1.8294	1.8773
2.16822	571.8977	1.7815	1.8238	1.9759	1.7756	1.8862	1.8196	1.8277	1.8292	1.8771

E (eV)	λ (nm)	ThO2 050429	ThO2 050503	ThO2 050505	ThO2 050520	ThO2 050526	ThO2 050527	ThO2 050604	ThO2 050604-2	ThO2 050818
		-- 27.726 nm	-- 27.725 nm	-- 17.861 nm	-- 69.202 nm	-- 57.080 nm	-- 46.896 nm	-- 24.145 nm	-- 356.9 nm	-- 578.432 nm
		-- 0 V	-- 50 V	-- 70 V	-- 68 V	-- 0 V	-- 0 V	-- 64 V	-- 0 V	-- 65 V
		n	n	n	n	n	n	n	n	n
2.16212	573.5112	1.7813	1.8236	1.9758	1.7755	1.8861	1.8195	1.8275	1.829	1.877
2.15605	575.1258	1.7811	1.8234	1.9756	1.7754	1.8859	1.8193	1.8273	1.8288	1.8768
2.15001	576.7415	1.7809	1.8232	1.9754	1.7752	1.8858	1.8191	1.8271	1.8287	1.8767
2.14401	578.3555	1.7807	1.823	1.9753	1.7751	1.8856	1.8189	1.8269	1.8285	1.8765
2.13805	579.9677	1.7805	1.8228	1.9751	1.775	1.8855	1.8187	1.8267	1.8283	1.8764
2.13211	581.5835	1.7804	1.8226	1.9749	1.7749	1.8853	1.8185	1.8265	1.8281	1.8762
2.12621	583.1973	1.7802	1.8224	1.9748	1.7748	1.8852	1.8184	1.8263	1.8279	1.876
2.12034	584.8119	1.78	1.8222	1.9746	1.7746	1.885	1.8182	1.8261	1.8278	1.8759
2.1145	586.4271	1.7798	1.822	1.9745	1.7745	1.8849	1.818	1.826	1.8276	1.8758
2.1087	588.04	1.7796	1.8219	1.9743	1.7744	1.8848	1.8179	1.8258	1.8274	1.8756
2.10292	589.6563	1.7795	1.8217	1.9742	1.7743	1.8846	1.8177	1.8256	1.8272	1.8755
2.09718	591.2702	1.7793	1.8215	1.974	1.7742	1.8845	1.8175	1.8254	1.8271	1.8753
2.09147	592.8844	1.7791	1.8213	1.9738	1.7741	1.8843	1.8174	1.8252	1.8269	1.8752
2.08579	594.499	1.779	1.8212	1.9737	1.774	1.8842	1.8172	1.825	1.8267	1.875
2.08015	596.1109	1.7788	1.821	1.9735	1.7739	1.8841	1.817	1.8248	1.8266	1.8749
2.07453	597.7257	1.7786	1.8208	1.9734	1.7737	1.8839	1.8169	1.8247	1.8264	1.8748
2.06894	599.3407	1.7785	1.8206	1.9733	1.7736	1.8838	1.8167	1.8245	1.8262	1.8746
2.06338	600.9557	1.7783	1.8205	1.9731	1.7735	1.8837	1.8165	1.8243	1.8261	1.8745
2.05786	602.5677	1.7781	1.8203	1.973	1.7734	1.8835	1.8164	1.8241	1.8259	1.8743
2.05236	604.1825	1.778	1.8201	1.9728	1.7733	1.8834	1.8162	1.824	1.8257	1.8742
2.04689	605.7971	1.7778	1.82	1.9727	1.7732	1.8833	1.8161	1.8238	1.8256	1.8741
2.04145	607.4114	1.7777	1.8198	1.9725	1.7731	1.8831	1.8159	1.8236	1.8254	1.874
2.03604	609.0254	1.7775	1.8196	1.9724	1.773	1.883	1.8158	1.8234	1.8253	1.8738
2.03066	610.6389	1.7773	1.8195	1.9723	1.7729	1.8829	1.8156	1.8233	1.8251	1.8737
2.02531	612.252	1.7772	1.8193	1.9721	1.7728	1.8828	1.8155	1.8231	1.825	1.8736
2.01998	613.8675	1.777	1.8192	1.972	1.7727	1.8826	1.8153	1.8229	1.8248	1.8734
2.01469	615.4793	1.7769	1.819	1.9719	1.7726	1.8825	1.8152	1.8228	1.8247	1.8733
2.00942	617.0935	1.7767	1.8189	1.9717	1.7725	1.8824	1.815	1.8226	1.8245	1.8732
2.00417	618.71	1.7766	1.8187	1.9716	1.7724	1.8823	1.8149	1.8225	1.8244	1.8731
1.99896	620.3226	1.7764	1.8185	1.9715	1.7723	1.8822	1.8147	1.8223	1.8242	1.8729
1.99377	621.9373	1.7763	1.8184	1.9713	1.7722	1.882	1.8146	1.8221	1.8241	1.8728

E (eV)	λ (nm)	ThO2 050429	ThO2 050503	ThO2 050505	ThO2 050520	ThO2 050526	ThO2 050527	ThO2 050604	ThO2 050604-2	ThO2 050818
		-- 27.726 nm	-- 27.725 nm	-- 17.861 nm	-- 69.202 nm	-- 57.080 nm	-- 46.896 nm	-- 24.145 nm	-- 356.9 nm	-- 578.432 nm
		-- 0 V	-- 50 V	-- 70 V	-- 68 V	-- 0 V	-- 0 V	-- 64 V	-- 0 V	-- 65 V
		n	n	n	n	n	n	n	n	n
1.98861	623.5511	1.7762	1.8182	1.9712	1.7721	1.8819	1.8145	1.822	1.8239	1.8727
1.98348	625.1639	1.776	1.8181	1.9711	1.772	1.8818	1.8143	1.8218	1.8238	1.8726
1.97837	626.7786	1.7759	1.818	1.9709	1.7719	1.8817	1.8142	1.8217	1.8236	1.8725
1.97329	628.3922	1.7757	1.8178	1.9708	1.7718	1.8816	1.814	1.8215	1.8235	1.8723
1.96824	630.0045	1.7756	1.8177	1.9707	1.7718	1.8815	1.8139	1.8214	1.8234	1.8722
1.96321	631.6186	1.7755	1.8175	1.9706	1.7717	1.8814	1.8138	1.8212	1.8232	1.8721
1.95821	633.2314	1.7753	1.8174	1.9704	1.7716	1.8812	1.8136	1.8211	1.8231	1.872
1.95323	634.8459	1.7752	1.8172	1.9703	1.7715	1.8811	1.8135	1.8209	1.823	1.8719
1.94828	636.4588	1.7751	1.8171	1.9702	1.7714	1.881	1.8134	1.8208	1.8228	1.8718
1.94335	638.0734	1.7749	1.8169	1.9701	1.7713	1.8809	1.8132	1.8206	1.8227	1.8717
1.93845	639.6863	1.7748	1.8168	1.97	1.7712	1.8808	1.8131	1.8205	1.8226	1.8715
1.93357	641.3008	1.7747	1.8167	1.9698	1.7711	1.8807	1.813	1.8203	1.8224	1.8714
1.92872	642.9134	1.7745	1.8165	1.9697	1.771	1.8806	1.8129	1.8202	1.8223	1.8713
1.92389	644.5275	1.7744	1.8164	1.9696	1.771	1.8805	1.8127	1.8201	1.8222	1.8712
1.91909	646.1396	1.7743	1.8163	1.9695	1.7709	1.8804	1.8126	1.8199	1.822	1.8711
1.91431	647.753	1.7741	1.8161	1.9694	1.7708	1.8803	1.8125	1.8198	1.8219	1.871
1.90955	649.3677	1.774	1.816	1.9693	1.7707	1.8802	1.8124	1.8196	1.8218	1.8709
1.90482	650.9801	1.7739	1.8159	1.9691	1.7706	1.8801	1.8122	1.8195	1.8217	1.8708
1.90011	652.5938	1.7738	1.8157	1.969	1.7705	1.88	1.8121	1.8194	1.8215	1.8707
1.89543	654.2051	1.7736	1.8156	1.9689	1.7705	1.8799	1.812	1.8192	1.8214	1.8706
1.89076	655.8209	1.7735	1.8155	1.9688	1.7704	1.8798	1.8119	1.8191	1.8213	1.8705
1.88612	657.4343	1.7734	1.8154	1.9687	1.7703	1.8797	1.8118	1.819	1.8212	1.8704
1.88151	659.0451	1.7733	1.8152	1.9686	1.7702	1.8796	1.8116	1.8188	1.821	1.8703
1.87691	660.6603	1.7732	1.8151	1.9685	1.7702	1.8795	1.8115	1.8187	1.8209	1.8702
1.87234	662.2729	1.7731	1.815	1.9684	1.7701	1.8794	1.8114	1.8186	1.8208	1.8701
1.86779	663.8862	1.7729	1.8149	1.9683	1.77	1.8793	1.8113	1.8184	1.8207	1.87
1.86327	665.4967	1.7728	1.8147	1.9682	1.7699	1.8792	1.8112	1.8183	1.8206	1.8699
1.85876	667.1114	1.7727	1.8146	1.9681	1.7698	1.8791	1.8111	1.8182	1.8204	1.8698
1.85428	668.7232	1.7726	1.8145	1.968	1.7698	1.879	1.811	1.8181	1.8203	1.8697
1.84982	670.3355	1.7725	1.8144	1.9679	1.7697	1.8789	1.8108	1.8179	1.8202	1.8696
1.84538	671.9483	1.7724	1.8143	1.9678	1.7696	1.8788	1.8107	1.8178	1.8201	1.8695

E (eV)	λ (nm)	ThO2 050429	ThO2 050503	ThO2 050505	ThO2 050520	ThO2 050526	ThO2 050527	ThO2 050604	ThO2 050604-2	ThO2 050818
		-- 27.726 nm	-- 27.725 nm	-- 17.861 nm	-- 69.202 nm	-- 57.080 nm	-- 46.896 nm	-- 24.145 nm	-- 356.9 nm	-- 578.432 nm
		-- 0 V	-- 50 V	-- 70 V	-- 68 V	-- 0 V	-- 0 V	-- 64 V	-- 0 V	-- 65 V
		n	n	n	n	n	n	n	n	n
1.84096	673.5616	1.7723	1.8141	1.9677	1.7695	1.8787	1.8106	1.8177	1.82	1.8694
1.83656	675.1753	1.7721	1.814	1.9676	1.7695	1.8786	1.8105	1.8176	1.8199	1.8693
1.83219	676.7857	1.772	1.8139	1.9675	1.7694	1.8786	1.8104	1.8174	1.8198	1.8692
1.82783	678.4001	1.7719	1.8138	1.9674	1.7693	1.8785	1.8103	1.8173	1.8197	1.8691
1.8235	680.011	1.7718	1.8137	1.9673	1.7693	1.8784	1.8102	1.8172	1.8195	1.869
1.81918	681.6258	1.7717	1.8136	1.9672	1.7692	1.8783	1.8101	1.8171	1.8194	1.869
1.81489	683.237	1.7716	1.8134	1.9671	1.7691	1.8782	1.81	1.817	1.8193	1.8689
1.81062	684.8483	1.7715	1.8133	1.967	1.769	1.8781	1.8099	1.8168	1.8192	1.8688
1.80637	686.4596	1.7714	1.8132	1.9669	1.769	1.878	1.8098	1.8167	1.8191	1.8687
1.80213	688.0747	1.7713	1.8131	1.9668	1.7689	1.8779	1.8097	1.8166	1.819	1.8686
1.79792	689.6859	1.7712	1.813	1.9667	1.7688	1.8779	1.8096	1.8165	1.8189	1.8685
1.79373	691.2969	1.7711	1.8129	1.9666	1.7688	1.8778	1.8095	1.8164	1.8188	1.8684
1.78955	692.9116	1.771	1.8128	1.9665	1.7687	1.8777	1.8094	1.8163	1.8187	1.8683
1.7854	694.5222	1.7709	1.8127	1.9664	1.7686	1.8776	1.8093	1.8162	1.8186	1.8683
1.78127	696.1325	1.7708	1.8126	1.9663	1.7686	1.8775	1.8092	1.8161	1.8185	1.8682
1.77715	697.7464	1.7707	1.8125	1.9662	1.7685	1.8774	1.8091	1.8159	1.8184	1.8681
1.77305	699.3599	1.7706	1.8124	1.9661	1.7684	1.8774	1.809	1.8158	1.8183	1.868
1.76898	700.9689	1.7705	1.8123	1.966	1.7684	1.8773	1.8089	1.8157	1.8182	1.8679
1.76492	702.5814	1.7704	1.8122	1.9659	1.7683	1.8772	1.8088	1.8156	1.8181	1.8678
1.76088	704.1934	1.7703	1.8121	1.9659	1.7683	1.8771	1.8087	1.8155	1.818	1.8678
1.75686	705.8047	1.7702	1.812	1.9658	1.7682	1.877	1.8086	1.8154	1.8179	1.8677
1.75286	707.4153	1.7701	1.8119	1.9657	1.7681	1.877	1.8085	1.8153	1.8178	1.8676
1.74887	709.0293	1.77	1.8118	1.9656	1.7681	1.8769	1.8084	1.8152	1.8177	1.8675
1.74491	710.6384	1.7699	1.8117	1.9655	1.768	1.8768	1.8083	1.8151	1.8176	1.8674
1.74096	712.2507	1.7698	1.8116	1.9654	1.7679	1.8767	1.8082	1.815	1.8175	1.8674
1.73703	713.8622	1.7697	1.8115	1.9653	1.7679	1.8767	1.8081	1.8149	1.8174	1.8673
1.73312	715.4727	1.7696	1.8114	1.9653	1.7678	1.8766	1.8081	1.8148	1.8173	1.8672
1.72923	717.0822	1.7695	1.8113	1.9652	1.7678	1.8765	1.808	1.8147	1.8172	1.8671
1.72535	718.6948	1.7695	1.8112	1.9651	1.7677	1.8764	1.8079	1.8146	1.8171	1.8671
1.72149	720.3062	1.7694	1.8111	1.965	1.7676	1.8764	1.8078	1.8145	1.817	1.867
1.71765	721.9166	1.7693	1.811	1.9649	1.7676	1.8763	1.8077	1.8144	1.8169	1.8669

E (eV)	λ (nm)	ThO2 050429	ThO2 050503	ThO2 050505	ThO2 050520	ThO2 050526	ThO2 050527	ThO2 050604	ThO2 050604-2	ThO2 050818
		-- 27.726 nm	-- 27.725 nm	-- 17.861 nm	-- 69.202 nm	-- 57.080 nm	-- 46.896 nm	-- 24.145 nm	-- 356.9 nm	-- 578.432 nm
		-- 0 V	-- 50 V	-- 70 V	-- 68 V	-- 0 V	-- 0 V	-- 64 V	-- 0 V	-- 65 V
		n	n	n	n	n	n	n	n	n
1.71382	723.5299	1.7692	1.8109	1.9648	1.7675	1.8762	1.8076	1.8143	1.8169	1.8668
1.71002	725.1377	1.7691	1.8108	1.9648	1.7675	1.8761	1.8075	1.8142	1.8168	1.8668
1.70623	726.7484	1.769	1.8107	1.9647	1.7674	1.8761	1.8074	1.8141	1.8167	1.8667
1.70246	728.3578	1.7689	1.8106	1.9646	1.7674	1.876	1.8074	1.814	1.8166	1.8666
1.6987	729.97	1.7688	1.8105	1.9645	1.7673	1.8759	1.8073	1.8139	1.8165	1.8665
1.69496	731.5807	1.7688	1.8104	1.9644	1.7672	1.8759	1.8072	1.8138	1.8164	1.8665
1.69124	733.1898	1.7687	1.8103	1.9644	1.7672	1.8758	1.8071	1.8137	1.8163	1.8664
1.68753	734.8018	1.7686	1.8102	1.9643	1.7671	1.8757	1.807	1.8136	1.8162	1.8663
1.68384	736.412	1.7685	1.8102	1.9642	1.7671	1.8756	1.8069	1.8135	1.8162	1.8662
1.68017	738.0206	1.7684	1.8101	1.9641	1.767	1.8756	1.8069	1.8134	1.8161	1.8662
1.67651	739.6317	1.7683	1.81	1.9641	1.767	1.8755	1.8068	1.8133	1.816	1.8661
1.67287	741.2411	1.7683	1.8099	1.964	1.7669	1.8754	1.8067	1.8132	1.8159	1.866
1.66924	742.853	1.7682	1.8098	1.9639	1.7669	1.8754	1.8066	1.8131	1.8158	1.866
1.66563	744.4631	1.7681	1.8097	1.9638	1.7668	1.8753	1.8065	1.8131	1.8157	1.8659
1.66204	746.0711	1.768	1.8096	1.9638	1.7668	1.8752	1.8065	1.813	1.8157	1.8658
1.65846	747.6816	1.7679	1.8095	1.9637	1.7667	1.8752	1.8064	1.8129	1.8156	1.8658
1.6549	749.29	1.7679	1.8095	1.9636	1.7667	1.8751	1.8063	1.8128	1.8155	1.8657
1.65136	750.8962	1.7678	1.8094	1.9635	1.7666	1.875	1.8062	1.8127	1.8154	1.8656
1.64782	752.5094	1.7677	1.8093	1.9635	1.7666	1.875	1.8061	1.8126	1.8153	1.8656
1.64431	754.1157	1.7676	1.8092	1.9634	1.7665	1.8749	1.8061	1.8125	1.8152	1.8655
1.64081	755.7243	1.7676	1.8091	1.9633	1.7665	1.8749	1.806	1.8124	1.8152	1.8654
1.63732	757.3352	1.7675	1.8091	1.9633	1.7664	1.8748	1.8059	1.8124	1.8151	1.8654
1.63385	758.9436	1.7674	1.809	1.9632	1.7664	1.8747	1.8058	1.8123	1.815	1.8653
1.63039	760.5542	1.7673	1.8089	1.9631	1.7663	1.8747	1.8058	1.8122	1.8149	1.8652
1.62695	762.1623	1.7673	1.8088	1.9631	1.7663	1.8746	1.8057	1.8121	1.8149	1.8652
1.62353	763.7678	1.7672	1.8087	1.963	1.7662	1.8745	1.8056	1.812	1.8148	1.8651
1.62012	765.3754	1.7671	1.8087	1.9629	1.7662	1.8745	1.8055	1.8119	1.8147	1.8651
1.61672	766.985	1.767	1.8086	1.9628	1.7661	1.8744	1.8055	1.8119	1.8146	1.865
1.61334	768.5919	1.767	1.8085	1.9628	1.7661	1.8744	1.8054	1.8118	1.8146	1.8649
1.60997	770.2007	1.7669	1.8084	1.9627	1.766	1.8743	1.8053	1.8117	1.8145	1.8649
1.60662	771.8066	1.7668	1.8083	1.9626	1.766	1.8742	1.8053	1.8116	1.8144	1.8648

E (eV)	λ (nm)	ThO2 050429	ThO2 050503	ThO2 050505	ThO2 050520	ThO2 050526	ThO2 050527	ThO2 050604	ThO2 050604-2	ThO2 050818
		-- 27.726 nm	-- 27.725 nm	-- 17.861 nm	-- 69.202 nm	-- 57.080 nm	-- 46.896 nm	-- 24.145 nm	-- 356.9 nm	-- 578.432 nm
		-- 0 V	-- 50 V	-- 70 V	-- 68 V	-- 0 V	-- 0 V	-- 64 V	-- 0 V	-- 65 V
		n	n	n	n	n	n	n	n	n
1.60328	773.4145	1.7668	1.8083	1.9626	1.7659	1.8742	1.8052	1.8115	1.8143	1.8648
1.59995	775.0242	1.7667	1.8082	1.9625	1.7659	1.8741	1.8051	1.8114	1.8143	1.8647
1.59664	776.6309	1.7666	1.8081	1.9625	1.7658	1.8741	1.8051	1.8114	1.8142	1.8646
1.59334	778.2394	1.7665	1.808	1.9624	1.7658	1.874	1.805	1.8113	1.8141	1.8646
1.59006	779.8448	1.7665	1.808	1.9623	1.7657	1.874	1.8049	1.8112	1.814	1.8645
1.58679	781.4519	1.7664	1.8079	1.9623	1.7657	1.8739	1.8048	1.8111	1.814	1.8645
1.58354	783.0557	1.7663	1.8078	1.9622	1.7656	1.8738	1.8048	1.8111	1.8139	1.8644
1.58029	784.6661	1.7663	1.8077	1.9621	1.7656	1.8738	1.8047	1.811	1.8138	1.8643
1.57706	786.2732	1.7662	1.8077	1.9621	1.7656	1.8737	1.8046	1.8109	1.8138	1.8643
1.57385	787.8769	1.7661	1.8076	1.962	1.7655	1.8737	1.8046	1.8108	1.8137	1.8642
1.57065	789.4821	1.7661	1.8075	1.9619	1.7655	1.8736	1.8045	1.8108	1.8136	1.8642
1.56746	791.0888	1.766	1.8075	1.9619	1.7654	1.8736	1.8044	1.8107	1.8136	1.8641
1.56428	792.697	1.7659	1.8074	1.9618	1.7654	1.8735	1.8044	1.8106	1.8135	1.8641
1.56112	794.3015	1.7659	1.8073	1.9618	1.7653	1.8735	1.8043	1.8105	1.8134	1.864
1.55797	795.9075	1.7658	1.8072	1.9617	1.7653	1.8734	1.8043	1.8105	1.8134	1.864
1.55484	797.5097	1.7657	1.8072	1.9616	1.7653	1.8733	1.8042	1.8104	1.8133	1.8639
1.55171	799.1184	1.7657	1.8071	1.9616	1.7652	1.8733	1.8041	1.8103	1.8132	1.8638
1.5486	800.7232	1.7656	1.807	1.9615	1.7652	1.8732	1.8041	1.8102	1.8132	1.8638
1.5455	802.3293	1.7656	1.807	1.9615	1.7651	1.8732	1.804	1.8102	1.8131	1.8637
1.54242	803.9315	1.7655	1.8069	1.9614	1.7651	1.8731	1.8039	1.8101	1.813	1.8637
1.53935	805.5348	1.7654	1.8068	1.9613	1.765	1.8731	1.8039	1.81	1.813	1.8636
1.53629	807.1393	1.7654	1.8068	1.9613	1.765	1.873	1.8038	1.81	1.8129	1.8636
1.53324	808.7449	1.7653	1.8067	1.9612	1.765	1.873	1.8038	1.8099	1.8128	1.8635
1.53021	810.3463	1.7652	1.8066	1.9612	1.7649	1.8729	1.8037	1.8098	1.8128	1.8635
1.52718	811.9541	1.7652	1.8066	1.9611	1.7649	1.8729	1.8036	1.8098	1.8127	1.8634
1.52417	813.5575	1.7651	1.8065	1.9611	1.7648	1.8728	1.8036	1.8097	1.8126	1.8634
1.52118	815.1567	1.7651	1.8064	1.961	1.7648	1.8728	1.8035	1.8096	1.8126	1.8633
1.51819	816.7621	1.765	1.8064	1.961	1.7648	1.8727	1.8035	1.8096	1.8125	1.8633
1.51522	818.363	1.7649	1.8063	1.9609	1.7647	1.8727	1.8034	1.8095	1.8125	1.8632
1.51226	819.9648	1.7649	1.8063	1.9608	1.7647	1.8726	1.8033	1.8094	1.8124	1.8632
1.50931	821.5675	1.7648	1.8062	1.9608	1.7647	1.8726	1.8033	1.8094	1.8123	1.8631

E (eV)	λ (nm)	ThO2 050429	ThO2 050503	ThO2 050505	ThO2 050520	ThO2 050526	ThO2 050527	ThO2 050604	ThO2 050604-2	ThO2 050818
		-- 27.726 nm	-- 27.725 nm	-- 17.861 nm	-- 69.202 nm	-- 57.080 nm	-- 46.896 nm	-- 24.145 nm	-- 356.9 nm	-- 578.432 nm
		-- 0 V	-- 50 V	-- 70 V	-- 68 V	-- 0 V	-- 0 V	-- 64 V	-- 0 V	-- 65 V
		n	n	n	n	n	n	n	n	n
1.50637	823.1709	1.7648	1.8061	1.9607	1.7646	1.8725	1.8032	1.8093	1.8123	1.8631
1.50344	824.7752	1.7647	1.8061	1.9607	1.7646	1.8725	1.8032	1.8092	1.8122	1.863
1.50053	826.3747	1.7647	1.806	1.9606	1.7645	1.8724	1.8031	1.8092	1.8121	1.863
1.49763	827.9749	1.7646	1.8059	1.9606	1.7645	1.8724	1.8031	1.8091	1.8121	1.8629
1.49473	829.5813	1.7645	1.8059	1.9605	1.7645	1.8724	1.803	1.809	1.812	1.8629
1.49186	831.1772	1.7645	1.8058	1.9605	1.7644	1.8723	1.8029	1.809	1.812	1.8628
1.48899	832.7793	1.7644	1.8058	1.9604	1.7644	1.8723	1.8029	1.8089	1.8119	1.8628
1.48613	834.3819	1.7644	1.8057	1.9604	1.7644	1.8722	1.8028	1.8088	1.8119	1.8627
1.48329	835.9795	1.7643	1.8056	1.9603	1.7643	1.8722	1.8028	1.8088	1.8118	1.8627
1.48045	837.5832	1.7643	1.8056	1.9603	1.7643	1.8721	1.8027	1.8087	1.8117	1.8626
1.47763	839.1817	1.7642	1.8055	1.9602	1.7642	1.8721	1.8027	1.8086	1.8117	1.8626
1.47482	840.7806	1.7642	1.8055	1.9602	1.7642	1.872	1.8026	1.8086	1.8116	1.8625
1.47202	842.3799	1.7641	1.8054	1.9601	1.7642	1.872	1.8026	1.8085	1.8116	1.8625
1.46923	843.9795	1.7641	1.8053	1.9601	1.7641	1.8719	1.8025	1.8085	1.8115	1.8625
1.46645	845.5795	1.764	1.8053	1.96	1.7641	1.8719	1.8025	1.8084	1.8115	1.8624
1.46368	847.1797	1.7639	1.8052	1.96	1.7641	1.8719	1.8024	1.8083	1.8114	1.8624
1.46093	848.7744	1.7639	1.8052	1.9599	1.764	1.8718	1.8023	1.8083	1.8114	1.8623
1.45818	850.3751	1.7638	1.8051	1.9599	1.764	1.8718	1.8023	1.8082	1.8113	1.8623
1.45545	851.9702	1.7638	1.8051	1.9598	1.764	1.8717	1.8022	1.8082	1.8112	1.8622
1.45272	853.5712	1.7637	1.805	1.9598	1.7639	1.8717	1.8022	1.8081	1.8112	1.8622
1.45001	855.1665	1.7637	1.805	1.9597	1.7639	1.8716	1.8021	1.808	1.8111	1.8621
1.44731	856.7619	1.7636	1.8049	1.9597	1.7639	1.8716	1.8021	1.808	1.8111	1.8621
1.44462	858.3572	1.7636	1.8048	1.9596	1.7638	1.8716	1.802	1.8079	1.811	1.8621
1.44193	859.9585	1.7635	1.8048	1.9596	1.7638	1.8715	1.802	1.8079	1.811	1.862
1.43926	861.5539	1.7635	1.8047	1.9595	1.7638	1.8715	1.8019	1.8078	1.8109	1.862
1.4366	863.1491	1.7634	1.8047	1.9595	1.7637	1.8714	1.8019	1.8078	1.8109	1.8619
1.43395	864.7442	1.7634	1.8046	1.9594	1.7637	1.8714	1.8018	1.8077	1.8108	1.8619
1.43131	866.3392	1.7633	1.8046	1.9594	1.7637	1.8713	1.8018	1.8076	1.8108	1.8618
1.42868	867.934	1.7633	1.8045	1.9593	1.7636	1.8713	1.8017	1.8076	1.8107	1.8618
1.42606	869.5286	1.7632	1.8045	1.9593	1.7636	1.8713	1.8017	1.8075	1.8107	1.8618
1.42345	871.123	1.7632	1.8044	1.9593	1.7636	1.8712	1.8016	1.8075	1.8106	1.8617

E (eV)	λ (nm)	ThO2 050429	ThO2 050503	ThO2 050505	ThO2 050520	ThO2 050526	ThO2 050527	ThO2 050604	ThO2 050604-2	ThO2 050818
		-- 27.726 nm	-- 27.725 nm	-- 17.861 nm	-- 69.202 nm	-- 57.080 nm	-- 46.896 nm	-- 24.145 nm	-- 356.9 nm	-- 578.432 nm
		-- 0 V	-- 50 V	-- 70 V	-- 68 V	-- 0 V	-- 0 V	-- 64 V	-- 0 V	-- 65 V
		n	n	n	n	n	n	n	n	n
1.42085	872.717	1.7631	1.8044	1.9592	1.7635	1.8712	1.8016	1.8074	1.8106	1.8617
1.41826	874.3108	1.7631	1.8043	1.9592	1.7635	1.8711	1.8016	1.8074	1.8105	1.8616
1.41568	875.9042	1.763	1.8043	1.9591	1.7635	1.8711	1.8015	1.8073	1.8105	1.8616
1.41311	877.4972	1.763	1.8042	1.9591	1.7634	1.8711	1.8015	1.8073	1.8104	1.8616
1.41055	879.0897	1.763	1.8042	1.959	1.7634	1.871	1.8014	1.8072	1.8104	1.8615
1.408	880.6818	1.7629	1.8041	1.959	1.7634	1.871	1.8014	1.8072	1.8103	1.8615
1.40546	882.2734	1.7629	1.8041	1.9589	1.7634	1.8709	1.8013	1.8071	1.8103	1.8614
1.40293	883.8645	1.7628	1.804	1.9589	1.7633	1.8709	1.8013	1.8071	1.8102	1.8614
1.40041	885.455	1.7628	1.804	1.9589	1.7633	1.8709	1.8012	1.807	1.8102	1.8614
1.3979	887.0449	1.7627	1.8039	1.9588	1.7633	1.8708	1.8012	1.8069	1.8101	1.8613
1.39539	888.6405	1.7627	1.8039	1.9588	1.7632	1.8708	1.8011	1.8069	1.8101	1.8613
1.3929	890.229	1.7626	1.8038	1.9587	1.7632	1.8708	1.8011	1.8068	1.81	1.8612
1.39042	891.8169	1.7626	1.8038	1.9587	1.7632	1.8707	1.8011	1.8068	1.81	1.8612
1.38795	893.4039	1.7625	1.8037	1.9586	1.7631	1.8707	1.801	1.8067	1.8099	1.8612
1.38548	894.9967	1.7625	1.8037	1.9586	1.7631	1.8706	1.801	1.8067	1.8099	1.8611
1.38303	896.5821	1.7625	1.8036	1.9586	1.7631	1.8706	1.8009	1.8066	1.8098	1.8611
1.38058	898.1732	1.7624	1.8036	1.9585	1.7631	1.8706	1.8009	1.8066	1.8098	1.8611
1.37815	899.7569	1.7624	1.8035	1.9585	1.763	1.8705	1.8008	1.8065	1.8098	1.861
1.37572	901.3462	1.7623	1.8035	1.9584	1.763	1.8705	1.8008	1.8065	1.8097	1.861
1.3733	902.9345	1.7623	1.8034	1.9584	1.763	1.8705	1.8007	1.8064	1.8097	1.8609
1.37089	904.5219	1.7622	1.8034	1.9584	1.7629	1.8704	1.8007	1.8064	1.8096	1.8609
1.36849	906.1082	1.7622	1.8033	1.9583	1.7629	1.8704	1.8007	1.8063	1.8096	1.8609
1.3661	907.6934	1.7622	1.8033	1.9583	1.7629	1.8704	1.8006	1.8063	1.8095	1.8608
1.36372	909.2776	1.7621	1.8032	1.9582	1.7629	1.8703	1.8006	1.8063	1.8095	1.8608
1.36135	910.8605	1.7621	1.8032	1.9582	1.7628	1.8703	1.8005	1.8062	1.8094	1.8608
1.35898	912.449	1.762	1.8032	1.9582	1.7628	1.8703	1.8005	1.8062	1.8094	1.8607
1.35663	914.0296	1.762	1.8031	1.9581	1.7628	1.8702	1.8005	1.8061	1.8094	1.8607
1.35428	915.6157	1.762	1.8031	1.9581	1.7628	1.8702	1.8004	1.8061	1.8093	1.8607
1.35194	917.2005	1.7619	1.803	1.958	1.7627	1.8702	1.8004	1.806	1.8093	1.8606
1.34962	918.7771	1.7619	1.803	1.958	1.7627	1.8701	1.8003	1.806	1.8092	1.8606
1.3473	920.3592	1.7618	1.8029	1.958	1.7627	1.8701	1.8003	1.8059	1.8092	1.8606

E (eV)	λ (nm)	ThO2 050429	ThO2 050503	ThO2 050505	ThO2 050520	ThO2 050526	ThO2 050527	ThO2 050604	ThO2 050604-2	ThO2 050818
		-- 27.726 nm	-- 27.725 nm	-- 17.861 nm	-- 69.202 nm	-- 57.080 nm	-- 46.896 nm	-- 24.145 nm	-- 356.9 nm	-- 578.432 nm
		-- 0 V	-- 50 V	-- 70 V	-- 68 V	-- 0 V	-- 0 V	-- 64 V	-- 0 V	-- 65 V
		n	n	n	n	n	n	n	n	n
1.34498	921.9468	1.7618	1.8029	1.9579	1.7626	1.8701	1.8003	1.8059	1.8091	1.8605
1.34268	923.5261	1.7617	1.8028	1.9579	1.7626	1.87	1.8002	1.8058	1.8091	1.8605
1.34039	925.1039	1.7617	1.8028	1.9579	1.7626	1.87	1.8002	1.8058	1.8091	1.8605
1.3381	926.6871	1.7617	1.8028	1.9578	1.7626	1.87	1.8001	1.8057	1.809	1.8604
1.33582	928.2688	1.7616	1.8027	1.9578	1.7625	1.8699	1.8001	1.8057	1.809	1.8604
1.33356	929.8419	1.7616	1.8027	1.9577	1.7625	1.8699	1.8001	1.8057	1.8089	1.8604
1.33129	931.4274	1.7616	1.8026	1.9577	1.7625	1.8699	1.8	1.8056	1.8089	1.8603
1.32904	933.0043	1.7615	1.8026	1.9577	1.7625	1.8698	1.8	1.8056	1.8089	1.8603
1.3268	934.5794	1.7615	1.8026	1.9576	1.7624	1.8698	1.7999	1.8055	1.8088	1.8603
1.32456	936.1599	1.7614	1.8025	1.9576	1.7624	1.8698	1.7999	1.8055	1.8088	1.8602
1.32234	937.7316	1.7614	1.8025	1.9576	1.7624	1.8697	1.7999	1.8054	1.8087	1.8602
1.32012	939.3085	1.7614	1.8024	1.9575	1.7624	1.8697	1.7998	1.8054	1.8087	1.8602
1.31791	940.8837	1.7613	1.8024	1.9575	1.7623	1.8697	1.7998	1.8053	1.8087	1.8601
1.3157	942.4641	1.7613	1.8023	1.9575	1.7623	1.8696	1.7998	1.8053	1.8086	1.8601
1.31351	944.0354	1.7613	1.8023	1.9574	1.7623	1.8696	1.7997	1.8053	1.8086	1.8601
1.31132	945.6121	1.7612	1.8023	1.9574	1.7623	1.8696	1.7997	1.8052	1.8085	1.86
1.30915	947.1795	1.7612	1.8022	1.9574	1.7622	1.8695	1.7996	1.8052	1.8085	1.86
1.30698	948.7521	1.7611	1.8022	1.9573	1.7622	1.8695	1.7996	1.8051	1.8085	1.86
1.30481	950.3299	1.7611	1.8021	1.9573	1.7622	1.8695	1.7996	1.8051	1.8084	1.8599
1.30266	951.8984	1.7611	1.8021	1.9573	1.7622	1.8694	1.7995	1.8051	1.8084	1.8599
1.30051	953.4721	1.761	1.8021	1.9572	1.7621	1.8694	1.7995	1.805	1.8084	1.8599
1.29837	955.0436	1.761	1.802	1.9572	1.7621	1.8694	1.7995	1.805	1.8083	1.8598
1.29624	956.613	1.761	1.802	1.9571	1.7621	1.8694	1.7994	1.8049	1.8083	1.8598
1.29412	958.1801	1.7609	1.802	1.9571	1.7621	1.8693	1.7994	1.8049	1.8082	1.8598
1.292	959.7523	1.7609	1.8019	1.9571	1.7621	1.8693	1.7994	1.8048	1.8082	1.8598
1.2899	961.3148	1.7609	1.8019	1.9571	1.762	1.8693	1.7993	1.8048	1.8082	1.8597
1.2878	962.8824	1.7608	1.8018	1.957	1.762	1.8692	1.7993	1.8048	1.8081	1.8597
1.28571	964.4477	1.7608	1.8018	1.957	1.762	1.8692	1.7993	1.8047	1.8081	1.8597
1.28362	966.018	1.7608	1.8018	1.957	1.762	1.8692	1.7992	1.8047	1.8081	1.8596
1.28154	967.5859	1.7607	1.8017	1.9569	1.7619	1.8692	1.7992	1.8047	1.808	1.8596
1.27948	969.1437	1.7607	1.8017	1.9569	1.7619	1.8691	1.7992	1.8046	1.808	1.8596

E (eV)	λ (nm)	ThO2 050429	ThO2 050503	ThO2 050505	ThO2 050520	ThO2 050526	ThO2 050527	ThO2 050604	ThO2 050604-2	ThO2 050818
		-- 27.726 nm	-- 27.725 nm	-- 17.861 nm	-- 69.202 nm	-- 57.080 nm	-- 46.896 nm	-- 24.145 nm	-- 356.9 nm	-- 578.432 nm
		-- 0 V	-- 50 V	-- 70 V	-- 68 V	-- 0 V	-- 0 V	-- 64 V	-- 0 V	-- 65 V
		n	n	n	n	n	n	n	n	n
1.27741	970.7142	1.7607	1.8017	1.9569	1.7619	1.8691	1.7991	1.8046	1.808	1.8596
1.27536	972.2745	1.7606	1.8016	1.9568	1.7619	1.8691	1.7991	1.8045	1.8079	1.8595
1.27331	973.8398	1.7606	1.8016	1.9568	1.7619	1.869	1.799	1.8045	1.8079	1.8595
1.27127	975.4026	1.7606	1.8015	1.9568	1.7618	1.869	1.799	1.8045	1.8079	1.8595
1.26924	976.9626	1.7605	1.8015	1.9567	1.7618	1.869	1.799	1.8044	1.8078	1.8594
1.26722	978.5199	1.7605	1.8015	1.9567	1.7618	1.869	1.799	1.8044	1.8078	1.8594
1.2652	980.0822	1.7605	1.8014	1.9567	1.7618	1.8689	1.7989	1.8043	1.8078	1.8594
1.26319	981.6417	1.7604	1.8014	1.9566	1.7617	1.8689	1.7989	1.8043	1.8077	1.8594
1.26119	983.1984	1.7604	1.8014	1.9566	1.7617	1.8689	1.7989	1.8043	1.8077	1.8593
1.25919	984.76	1.7604	1.8013	1.9566	1.7617	1.8689	1.7988	1.8042	1.8077	1.8593
1.2572	986.3188	1.7603	1.8013	1.9565	1.7617	1.8688	1.7988	1.8042	1.8076	1.8593
1.25522	987.8746	1.7603	1.8013	1.9565	1.7617	1.8688	1.7988	1.8042	1.8076	1.8592
1.25325	989.4275	1.7603	1.8012	1.9565	1.7616	1.8688	1.7987	1.8041	1.8076	1.8592

B.3. Our Values of k fit with Oscillators

(Note that we only included the most recent fit data.)

(Note also that the thicknesses listed (nm) are the thicknesses of the film as fit by ellipsometry, and the voltages listed (V) are the voltages at which each sample was sputtered.)

E (eV)	λ (nm)	ThO2 050429 -- 10.468 nm -- 0 V k (oscillators)	ThO2 050503 -- 19.112 nm -- 50 V k (oscillators)	ThO2 050505 -- 14.062 nm -- 70 V k (oscillators)	ThO2 050520 -- 54.194nm -- 68 V k (oscillators)	ThO2 050526 -- 53.005nm -- 0 V k (oscillators)	ThO2 050527 -- 51.349nm -- 0 V k (oscillators)	ThO2 050604 -- 9.981nm -- 64 V k (oscillators)	ThO2 050604-2 -- 336.938nm -- 0 V k (oscillators)	ThO2 050818 -- 538.033nm -- 65 V k (oscillators)
6.50868	190.5148	0.32259	0.011955	0.063589		0.113		0.087088		-0.00076
6.45406	192.1271	0.32488	0.65484	0.7645		0.10556		0.081611		0.001418
6.40035	193.7394	0.12538	0.038677	0.20438	0.050467	0.097947		0.076715		0.027168
6.34751	195.3522	0.20786	0.006795	0.038155	0.044252	0.090311	0.07577	0.072318		0.04031
6.29554	196.9648	0.20121	0.00277	0.015456	0.039214	0.082777	0.074334	0.068353		0.043643
6.24441	198.5776	0.18934	0.00151	0.008344	0.035065	0.075449	0.072956	0.064764		0.042697
6.1941	200.1905	0.17702	0.000956	0.005231	0.031602	0.06841	0.071637	0.061507	0.085334	0.040173
6.14459	201.8035	0.16525	0.000663	0.003594	0.028679	0.06172	0.07056	0.058543	0.074584	0.037201
6.09586	203.4167	0.15432	0.000489	0.002627	0.026184	0.055421	0.069076	0.055856	0.064501	0.03424
6.04789	205.0302	0.14426	0.000377	0.002008	0.024037	0.049538	0.067901	0.053619	0.056368	0.031465
6.00067	206.6436	0.13504	0.000301	0.001587	0.022173	0.044081	0.066758	0.050791	0.049746	0.028929
5.95418	208.2571	0.1266	0.000246	0.001288	0.020543	0.039051	0.065653	0.048772	0.044286	0.02664
5.90839	209.871	0.11887	0.000206	0.001067	0.019109	0.034439	0.064585	0.046834	0.039731	0.02458
5.86331	211.4846	0.11179	0.000175	0.0009	0.017839	0.030232	0.063552	0.045024	0.035891	0.022728
5.8189	213.0987	0.1053	0.000151	0.00077	0.016708	0.02641	0.062554	0.043337	0.032621	0.021061
5.77516	214.7127	0.099328	0.000132	0.000667	0.015696	0.022953	0.061587	0.041765	0.029813	0.019556
5.73207	216.3267	0.093836	0.000116	0.000584	0.014786	0.019838	0.060652	0.040296	0.027383	0.018211

E (eV)	λ (nm)	ThO2 050429 -- 10.468 nm -- 0 V k (oscillators)	ThO2 050503 -- 19.112 nm -- 50 V k (oscillators)	ThO2 050505 -- 14.062 nm -- 70 V k (oscillators)	ThO2 050520 -- 54.194nm -- 68 V k (oscillators)	ThO2 050526 -- 53.005nm -- 0 V k (oscillators)	ThO2 050527 -- 51.349nm -- 0 V k (oscillators)	ThO2 050604 -- 9.981nm -- 64 V k (oscillators)	ThO2 050604-2 -- 336.938nm -- 0 V k (oscillators)	ThO2 050818 -- 538.033nm -- 65 V k (oscillators)
5.68961	217.9411	0.088772	0.000103	0.000515	0.013965	0.017042	0.059746	0.038922	0.025263	0.017017
5.64777	219.5557	0.084095	9.28E-05	0.000459	0.013221	0.014541	0.058868	0.037634	0.023404	0.015954
5.60655	221.1699	0.079767	8.38E-05	0.000411	0.012544	0.012314	0.058018	0.036426	0.021762	0.015
5.56591	222.7848	0.075755	7.61E-05	0.000371	0.011926	0.010339	0.057192	0.03529	0.020305	0.014142
5.52586	224.3995	0.07203	6.95E-05	0.000336	0.01136	0.008595	0.056392	0.03422	0.019004	0.013367
5.48638	226.0142	0.068565	6.38E-05	0.000307	0.01084	0.007064	0.055614	0.033211	0.017839	0.012663
5.44746	227.629	0.065337	5.89E-05	0.000281	0.010361	0.005727	0.054859	0.032258	0.016789	0.012022
5.40909	229.2437	0.062324	5.45E-05	0.000258	0.00992	0.004569	0.054126	0.031358	0.015841	0.011436
5.37124	230.8592	0.059508	5.06E-05	0.000238	0.00951	0.003573	0.053413	0.030505	0.01498	0.0109
5.33393	232.474	0.056873	4.72E-05	0.00022	0.009131	0.002726	0.05272	0.029696	0.014197	0.010406
5.29712	234.0895	0.054402	4.41E-05	0.000205	0.008778	0.002016	0.052046	0.028929	0.013481	0.009952
5.26082	235.7047	0.052083	4.14E-05	0.000191	0.008449	0.00143	0.05139	0.028199	0.012825	0.009532
5.22501	237.3201	0.049902	3.89E-05	0.000178	0.008142	0.000959	0.050751	0.027505	0.012223	0.009142
5.18968	238.9357	0.04785	3.67E-05	0.000167	0.007855	0.000591	0.050129	0.026845	0.011668	0.008781
5.15483	240.5511	0.045916	3.47E-05	0.000156	0.007586	0.000319	0.049524	0.026215	0.011155	0.008445
5.12044	242.1667	0.044091	3.28E-05	0.000147	0.007334	0.000135	0.048933	0.025614	0.01068	0.008131
5.0865	243.7826	0.042367	3.11E-05	0.000138	0.007096	3.07E-05	0.048358	0.025039	0.01024	0.007839
5.05301	245.3983	0.040736	2.96E-05	0.000131	0.006873	0	0.047797	0.024491	0.00983	0.007565
5.01996	247.0139	0.039192	2.81E-05	0.000123	0.006662	0	0.04725	0.023965	0.009448	0.007308
4.98733	248.63	0.037729	2.68E-05	0.000117	0.006463	0	0.046716	0.023462	0.009092	0.007067
4.95512	250.2462	0.036341	2.56E-05	0.000111	0.006275	0	0.046195	0.02298	0.008758	0.00684
4.92333	251.8621	0.035022	2.45E-05	0.000105	0.006097	0	0.045686	0.022517	0.008446	0.006626
4.89194	253.4782	0.033768	2.34E-05	0.0001	0.005928	0	0.045189	0.022073	0.008153	0.006424
4.86095	255.0942	0.032576	2.25E-05	9.53E-05	0.005768	0	0.044703	0.021647	0.007877	0.006234
4.83034	256.7107	0.03144	2.16E-05	9.08E-05	0.005616	0	0.044229	0.021237	0.007617	0.006054
4.80012	258.3269	0.030357	2.07E-05	8.67E-05	0.005471	0	0.043765	0.020842	0.007373	0.005883
4.77027	259.9434	0.029324	1.99E-05	8.28E-05	0.005333	0	0.043312	0.020462	0.007142	0.005722
4.74079	261.5598	0.028338	1.92E-05	7.92E-05	0.005202	0	0.042869	0.020096	0.006923	0.005568

E (eV)	λ (nm)	ThO2 050429 -- 10.468 nm -- 0 V	ThO2 050503 -- 19.112 nm -- 50 V	ThO2 050505 -- 14.062 nm -- 70 V	ThO2 050520 -- 54.194nm -- 68 V	ThO2 050526 -- 53.005nm -- 0 V	ThO2 050527 -- 51.349nm -- 0 V	ThO2 050604 -- 9.981nm -- 64 V	ThO2 050604-2 -- 336.938nm -- 0 V	ThO2 050818 -- 538.033nm -- 65 V
		k (oscillators)	k (oscillators)	k (oscillators)	k (oscillators)	k (oscillators)	k (oscillators)	k (oscillators)	k (oscillators)	k (oscillators)
4.71168	263.1758	0.027395	1.85E-05	7.58E-05	0.005077	0	0.042435	0.019744	0.006716	0.005422
4.68291	264.7926	0.026494	1.78E-05	7.26E-05	0.004957	0	0.042011	0.019403	0.00652	0.005284
4.6545	266.4089	0.025632	1.72E-05	6.96E-05	0.004843	0	0.041596	0.019075	0.006334	0.005152
4.62642	268.0258	0.024806	1.66E-05	6.68E-05	0.004734	0	0.04119	0.018758	0.006158	0.005026
4.59869	269.642	0.024015	1.61E-05	6.41E-05	0.004629	0	0.040792	0.018452	0.00599	0.004905
4.57128	271.2588	0.023256	1.56E-05	6.16E-05	0.004529	0	0.040402	0.018155	0.00583	0.004791
4.54419	272.8759	0.022529	1.51E-05	5.93E-05	0.004433	0	0.04002	0.017869	0.005677	0.004681
4.51743	274.4924	0.02183	1.46E-05	5.70E-05	0.004341	0	0.039646	0.017592	0.005532	0.004576
4.49098	276.109	0.021158	1.42E-05	5.49E-05	0.004252	0	0.039279	0.017323	0.005393	0.004475
4.46483	277.7261	0.020513	1.37E-05	5.29E-05	0.004167	0	0.03892	0.017063	0.005261	0.004379
4.43899	279.3428	0.019893	1.33E-05	5.10E-05	0.004086	0	0.038568	0.016811	0.005134	0.004287
4.41344	280.96	0.019295	1.30E-05	4.92E-05	0.004007	0	0.038222	0.016567	0.005012	0.004198
4.38819	282.5766	0.01872	1.26E-05	4.75E-05	0.003931	0	0.037884	0.01633	0.004896	0.004113
4.36322	284.1938	0.018167	1.22E-05	4.59E-05	0.003858	0	0.037551	0.0161	0.004785	0.004031
4.33853	285.8111	0.017633	1.19E-05	4.43E-05	0.003788	0	0.037225	0.015876	0.004678	0.003953
4.31413	287.4276	0.017118	1.16E-05	4.28E-05	0.00372	0	0.036905	0.015659	0.004575	0.003877
4.28999	289.045	0.016622	1.13E-05	4.14E-05	0.003655	0	0.036591	0.015449	0.004476	0.003804
4.26612	290.6622	0.016143	1.10E-05	4.01E-05	0.003591	0	0.036282	0.015244	0.004381	0.003734
4.24252	292.2791	0.01568	1.07E-05	3.88E-05	0.00353	0	0.035979	0.015045	0.00429	0.003666
4.21918	293.896	0.015233	1.05E-05	3.76E-05	0.003471	0	0.035682	0.014851	0.004202	0.003601
4.19609	295.5132	0.014801	1.02E-05	3.64E-05	0.003414	0	0.03539	0.014662	0.004118	0.003538
4.17325	297.1305	0.014384	9.97E-06	3.52E-05	0.003359	0	0.035103	0.014479	0.004036	0.003477
4.15066	298.7477	0.01398	9.73E-06	3.42E-05	0.003306	0	0.034821	0.0143	0.003957	0.003418
4.12831	300.365	0.01359	9.51E-06	3.31E-05	0.003254	0	0.034543	0.014126	0.003881	0.003361
4.1062	301.9824	0.013212	9.29E-06	3.21E-05	0.003204	0	0.034271	0.013956	0.003808	0.003306
4.08433	303.5994	0.012846	9.08E-06	3.12E-05	0.003155	0	0.034003	0.01379	0.003737	0.003253
4.06269	305.2165	0.012491	8.88E-06	3.03E-05	0.003108	0	0.03374	0.013629	0.003669	0.003201
4.04127	306.8342	0.012148	8.69E-06	2.94E-05	0.003062	0	0.033481	0.013472	0.003602	0.003151

E (eV)	λ (nm)	ThO2 050429 -- 10.468 nm -- 0 V k (oscillators)	ThO2 050503 -- 19.112 nm -- 50 V k (oscillators)	ThO2 050505 -- 14.062 nm -- 70 V k (oscillators)	ThO2 050520 -- 54.194nm -- 68 V k (oscillators)	ThO2 050526 -- 53.005nm -- 0 V k (oscillators)	ThO2 050527 -- 51.349nm -- 0 V k (oscillators)	ThO2 050604 -- 9.981nm -- 64 V k (oscillators)	ThO2 050604-2 -- 336.938nm -- 0 V k (oscillators)	ThO2 050818 -- 538.033nm -- 65 V k (oscillators)
4.02008	308.4516	0.011815	8.50E-06	2.85E-05	0.003018	0	0.033226	0.013318	0.003538	0.003103
3.99911	310.069	0.011493	8.32E-06	2.77E-05	0.002975	0	0.032976	0.013168	0.003476	0.003056
3.97836	311.6862	0.01118	8.14E-06	2.69E-05	0.002933	0	0.032729	0.013022	0.003416	0.003011
3.95782	313.3038	0.010876	7.97E-06	2.61E-05	0.002892	0	0.032486	0.012879	0.003358	0.002967
3.9375	314.9206	0.010582	7.81E-06	2.54E-05	0.002853	0	0.032248	0.01274	0.003302	0.002924
3.91738	316.5381	0.010296	7.65E-06	2.47E-05	0.002814	0	0.032013	0.012603	0.003247	0.002882
3.89746	318.1559	0.010019	7.50E-06	2.40E-05	0.002777	0	0.031782	0.01247	0.003194	0.002842
3.87775	319.7731	0.009749	7.35E-06	2.34E-05	0.00274	0	0.031554	0.01234	0.003142	0.002803
3.85824	321.3901	0.009487	7.21E-06	2.27E-05	0.002705	0	0.03133	0.012212	0.003092	0.002764
3.83892	323.0075	0.009233	7.07E-06	2.21E-05	0.00267	0	0.031109	0.012088	0.003044	0.002727
3.81979	324.6252	0.008986	6.94E-06	2.15E-05	0.002637	0	0.030892	0.011966	0.002996	0.002691
3.80085	326.2428	0.008746	6.81E-06	2.09E-05	0.002604	0	0.030677	0.011847	0.002951	0.002656
3.7821	327.8602	0.008512	6.68E-06	2.04E-05	0.002572	0	0.030466	0.01173	0.002906	0.002622
3.76354	329.477	0.008285	6.56E-06	1.99E-05	0.002541	0	0.030259	0.011616	0.002863	0.002588
3.74515	331.0949	0.008064	6.44E-06	1.93E-05	0.002511	0	0.030054	0.011504	0.00282	0.002556
3.72694	332.7126	0.007849	6.32E-06	1.88E-05	0.002481	0	0.029852	0.011394	0.002779	0.002524
3.70891	334.33	0.00764	6.21E-06	1.83E-05	0.002452	0	0.029653	0.011287	0.002739	0.002493
3.69106	335.9469	0.007437	6.10E-06	1.79E-05	0.002424	0	0.029457	0.011181	0.0027	0.002463
3.67337	337.5647	0.007239	6.00E-06	1.74E-05	0.002396	0	0.029264	0.011078	0.002662	0.002434
3.65586	339.1815	0.007046	5.89E-06	1.70E-05	0.002369	0	0.029073	0.010977	0.002625	0.002405
3.63851	340.7988	0.006858	5.79E-06	1.65E-05	0.002343	0	0.028885	0.010878	0.002589	0.002378
3.62132	342.4166	0.006675	5.70E-06	1.61E-05	0.002317	0	0.0287	0.010781	0.002554	0.00235
3.6043	344.0335	0.006497	5.60E-06	1.57E-05	0.002292	0	0.028517	0.010685	0.002519	0.002324
3.58743	345.6513	0.006323	5.51E-06	1.53E-05	0.002268	0	0.028337	0.010592	0.002486	0.002298
3.57072	347.2689	0.006154	5.42E-06	1.49E-05	0.002244	0	0.028159	0.0105	0.002453	0.002272
3.55417	348.886	0.005989	5.33E-06	1.46E-05	0.00222	0	0.027984	0.01041	0.002421	0.002247
3.53777	350.5033	0.005828	5.24E-06	1.42E-05	0.002197	0	0.02781	0.010322	0.00239	0.002223
3.52152	352.1207	0.005672	5.16E-06	1.38E-05	0.002175	0	0.02764	0.010235	0.002359	0.0022

E (eV)	λ (nm)	ThO2 050429 -- 10.468 nm -- 0 V k (oscillators)	ThO2 050503 -- 19.112 nm -- 50 V k (oscillators)	ThO2 050505 -- 14.062 nm -- 70 V k (oscillators)	ThO2 050520 -- 54.194nm -- 68 V k (oscillators)	ThO2 050526 -- 53.005nm -- 0 V k (oscillators)	ThO2 050527 -- 51.349nm -- 0 V k (oscillators)	ThO2 050604 -- 9.981nm -- 64 V k (oscillators)	ThO2 050604-2 -- 336.938nm -- 0 V k (oscillators)	ThO2 050818 -- 538.033nm -- 65 V k (oscillators)
3.50542	353.7379	0.005519	5.08E-06	1.35E-05	0.002153	0	0.027471	0.01015	0.002329	0.002176
3.48946	355.3558	0.00537	5.00E-06	1.32E-05	0.002131	0	0.027305	0.010066	0.0023	0.002154
3.47365	356.9732	0.005225	4.92E-06	1.28E-05	0.00211	0	0.027141	0.009984	0.002272	0.002131
3.45799	358.5898	0.005083	4.85E-06	1.25E-05	0.00209	0	0.026978	0.009903	0.002244	0.00211
3.44246	360.2075	0.004945	4.77E-06	1.22E-05	0.00207	0	0.026818	0.009823	0.002217	0.002088
3.42707	361.8251	0.004811	4.70E-06	1.19E-05	0.00205	0	0.02666	0.009745	0.00219	0.002068
3.41182	363.4424	0.004679	4.63E-06	1.16E-05	0.00203	0	0.026505	0.009669	0.002164	0.002047
3.39671	365.0591	0.004551	4.56E-06	1.13E-05	0.002011	0	0.02635	0.009593	0.002138	0.002027
3.38173	366.6762	0.004426	4.49E-06	1.11E-05	0.001993	0	0.026198	0.009519	0.002113	0.002008
3.36688	368.2935	0.004304	4.43E-06	1.08E-05	0.001974	0	0.026048	0.009446	0.002089	0.001989
3.35216	369.9107	0.004185	4.36E-06	1.05E-05	0.001956	0	0.0259	0.009375	0.002065	0.00197
3.33757	371.5278	0.004069	4.30E-06	1.03E-05	0.001939	0	0.025753	0.009304	0.002042	0.001951
3.3231	373.1456	0.003955	4.24E-06	1.00E-05	0.001922	0	0.025608	0.009235	0.002018	0.001933
3.30876	374.7628	0.003844	4.18E-06	9.79E-06	0.001905	0	0.025465	0.009167	0.001996	0.001916
3.29454	376.3803	0.003736	4.12E-06	9.55E-06	0.001888	0	0.025324	0.0091	0.001974	0.001898
3.28045	377.9969	0.003631	4.06E-06	9.32E-06	0.001872	0	0.025184	0.009033	0.001952	0.001881
3.26647	379.6147	0.003528	4.00E-06	9.10E-06	0.001856	0	0.025046	0.008968	0.001931	0.001865
3.25262	381.2311	0.003427	3.95E-06	8.88E-06	0.00184	0	0.02491	0.008904	0.00191	0.001848
3.23888	382.8484	0.003329	3.89E-06	8.66E-06	0.001824	0	0.024775	0.008841	0.00189	0.001832
3.22526	384.4651	0.003233	3.84E-06	8.45E-06	0.001809	0	0.024642	0.008779	0.001869	0.001816
3.21175	386.0824	0.00314	3.79E-06	8.25E-06	0.001794	0	0.02451	0.008718	0.00185	0.001801
3.19835	387.6999	0.003048	3.74E-06	8.05E-06	0.00178	0	0.02438	0.008658	0.00183	0.001786
3.18507	389.3164	0.002959	3.69E-06	7.85E-06	0.001765	0	0.024251	0.008599	0.001811	0.001771
3.17189	390.9341	0.002872	3.64E-06	7.66E-06	0.001751	0	0.024124	0.00854	0.001793	0.001756
3.15883	392.5504	0.002787	3.59E-06	7.48E-06	0.001737	0	0.023998	0.008482	0.001775	0.001741
3.14587	394.1676	0.002704	3.54E-06	7.30E-06	0.001724	0	0.023873	0.008426	0.001757	0.001727
3.13302	395.7843	0.002623	3.50E-06	7.12E-06	0.00171	0	0.02375	0.00837	0.001739	0.001713
3.12027	397.4015	0.002544	3.45E-06	6.94E-06	0.001697	0	0.023628	0.008315	0.001722	0.0017

E (eV)	λ (nm)	ThO2 050429 -- 10.468 nm -- 0 V k (oscillators)	ThO2 050503 -- 19.112 nm -- 50 V k (oscillators)	ThO2 050505 -- 14.062 nm -- 70 V k (oscillators)	ThO2 050520 -- 54.194nm -- 68 V k (oscillators)	ThO2 050526 -- 53.005nm -- 0 V k (oscillators)	ThO2 050527 -- 51.349nm -- 0 V k (oscillators)	ThO2 050604 -- 9.981nm -- 64 V k (oscillators)	ThO2 050604-2 -- 336.938nm -- 0 V k (oscillators)	ThO2 050818 -- 538.033nm -- 65 V k (oscillators)
3.10763	399.0179	0.002467	3.41E-06	6.78E-06	0.001684	0	0.023508	0.00826	0.001705	0.001686
3.09508	400.6358	0.002391	3.36E-06	6.61E-06	0.001671	0	0.023389	0.008207	0.001688	0.001673
3.08265	402.2513	0.002318	3.32E-06	6.45E-06	0.001658	0	0.023271	0.008154	0.001671	0.00166
3.0703	403.8693	0.002246	3.28E-06	6.29E-06	0.001646	0	0.023155	0.008102	0.001655	0.001647
3.05806	405.4858	0.002175	3.24E-06	6.14E-06	0.001634	0	0.023039	0.008051	0.001639	0.001634
3.04592	407.102	0.002107	3.20E-06	5.99E-06	0.001622	0	0.022925	0.008	0.001624	0.001622
3.03387	408.7189	0.00204	3.16E-06	5.84E-06	0.00161	0	0.022812	0.00795	0.001608	0.00161
3.02191	410.3365	0.001975	3.12E-06	5.69E-06	0.001598	0	0.022701	0.007901	0.001593	0.001598
3.01005	411.9533	0.001911	3.08E-06	5.55E-06	0.001587	0	0.02259	0.007852	0.001578	0.001586
2.99829	413.5691	0.001849	3.04E-06	5.41E-06	0.001576	0	0.022481	0.007804	0.001564	0.001574
2.98661	415.1864	0.001788	3.00E-06	5.28E-06	0.001565	0	0.022372	0.007757	0.001549	0.001563
2.97503	416.8025	0.001729	2.97E-06	5.15E-06	0.001554	0	0.022265	0.00771	0.001535	0.001552
2.96353	418.4199	0.001671	2.93E-06	5.02E-06	0.001543	0	0.022159	0.007664	0.001521	0.001541
2.95213	420.0357	0.001614	2.90E-06	4.89E-06	0.001532	0	0.022054	0.007618	0.001507	0.00153
2.94081	421.6525	0.001559	2.86E-06	4.77E-06	0.001522	0	0.02195	0.007574	0.001494	0.001519
2.92958	423.2689	0.001506	2.83E-06	4.65E-06	0.001512	0	0.021847	0.007529	0.00148	0.001508
2.91843	424.886	0.001453	2.79E-06	4.53E-06	0.001501	0	0.021746	0.007485	0.001467	0.001498
2.90737	426.5023	0.001402	2.76E-06	4.41E-06	0.001491	0	0.021645	0.007442	0.001454	0.001488
2.89639	428.1191	0.001352	2.73E-06	4.30E-06	0.001481	0	0.021545	0.007399	0.001442	0.001478
2.8855	429.7349	0.001304	2.70E-06	4.19E-06	0.001472	0	0.021446	0.007357	0.001429	0.001468
2.87468	431.3524	0.001257	2.66E-06	4.08E-06	0.001462	0	0.021348	0.007316	0.001417	0.001458
2.86395	432.9685	0.00121	2.63E-06	3.98E-06	0.001453	0	0.021251	0.007275	0.001404	0.001448
2.8533	434.5845	0.001165	2.60E-06	3.87E-06	0.001443	0	0.021155	0.007234	0.001392	0.001438
2.84273	436.2004	0.001122	2.57E-06	3.77E-06	0.001434	0	0.02106	0.007194	0.001381	0.001429
2.83223	437.8176	0.001079	2.54E-06	3.67E-06	0.001425	0	0.020966	0.007154	0.001369	0.00142
2.82181	439.4343	0.001037	2.51E-06	3.58E-06	0.001416	0	0.020872	0.007115	0.001357	0.001411
2.81147	441.0504	0.000997	2.48E-06	3.48E-06	0.001407	0	0.02078	0.007076	0.001346	0.001402
2.80121	442.6658	0.000957	2.46E-06	3.39E-06	0.001399	0	0.020688	0.007038	0.001335	0.001393

E (eV)	λ (nm)	ThO2 050429 -- 10.468 nm -- 0 V k (oscillators)	ThO2 050503 -- 19.112 nm -- 50 V k (oscillators)	ThO2 050505 -- 14.062 nm -- 70 V k (oscillators)	ThO2 050520 -- 54.194nm -- 68 V k (oscillators)	ThO2 050526 -- 53.005nm -- 0 V k (oscillators)	ThO2 050527 -- 51.349nm -- 0 V k (oscillators)	ThO2 050604 -- 9.981nm -- 64 V k (oscillators)	ThO2 050604-2 -- 336.938nm -- 0 V k (oscillators)	ThO2 050818 -- 538.033nm -- 65 V k (oscillators)
2.79102	444.282	0.000919	2.43E-06	3.30E-06	0.00139	0	0.020598	0.007	0.001324	0.001384
2.7809	445.8988	0.000882	2.40E-06	3.21E-06	0.001382	0	0.020508	0.006963	0.001313	0.001375
2.77086	447.5145	0.000845	2.37E-06	3.12E-06	0.001373	0	0.020419	0.006926	0.001302	0.001367
2.76088	449.1322	0.00081	2.35E-06	3.04E-06	0.001365	0	0.020331	0.006889	0.001292	0.001358
2.75099	450.7468	0.000775	2.32E-06	2.95E-06	0.001357	0	0.020243	0.006853	0.001281	0.00135
2.74116	452.3632	0.000742	2.30E-06	2.87E-06	0.001349	0	0.020157	0.006818	0.001271	0.001342
2.7314	453.9796	0.000709	2.27E-06	2.79E-06	0.001341	0	0.020071	0.006782	0.001261	0.001334
2.72171	455.5959	0.000678	2.24E-06	2.71E-06	0.001333	0	0.019986	0.006747	0.001251	0.001326
2.71209	457.212	0.000647	2.22E-06	2.64E-06	0.001325	0	0.019901	0.006713	0.001241	0.001318
2.70254	458.8276	0.000617	2.20E-06	2.56E-06	0.001318	0	0.019818	0.006679	0.001231	0.00131
2.69305	460.4445	0.000588	2.17E-06	2.49E-06	0.00131	0	0.019735	0.006645	0.001222	0.001302
2.68363	462.0607	0.00056	2.15E-06	2.42E-06	0.001303	0	0.019653	0.006612	0.001212	0.001295
2.67428	463.6762	0.000533	2.12E-06	2.35E-06	0.001295	0	0.019572	0.006579	0.001203	0.001287
2.66499	465.2926	0.000507	2.10E-06	2.28E-06	0.001288	0	0.019491	0.006546	0.001194	0.00128
2.65577	466.9079	0.000481	2.08E-06	2.21E-06	0.001281	0	0.019411	0.006514	0.001184	0.001272
2.64661	468.5239	0.000456	2.06E-06	2.15E-06	0.001274	0	0.019332	0.006482	0.001175	0.001265
2.63751	470.1404	0.000432	2.03E-06	2.08E-06	0.001267	0	0.019253	0.00645	0.001166	0.001258
2.62848	471.7555	0.000409	2.01E-06	2.02E-06	0.00126	0	0.019175	0.006419	0.001158	0.001251
2.61951	473.371	0.000387	1.99E-06	1.96E-06	0.001253	0	0.019098	0.006388	0.001149	0.001244
2.6106	474.9866	0.000365	1.97E-06	1.90E-06	0.001246	0	0.019022	0.006357	0.00114	0.001237
2.60174	476.6041	0.000344	1.95E-06	1.84E-06	0.001239	0	0.018946	0.006327	0.001132	0.00123
2.59295	478.2198	0.000324	1.93E-06	1.78E-06	0.001233	0	0.01887	0.006297	0.001124	0.001224
2.58422	479.8353	0.000304	1.91E-06	1.72E-06	0.001226	0	0.018796	0.006267	0.001115	0.001217
2.57555	481.4506	0.000286	1.89E-06	1.67E-06	0.00122	0	0.018722	0.006238	0.001107	0.00121
2.56694	483.0654	0.000268	1.87E-06	1.62E-06	0.001213	0	0.018648	0.006209	0.001099	0.001204
2.55838	484.6817	0.00025	1.85E-06	1.56E-06	0.001207	0	0.018576	0.00618	0.001091	0.001197
2.54988	486.2974	0.000233	1.83E-06	1.51E-06	0.001201	0	0.018503	0.006152	0.001083	0.001191
2.54144	487.9124	0.000217	1.81E-06	1.46E-06	0.001195	0	0.018432	0.006123	0.001075	0.001185

E (eV)	λ (nm)	ThO2 050429 -- 10.468 nm -- 0 V k (oscillators)	ThO2 050503 -- 19.112 nm -- 50 V k (oscillators)	ThO2 050505 -- 14.062 nm -- 70 V k (oscillators)	ThO2 050520 -- 54.194nm -- 68 V k (oscillators)	ThO2 050526 -- 53.005nm -- 0 V k (oscillators)	ThO2 050527 -- 51.349nm -- 0 V k (oscillators)	ThO2 050604 -- 9.981nm -- 64 V k (oscillators)	ThO2 050604-2 -- 336.938nm -- 0 V k (oscillators)	ThO2 050818 -- 538.033nm -- 65 V k (oscillators)
2.53305	489.5284	0.000202	1.79E-06	1.41E-06	0.001188	0	0.018361	0.006095	0.001068	0.001179
2.52472	491.1436	0.000187	1.77E-06	1.37E-06	0.001182	0	0.01829	0.006068	0.00106	0.001172
2.51644	492.7596	0.000173	1.75E-06	1.32E-06	0.001176	0	0.01822	0.00604	0.001052	0.001166
2.50821	494.3765	0.000159	1.74E-06	1.27E-06	0.00117	0	0.018151	0.006013	0.001045	0.00116
2.50005	495.9901	0.000147	1.72E-06	1.23E-06	0.001165	0	0.018082	0.005986	0.001038	0.001154
2.49193	497.6063	0.000134	1.70E-06	1.19E-06	0.001159	0	0.018014	0.00596	0.00103	0.001149
2.48387	499.221	0.000123	1.68E-06	1.14E-06	0.001153	0	0.017946	0.005933	0.001023	0.001143
2.47585	500.8381	0.000111	1.67E-06	1.10E-06	0.001147	0	0.017879	0.005907	0.001016	0.001137
2.46789	502.4535	0.000101	1.65E-06	1.06E-06	0.001142	0	0.017813	0.005881	0.001009	0.001131
2.45998	504.0691	9.09E-05	1.63E-06	1.02E-06	0.001136	0	0.017747	0.005856	0.001002	0.001126
2.45213	505.6828	8.15E-05	1.62E-06	9.84E-07	0.001131	0	0.017681	0.00583	0.000995	0.00112
2.44432	507.2986	7.26E-05	1.60E-06	9.47E-07	0.001125	0	0.017616	0.005805	0.000988	0.001115
2.43656	508.9142	6.43E-05	1.58E-06	9.10E-07	0.00112	0	0.017551	0.00578	0.000981	0.001109
2.42885	510.5297	5.66E-05	1.57E-06	8.74E-07	0.001115	0	0.017487	0.005756	0.000975	0.001104
2.42119	512.1449	4.93E-05	1.55E-06	8.40E-07	0.001109	0	0.017424	0.005731	0.000968	0.001099
2.41358	513.7596	4.26E-05	1.53E-06	8.06E-07	0.001104	0	0.017361	0.005707	0.000962	0.001093
2.40601	515.3761	3.64E-05	1.52E-06	7.73E-07	0.001099	0	0.017298	0.005683	0.000955	0.001088
2.39849	516.9919	3.07E-05	1.50E-06	7.41E-07	0.001094	0	0.017236	0.005659	0.000949	0.001083
2.39102	518.6071	2.56E-05	1.49E-06	7.10E-07	0.001089	0	0.017174	0.005636	0.000942	0.001078
2.3836	520.2215	2.09E-05	1.47E-06	6.79E-07	0.001084	0	0.017113	0.005613	0.000936	0.001073
2.37622	521.8372	1.67E-05	1.46E-06	6.50E-07	0.001079	0	0.017052	0.005589	0.00093	0.001068
2.36889	523.4519	1.30E-05	1.44E-06	6.21E-07	0.001074	0	0.016992	0.005566	0.000924	0.001063
2.3616	525.0678	9.77E-06	1.43E-06	5.93E-07	0.001069	0	0.016932	0.005544	0.000918	0.001058
2.35436	526.6824	7.02E-06	1.42E-06	5.66E-07	0.001064	0	0.016873	0.005521	0.000912	0.001053
2.34716	528.298	4.73E-06	1.40E-06	5.39E-07	0.00106	0	0.016814	0.005499	0.000906	0.001048
2.34001	529.9123	2.89E-06	1.39E-06	5.14E-07	0.001055	0	0.016755	0.005477	0.0009	0.001044
2.3329	531.5273	1.51E-06	1.37E-06	4.89E-07	0.00105	0	0.016697	0.005455	0.000894	0.001039
2.32583	533.143	5.79E-07	1.36E-06	4.65E-07	0.001046	0	0.01664	0.005433	0.000888	0.001034

E (eV)	λ (nm)	ThO2 050429 -- 10.468 nm -- 0 V k (oscillators)	ThO2 050503 -- 19.112 nm -- 50 V k (oscillators)	ThO2 050505 -- 14.062 nm -- 70 V k (oscillators)	ThO2 050520 -- 54.194nm -- 68 V k (oscillators)	ThO2 050526 -- 53.005nm -- 0 V k (oscillators)	ThO2 050527 -- 51.349nm -- 0 V k (oscillators)	ThO2 050604 -- 9.981nm -- 64 V k (oscillators)	ThO2 050604-2 -- 336.938nm -- 0 V k (oscillators)	ThO2 050818 -- 538.033nm -- 65 V k (oscillators)
2.31881	534.7571	8.62E-08	1.35E-06	4.41E-07	0.001041	0	0.016582	0.005411	0.000883	0.00103
2.31183	536.3716	0	1.33E-06	4.19E-07	0.001037	0	0.016526	0.00539	0.000877	0.001025
2.30489	537.9866	0	1.32E-06	3.97E-07	0.001032	0	0.016469	0.005369	0.000871	0.001021
2.29799	539.602	0	1.31E-06	3.75E-07	0.001028	0	0.016413	0.005348	0.000866	0.001016
2.29113	541.2177	0	1.29E-06	3.55E-07	0.001023	0	0.016357	0.005327	0.00086	0.001012
2.28432	542.8311	0	1.28E-06	3.35E-07	0.001019	0	0.016302	0.005306	0.000855	0.001007
2.27754	544.4471	0	1.27E-06	3.16E-07	0.001014	0	0.016247	0.005286	0.00085	0.001003
2.27081	546.0607	0	1.26E-06	2.97E-07	0.00101	0	0.016193	0.005265	0.000844	0.000999
2.26411	547.6766	0	1.24E-06	2.79E-07	0.001006	0	0.016139	0.005245	0.000839	0.000994
2.25746	549.2899	0	1.23E-06	2.62E-07	0.001002	0	0.016085	0.005225	0.000834	0.00099
2.25084	550.9054	0	1.22E-06	2.45E-07	0.000997	0	0.016032	0.005205	0.000829	0.000986
2.24426	552.5207	0	1.21E-06	2.29E-07	0.000993	0	0.015979	0.005186	0.000823	0.000982
2.23772	554.1355	0	1.20E-06	2.13E-07	0.000989	0	0.015926	0.005166	0.000818	0.000978
2.23122	555.7498	0	1.18E-06	1.99E-07	0.000985	0	0.015874	0.005147	0.000813	0.000973
2.22475	557.366	0	1.17E-06	1.84E-07	0.000981	0	0.015822	0.005128	0.000808	0.000969
2.21833	558.9791	0	1.16E-06	1.71E-07	0.000977	0	0.015771	0.005109	0.000803	0.000965
2.21194	560.5939	0	1.15E-06	1.58E-07	0.000973	0	0.015719	0.00509	0.000798	0.000961
2.20558	562.2104	0	1.14E-06	1.45E-07	0.000969	0	0.015669	0.005071	0.000794	0.000957
2.19927	563.8235	0	1.13E-06	1.33E-07	0.000965	0	0.015618	0.005053	0.000789	0.000954
2.19299	565.4381	0	1.12E-06	1.22E-07	0.000962	0	0.015568	0.005034	0.000784	0.00095
2.18674	567.0542	0	1.11E-06	1.11E-07	0.000958	0	0.015518	0.005016	0.000779	0.000946
2.18054	568.6665	0	1.09E-06	1.01E-07	0.000954	0	0.015469	0.004998	0.000775	0.000942
2.17436	570.2827	0	1.08E-06	9.12E-08	0.00095	0	0.01542	0.00498	0.00077	0.000938
2.16822	571.8977	0	1.07E-06	8.20E-08	0.000946	0	0.015371	0.004962	0.000765	0.000935
2.16212	573.5112	0	1.06E-06	7.34E-08	0.000943	0	0.015322	0.004944	0.000761	0.000931
2.15605	575.1258	0	1.05E-06	6.52E-08	0.000939	0	0.015274	0.004926	0.000756	0.000927
2.15001	576.7415	0	1.04E-06	5.76E-08	0.000935	0	0.015226	0.004909	0.000752	0.000924
2.14401	578.3555	0	1.03E-06	5.04E-08	0.000932	0	0.015179	0.004892	0.000747	0.00092

E (eV)	λ (nm)	ThO2 050429 -- 10.468 nm -- 0 V k (oscillators)	ThO2 050503 -- 19.112 nm -- 50 V k (oscillators)	ThO2 050505 -- 14.062 nm -- 70 V k (oscillators)	ThO2 050520 -- 54.194nm -- 68 V k (oscillators)	ThO2 050526 -- 53.005nm -- 0 V k (oscillators)	ThO2 050527 -- 51.349nm -- 0 V k (oscillators)	ThO2 050604 -- 9.981nm -- 64 V k (oscillators)	ThO2 050604-2 -- 336.938nm -- 0 V k (oscillators)	ThO2 050818 -- 538.033nm -- 65 V k (oscillators)
2.13805	579.9677	0	1.02E-06	4.38E-08	0.000928	0	0.015132	0.004874	0.000743	0.000916
2.13211	581.5835	0	1.01E-06	3.77E-08	0.000925	0	0.015085	0.004857	0.000739	0.000913
2.12621	583.1973	0	1.00E-06	3.20E-08	0.000921	0	0.015038	0.00484	0.000734	0.000909
2.12034	584.8119	0	9.93E-07	2.68E-08	0.000918	0	0.014992	0.004824	0.00073	0.000906
2.1145	586.4271	0	9.83E-07	2.21E-08	0.000914	0	0.014946	0.004807	0.000726	0.000902
2.1087	588.04	0	9.74E-07	1.79E-08	0.000911	0	0.0149	0.00479	0.000721	0.000899
2.10292	589.6563	0	9.65E-07	1.41E-08	0.000907	0	0.014854	0.004774	0.000717	0.000895
2.09718	591.2702	0	9.55E-07	1.08E-08	0.000904	0	0.014809	0.004757	0.000713	0.000892
2.09147	592.8844	0	9.46E-07	7.97E-09	0.000901	0	0.014764	0.004741	0.000709	0.000889
2.08579	594.499	0	9.37E-07	5.56E-09	0.000897	0	0.01472	0.004725	0.000705	0.000885
2.08015	596.1109	0	9.28E-07	3.59E-09	0.000894	0	0.014676	0.004709	0.000701	0.000882
2.07453	597.7257	0	9.19E-07	2.05E-09	0.000891	0	0.014632	0.004693	0.000697	0.000879
2.06894	599.3407	0	9.10E-07	9.43E-10	0.000888	0	0.014588	0.004678	0.000693	0.000876
2.06338	600.9557	0	9.01E-07	2.63E-10	0.000884	0	0.014544	0.004662	0.000689	0.000872
2.05786	602.5677	0	8.92E-07	3.12E-12	0.000881	0	0.014501	0.004646	0.000685	0.000869
2.05236	604.1825	0	8.84E-07	0	0.000878	0	0.014458	0.004631	0.000681	0.000866
2.04689	605.7971	0	8.75E-07	0	0.000875	0	0.014415	0.004616	0.000677	0.000863
2.04145	607.4114	0	8.67E-07	0	0.000872	0	0.014373	0.004601	0.000673	0.00086
2.03604	609.0254	0	8.58E-07	0	0.000869	0	0.014331	0.004585	0.00067	0.000857
2.03066	610.6389	0	8.50E-07	0	0.000866	0	0.014289	0.00457	0.000666	0.000854
2.02531	612.252	0	8.42E-07	0	0.000863	0	0.014247	0.004556	0.000662	0.000851
2.01998	613.8675	0	8.33E-07	0	0.00086	0	0.014206	0.004541	0.000658	0.000848
2.01469	615.4793	0	8.25E-07	0	0.000857	0	0.014165	0.004526	0.000655	0.000845
2.00942	617.0935	0	8.17E-07	0	0.000854	0	0.014124	0.004512	0.000651	0.000842
2.00417	618.71	0	8.09E-07	0	0.000851	0	0.014083	0.004497	0.000648	0.000839
1.99896	620.3226	0	8.02E-07	0	0.000848	0	0.014043	0.004483	0.000644	0.000836
1.99377	621.9373	0	7.94E-07	0	0.000845	0	0.014003	0.004469	0.00064	0.000833
1.98861	623.5511	0	7.86E-07	0	0.000842	0	0.013963	0.004454	0.000637	0.00083

E (eV)	λ (nm)	ThO2 050429 -- 10.468 nm -- 0 V k (oscillators)	ThO2 050503 -- 19.112 nm -- 50 V k (oscillators)	ThO2 050505 -- 14.062 nm -- 70 V k (oscillators)	ThO2 050520 -- 54.194nm -- 68 V k (oscillators)	ThO2 050526 -- 53.005nm -- 0 V k (oscillators)	ThO2 050527 -- 51.349nm -- 0 V k (oscillators)	ThO2 050604 -- 9.981nm -- 64 V k (oscillators)	ThO2 050604-2 -- 336.938nm -- 0 V k (oscillators)	ThO2 050818 -- 538.033nm -- 65 V k (oscillators)
1.98348	625.1639	0	7.79E-07	0	0.000839	0	0.013923	0.00444	0.000633	0.000827
1.97837	626.7786	0	7.71E-07	0	0.000836	0	0.013884	0.004426	0.00063	0.000824
1.97329	628.3922	0	7.63E-07	0	0.000833	0	0.013844	0.004412	0.000626	0.000821
1.96824	630.0045	0	7.56E-07	0	0.000831	0	0.013806	0.004399	0.000623	0.000819
1.96321	631.6186	0	7.49E-07	0	0.000828	0	0.013767	0.004385	0.00062	0.000816
1.95821	633.2314	0	7.41E-07	0	0.000825	0	0.013728	0.004371	0.000616	0.000813
1.95323	634.8459	0	7.34E-07	0	0.000822	0	0.01369	0.004358	0.000613	0.00081
1.94828	636.4588	0	7.27E-07	0	0.00082	0	0.013652	0.004344	0.00061	0.000808
1.94335	638.0734	0	7.20E-07	0	0.000817	0	0.013614	0.004331	0.000606	0.000805
1.93845	639.6863	0	7.13E-07	0	0.000814	0	0.013576	0.004318	0.000603	0.000802
1.93357	641.3008	0	7.06E-07	0	0.000811	0	0.013539	0.004305	0.0006	0.0008
1.92872	642.9134	0	6.99E-07	0	0.000809	0	0.013502	0.004291	0.000597	0.000797
1.92389	644.5275	0	6.92E-07	0	0.000806	0	0.013465	0.004278	0.000593	0.000794
1.91909	646.1396	0	6.85E-07	0	0.000804	0	0.013428	0.004266	0.00059	0.000792
1.91431	647.753	0	6.79E-07	0	0.000801	0	0.013391	0.004253	0.000587	0.000789
1.90955	649.3677	0	6.72E-07	0	0.000798	0	0.013355	0.00424	0.000584	0.000787
1.90482	650.9801	0	6.66E-07	0	0.000796	0	0.013319	0.004227	0.000581	0.000784
1.90011	652.5938	0	6.59E-07	0	0.000793	0	0.013283	0.004215	0.000578	0.000781
1.89543	654.2051	0	6.53E-07	0	0.000791	0	0.013247	0.004202	0.000575	0.000779
1.89076	655.8209	0	6.46E-07	0	0.000788	0	0.013211	0.00419	0.000572	0.000776
1.88612	657.4343	0	6.40E-07	0	0.000786	0	0.013176	0.004177	0.000569	0.000774
1.88151	659.0451	0	6.33E-07	0	0.000783	0	0.013141	0.004165	0.000566	0.000771
1.87691	660.6603	0	6.27E-07	0	0.000781	0	0.013106	0.004153	0.000563	0.000769
1.87234	662.2729	0	6.21E-07	0	0.000778	0	0.013071	0.004141	0.00056	0.000767
1.86779	663.8862	0	6.15E-07	0	0.000776	0	0.013036	0.004129	0.000557	0.000764
1.86327	665.4967	0	6.09E-07	0	0.000774	0	0.013002	0.004117	0.000554	0.000762
1.85876	667.1114	0	6.03E-07	0	0.000771	0	0.012968	0.004105	0.000551	0.000759
1.85428	668.7232	0	5.97E-07	0	0.000769	0	0.012934	0.004093	0.000548	0.000757

E (eV)	λ (nm)	ThO2 050429 -- 10.468 nm -- 0 V k (oscillators)	ThO2 050503 -- 19.112 nm -- 50 V k (oscillators)	ThO2 050505 -- 14.062 nm -- 70 V k (oscillators)	ThO2 050520 -- 54.194nm -- 68 V k (oscillators)	ThO2 050526 -- 53.005nm -- 0 V k (oscillators)	ThO2 050527 -- 51.349nm -- 0 V k (oscillators)	ThO2 050604 -- 9.981nm -- 64 V k (oscillators)	ThO2 050604-2 -- 336.938nm -- 0 V k (oscillators)	ThO2 050818 -- 538.033nm -- 65 V k (oscillators)
1.84982	670.3355	0	5.91E-07	0	0.000766	0	0.0129	0.004081	0.000545	0.000755
1.84538	671.9483	0	5.85E-07	0	0.000764	0	0.012866	0.00407	0.000542	0.000752
1.84096	673.5616	0	5.79E-07	0	0.000762	0	0.012833	0.004058	0.00054	0.00075
1.83656	675.1753	0	5.74E-07	0	0.000759	0	0.0128	0.004047	0.000537	0.000748
1.83219	676.7857	0	5.68E-07	0	0.000757	0	0.012766	0.004035	0.000534	0.000745
1.82783	678.4001	0	5.62E-07	0	0.000755	0	0.012733	0.004024	0.000531	0.000743
1.8235	680.011	0	5.57E-07	0	0.000753	0	0.012701	0.004012	0.000529	0.000741
1.81918	681.6258	0	5.51E-07	0	0.00075	0	0.012668	0.004001	0.000526	0.000739
1.81489	683.237	0	5.45E-07	0	0.000748	0	0.012636	0.00399	0.000523	0.000736
1.81062	684.8483	0	5.40E-07	0	0.000746	0	0.012603	0.003979	0.000521	0.000734
1.80637	686.4596	0	5.35E-07	0	0.000744	0	0.012571	0.003968	0.000518	0.000732
1.80213	688.0747	0	5.29E-07	0	0.000741	0	0.012539	0.003957	0.000515	0.00073
1.79792	689.6859	0	5.24E-07	0	0.000739	0	0.012508	0.003946	0.000513	0.000728
1.79373	691.2969	0	5.19E-07	0	0.000737	0	0.012476	0.003935	0.00051	0.000726
1.78955	692.9116	0	5.13E-07	0	0.000735	0	0.012445	0.003924	0.000507	0.000723
1.7854	694.5222	0	5.08E-07	0	0.000733	0	0.012414	0.003913	0.000505	0.000721
1.78127	696.1325	0	5.03E-07	0	0.000731	0	0.012382	0.003903	0.000502	0.000719
1.77715	697.7464	0	4.98E-07	0	0.000729	0	0.012352	0.003892	0.0005	0.000717
1.77305	699.3599	0	4.93E-07	0	0.000727	0	0.012321	0.003881	0.000497	0.000715
1.76898	700.9689	0	4.88E-07	0	0.000724	0	0.01229	0.003871	0.000495	0.000713
1.76492	702.5814	0	4.83E-07	0	0.000722	0	0.01226	0.003861	0.000492	0.000711
1.76088	704.1934	0	4.78E-07	0	0.00072	0	0.012229	0.00385	0.00049	0.000709
1.75686	705.8047	0	4.73E-07	0	0.000718	0	0.012199	0.00384	0.000487	0.000707
1.75286	707.4153	0	4.68E-07	0	0.000716	0	0.012169	0.00383	0.000485	0.000705
1.74887	709.0293	0	4.64E-07	0	0.000714	0	0.01214	0.003819	0.000482	0.000703
1.74491	710.6384	0	4.59E-07	0	0.000712	0	0.01211	0.003809	0.00048	0.000701
1.74096	712.2507	0	4.54E-07	0	0.00071	0	0.01208	0.003799	0.000478	0.000699
1.73703	713.8622	0	4.49E-07	0	0.000708	0	0.012051	0.003789	0.000475	0.000697

E (eV)	λ (nm)	ThO2 050429 -- 10.468 nm -- 0 V k (oscillators)	ThO2 050503 -- 19.112 nm -- 50 V k (oscillators)	ThO2 050505 -- 14.062 nm -- 70 V k (oscillators)	ThO2 050520 -- 54.194nm -- 68 V k (oscillators)	ThO2 050526 -- 53.005nm -- 0 V k (oscillators)	ThO2 050527 -- 51.349nm -- 0 V k (oscillators)	ThO2 050604 -- 9.981nm -- 64 V k (oscillators)	ThO2 050604-2 -- 336.938nm -- 0 V k (oscillators)	ThO2 050818 -- 538.033nm -- 65 V k (oscillators)
1.73312	715.4727	0	4.45E-07	0	0.000706	0	0.012022	0.003779	0.000473	0.000695
1.72923	717.0822	0	4.40E-07	0	0.000704	0	0.011993	0.003769	0.000471	0.000693
1.72535	718.6948	0	4.36E-07	0	0.000702	0	0.011964	0.003759	0.000468	0.000691
1.72149	720.3062	0	4.31E-07	0	0.0007	0	0.011935	0.00375	0.000466	0.000689
1.71765	721.9166	0	4.27E-07	0	0.000698	0	0.011906	0.00374	0.000464	0.000687
1.71382	723.5299	0	4.22E-07	0	0.000696	0	0.011878	0.00373	0.000461	0.000685
1.71002	725.1377	0	4.18E-07	0	0.000695	0	0.01185	0.003721	0.000459	0.000683
1.70623	726.7484	0	4.14E-07	0	0.000693	0	0.011821	0.003711	0.000457	0.000681
1.70246	728.3578	0	4.09E-07	0	0.000691	0	0.011793	0.003701	0.000455	0.00068
1.6987	729.97	0	4.05E-07	0	0.000689	0	0.011765	0.003692	0.000452	0.000678
1.69496	731.5807	0	4.01E-07	0	0.000687	0	0.011738	0.003682	0.00045	0.000676
1.69124	733.1898	0	3.97E-07	0	0.000685	0	0.01171	0.003673	0.000448	0.000674
1.68753	734.8018	0	3.92E-07	0	0.000683	0	0.011682	0.003664	0.000446	0.000672
1.68384	736.412	0	3.88E-07	0	0.000682	0	0.011655	0.003654	0.000444	0.00067
1.68017	738.0206	0	3.84E-07	0	0.00068	0	0.011628	0.003645	0.000441	0.000669
1.67651	739.6317	0	3.80E-07	0	0.000678	0	0.011601	0.003636	0.000439	0.000667
1.67287	741.2411	0	3.76E-07	0	0.000676	0	0.011574	0.003627	0.000437	0.000665
1.66924	742.853	0	3.72E-07	0	0.000674	0	0.011547	0.003618	0.000435	0.000663
1.66563	744.4631	0	3.68E-07	0	0.000673	0	0.01152	0.003609	0.000433	0.000661
1.66204	746.0711	0	3.64E-07	0	0.000671	0	0.011493	0.0036	0.000431	0.00066
1.65846	747.6816	0	3.60E-07	0	0.000669	0	0.011467	0.003591	0.000429	0.000658
1.6549	749.29	0	3.56E-07	0	0.000667	0	0.011441	0.003582	0.000427	0.000656
1.65136	750.8962	0	3.53E-07	0	0.000666	0	0.011414	0.003573	0.000425	0.000655
1.64782	752.5094	0	3.49E-07	0	0.000664	0	0.011388	0.003564	0.000423	0.000653
1.64431	754.1157	0	3.45E-07	0	0.000662	0	0.011362	0.003556	0.00042	0.000651
1.64081	755.7243	0	3.41E-07	0	0.00066	0	0.011336	0.003547	0.000418	0.000649
1.63732	757.3352	0	3.38E-07	0	0.000659	0	0.011311	0.003538	0.000416	0.000648
1.63385	758.9436	0	3.34E-07	0	0.000657	0	0.011285	0.00353	0.000414	0.000646

E (eV)	λ (nm)	ThO2 050429 -- 10.468 nm -- 0 V k (oscillators)	ThO2 050503 -- 19.112 nm -- 50 V k (oscillators)	ThO2 050505 -- 14.062 nm -- 70 V k (oscillators)	ThO2 050520 -- 54.194nm -- 68 V k (oscillators)	ThO2 050526 -- 53.005nm -- 0 V k (oscillators)	ThO2 050527 -- 51.349nm -- 0 V k (oscillators)	ThO2 050604 -- 9.981nm -- 64 V k (oscillators)	ThO2 050604-2 -- 336.938nm -- 0 V k (oscillators)	ThO2 050818 -- 538.033nm -- 65 V k (oscillators)
1.63039	760.5542	0	3.30E-07	0	0.000655	0	0.01126	0.003521	0.000412	0.000644
1.62695	762.1623	0	3.27E-07	0	0.000654	0	0.011234	0.003513	0.00041	0.000643
1.62353	763.7678	0	3.23E-07	0	0.000652	0	0.011209	0.003504	0.000409	0.000641
1.62012	765.3754	0	3.20E-07	0	0.00065	0	0.011184	0.003496	0.000407	0.000639
1.61672	766.985	0	3.16E-07	0	0.000649	0	0.011159	0.003487	0.000405	0.000638
1.61334	768.5919	0	3.13E-07	0	0.000647	0	0.011134	0.003479	0.000403	0.000636
1.60997	770.2007	0	3.09E-07	0	0.000645	0	0.011109	0.003471	0.000401	0.000635
1.60662	771.8066	0	3.06E-07	0	0.000644	0	0.011084	0.003462	0.000399	0.000633
1.60328	773.4145	0	3.02E-07	0	0.000642	0	0.01106	0.003454	0.000397	0.000631
1.59995	775.0242	0	2.99E-07	0	0.000641	0	0.011035	0.003446	0.000395	0.00063
1.59664	776.6309	0	2.96E-07	0	0.000639	0	0.011011	0.003438	0.000393	0.000628
1.59334	778.2394	0	2.92E-07	0	0.000637	0	0.010987	0.00343	0.000391	0.000627
1.59006	779.8448	0	2.89E-07	0	0.000636	0	0.010963	0.003422	0.00039	0.000625
1.58679	781.4519	0	2.86E-07	0	0.000634	0	0.010939	0.003414	0.000388	0.000624
1.58354	783.0557	0	2.83E-07	0	0.000633	0	0.010915	0.003406	0.000386	0.000622
1.58029	784.6661	0	2.79E-07	0	0.000631	0	0.010891	0.003398	0.000384	0.00062
1.57706	786.2732	0	2.76E-07	0	0.00063	0	0.010868	0.00339	0.000382	0.000619
1.57385	787.8769	0	2.73E-07	0	0.000628	0	0.010844	0.003382	0.00038	0.000617
1.57065	789.4821	0	2.70E-07	0	0.000627	0	0.010821	0.003374	0.000379	0.000616
1.56746	791.0888	0	2.67E-07	0	0.000625	0	0.010797	0.003366	0.000377	0.000614
1.56428	792.697	0	2.64E-07	0	0.000623	0	0.010774	0.003358	0.000375	0.000613
1.56112	794.3015	0	2.61E-07	0	0.000622	0	0.010751	0.003351	0.000373	0.000611
1.55797	795.9075	0	2.58E-07	0	0.00062	0	0.010728	0.003343	0.000372	0.00061
1.55484	797.5097	0	2.55E-07	0	0.000619	0	0.010705	0.003335	0.00037	0.000609
1.55171	799.1184	0	2.52E-07	0	0.000618	0	0.010682	0.003328	0.000368	0.000607
1.5486	800.7232	0	2.49E-07	0	0.000616	0	0.010659	0.00332	0.000366	0.000606
1.5455	802.3293	0	2.46E-07	0	0.000615	0	0.010637	0.003313	0.000365	0.000604
1.54242	803.9315	0	2.43E-07	0	0.000613	0	0.010614	0.003305	0.000363	0.000603

E (eV)	λ (nm)	ThO2 050429 -- 10.468 nm -- 0 V k (oscillators)	ThO2 050503 -- 19.112 nm -- 50 V k (oscillators)	ThO2 050505 -- 14.062 nm -- 70 V k (oscillators)	ThO2 050520 -- 54.194nm -- 68 V k (oscillators)	ThO2 050526 -- 53.005nm -- 0 V k (oscillators)	ThO2 050527 -- 51.349nm -- 0 V k (oscillators)	ThO2 050604 -- 9.981nm -- 64 V k (oscillators)	ThO2 050604-2 -- 336.938nm -- 0 V k (oscillators)	ThO2 050818 -- 538.033nm -- 65 V k (oscillators)
1.53935	805.5348	0	2.40E-07	0	0.000612	0	0.010592	0.003298	0.000361	0.000601
1.53629	807.1393	0	2.38E-07	0	0.00061	0	0.01057	0.00329	0.00036	0.0006
1.53324	808.7449	0	2.35E-07	0	0.000609	0	0.010547	0.003283	0.000358	0.000598
1.53021	810.3463	0	2.32E-07	0	0.000607	0	0.010525	0.003276	0.000356	0.000597
1.52718	811.9541	0	2.29E-07	0	0.000606	0	0.010503	0.003268	0.000355	0.000596
1.52417	813.5575	0	2.26E-07	0	0.000605	0	0.010481	0.003261	0.000353	0.000594
1.52118	815.1567	0	2.24E-07	0	0.000603	0	0.010459	0.003254	0.000351	0.000593
1.51819	816.7621	0	2.21E-07	0	0.000602	0	0.010438	0.003247	0.00035	0.000591
1.51522	818.363	0	2.18E-07	0	0.0006	0	0.010416	0.00324	0.000348	0.00059
1.51226	819.9648	0	2.16E-07	0	0.000599	0	0.010394	0.003232	0.000347	0.000589
1.50931	821.5675	0	2.13E-07	0	0.000598	0	0.010373	0.003225	0.000345	0.000587
1.50637	823.1709	0	2.11E-07	0	0.000596	0	0.010352	0.003218	0.000343	0.000586
1.50344	824.7752	0	2.08E-07	0	0.000595	0	0.01033	0.003211	0.000342	0.000585
1.50053	826.3747	0	2.05E-07	0	0.000593	0	0.010309	0.003204	0.00034	0.000583
1.49763	827.9749	0	2.03E-07	0	0.000592	0	0.010288	0.003197	0.000339	0.000582
1.49473	829.5813	0	2.00E-07	0	0.000591	0	0.010267	0.00319	0.000337	0.000581
1.49186	831.1772	0	1.98E-07	0	0.000589	0	0.010246	0.003183	0.000336	0.000579
1.48899	832.7793	0	1.96E-07	0	0.000588	0	0.010225	0.003177	0.000334	0.000578
1.48613	834.3819	0	1.93E-07	0	0.000587	0	0.010205	0.00317	0.000333	0.000577
1.48329	835.9795	0	1.91E-07	0	0.000585	0	0.010184	0.003163	0.000331	0.000575
1.48045	837.5832	0	1.88E-07	0	0.000584	0	0.010164	0.003156	0.00033	0.000574
1.47763	839.1817	0	1.86E-07	0	0.000583	0	0.010143	0.003149	0.000328	0.000573
1.47482	840.7806	0	1.84E-07	0	0.000582	0	0.010123	0.003143	0.000327	0.000572
1.47202	842.3799	0	1.81E-07	0	0.00058	0	0.010102	0.003136	0.000325	0.00057
1.46923	843.9795	0	1.79E-07	0	0.000579	0	0.010082	0.003129	0.000324	0.000569
1.46645	845.5795	0	1.77E-07	0	0.000578	0	0.010062	0.003123	0.000322	0.000568
1.46368	847.1797	0	1.74E-07	0	0.000576	0	0.010042	0.003116	0.000321	0.000567
1.46093	848.7744	0	1.72E-07	0	0.000575	0	0.010022	0.00311	0.000319	0.000565

E (eV)	λ (nm)	ThO2 050429 -- 10.468 nm -- 0 V k (oscillators)	ThO2 050503 -- 19.112 nm -- 50 V k (oscillators)	ThO2 050505 -- 14.062 nm -- 70 V k (oscillators)	ThO2 050520 -- 54.194nm -- 68 V k (oscillators)	ThO2 050526 -- 53.005nm -- 0 V k (oscillators)	ThO2 050527 -- 51.349nm -- 0 V k (oscillators)	ThO2 050604 -- 9.981nm -- 64 V k (oscillators)	ThO2 050604-2 -- 336.938nm -- 0 V k (oscillators)	ThO2 050818 -- 538.033nm -- 65 V k (oscillators)
1.45818	850.3751	0	1.70E-07	0	0.000574	0	0.010002	0.003103	0.000318	0.000564
1.45545	851.9702	0	1.68E-07	0	0.000573	0	0.009983	0.003097	0.000316	0.000563
1.45272	853.5712	0	1.66E-07	0	0.000571	0	0.009963	0.00309	0.000315	0.000562
1.45001	855.1665	0	1.63E-07	0	0.00057	0	0.009943	0.003084	0.000313	0.00056
1.44731	856.7619	0	1.61E-07	0	0.000569	0	0.009924	0.003077	0.000312	0.000559
1.44462	858.3572	0	1.59E-07	0	0.000568	0	0.009904	0.003071	0.000311	0.000558
1.44193	859.9585	0	1.57E-07	0	0.000566	0	0.009885	0.003064	0.000309	0.000557
1.43926	861.5539	0	1.55E-07	0	0.000565	0	0.009866	0.003058	0.000308	0.000556
1.4366	863.1491	0	1.53E-07	0	0.000564	0	0.009847	0.003052	0.000306	0.000554
1.43395	864.7442	0	1.51E-07	0	0.000563	0	0.009827	0.003046	0.000305	0.000553
1.43131	866.3392	0	1.49E-07	0	0.000562	0	0.009808	0.003039	0.000304	0.000552
1.42868	867.934	0	1.47E-07	0	0.00056	0	0.009789	0.003033	0.000302	0.000551
1.42606	869.5286	0	1.45E-07	0	0.000559	0	0.009771	0.003027	0.000301	0.00055
1.42345	871.123	0	1.43E-07	0	0.000558	0	0.009752	0.003021	0.0003	0.000548
1.42085	872.717	0	1.41E-07	0	0.000557	0	0.009733	0.003015	0.000298	0.000547
1.41826	874.3108	0	1.39E-07	0	0.000556	0	0.009714	0.003009	0.000297	0.000546
1.41568	875.9042	0	1.37E-07	0	0.000555	0	0.009696	0.003002	0.000296	0.000545
1.41311	877.4972	0	1.35E-07	0	0.000553	0	0.009677	0.002996	0.000294	0.000544
1.41055	879.0897	0	1.33E-07	0	0.000552	0	0.009659	0.00299	0.000293	0.000543
1.408	880.6818	0	1.32E-07	0	0.000551	0	0.009641	0.002984	0.000292	0.000542
1.40546	882.2734	0	1.30E-07	0	0.00055	0	0.009622	0.002978	0.00029	0.00054
1.40293	883.8645	0	1.28E-07	0	0.000549	0	0.009604	0.002972	0.000289	0.000539
1.40041	885.455	0	1.26E-07	0	0.000548	0	0.009586	0.002967	0.000288	0.000538
1.3979	887.0449	0	1.24E-07	0	0.000547	0	0.009568	0.002961	0.000286	0.000537
1.39539	888.6405	0	1.23E-07	0	0.000545	0	0.00955	0.002955	0.000285	0.000536
1.3929	890.229	0	1.21E-07	0	0.000544	0	0.009532	0.002949	0.000284	0.000535
1.39042	891.8169	0	1.19E-07	0	0.000543	0	0.009514	0.002943	0.000283	0.000534
1.38795	893.4039	0	1.17E-07	0	0.000542	0	0.009497	0.002937	0.000281	0.000533

E (eV)	λ (nm)	ThO2 050429 -- 10.468 nm -- 0 V k (oscillators)	ThO2 050503 -- 19.112 nm -- 50 V k (oscillators)	ThO2 050505 -- 14.062 nm -- 70 V k (oscillators)	ThO2 050520 -- 54.194nm -- 68 V k (oscillators)	ThO2 050526 -- 53.005nm -- 0 V k (oscillators)	ThO2 050527 -- 51.349nm -- 0 V k (oscillators)	ThO2 050604 -- 9.981nm -- 64 V k (oscillators)	ThO2 050604-2 -- 336.938nm -- 0 V k (oscillators)	ThO2 050818 -- 538.033nm -- 65 V k (oscillators)
1.38548	894.9967	0	1.16E-07	0	0.000541	0	0.009479	0.002932	0.00028	0.000532
1.38303	896.5821	0	1.14E-07	0	0.00054	0	0.009461	0.002926	0.000279	0.000531
1.38058	898.1732	0	1.12E-07	0	0.000539	0	0.009444	0.00292	0.000278	0.00053
1.37815	899.7569	0	1.11E-07	0	0.000538	0	0.009426	0.002914	0.000276	0.000528
1.37572	901.3462	0	1.09E-07	0	0.000537	0	0.009409	0.002909	0.000275	0.000527
1.3733	902.9345	0	1.07E-07	0	0.000535	0	0.009392	0.002903	0.000274	0.000526
1.37089	904.5219	0	1.06E-07	0	0.000534	0	0.009374	0.002898	0.000273	0.000525
1.36849	906.1082	0	1.04E-07	0	0.000533	0	0.009357	0.002892	0.000272	0.000524
1.3661	907.6934	0	1.03E-07	0	0.000532	0	0.00934	0.002886	0.00027	0.000523
1.36372	909.2776	0	1.01E-07	0	0.000531	0	0.009323	0.002881	0.000269	0.000522
1.36135	910.8605	0	9.95E-08	0	0.00053	0	0.009306	0.002875	0.000268	0.000521
1.35898	912.449	0	9.80E-08	0	0.000529	0	0.009289	0.00287	0.000267	0.00052
1.35663	914.0296	0	9.65E-08	0	0.000528	0	0.009272	0.002864	0.000266	0.000519
1.35428	915.6157	0	9.50E-08	0	0.000527	0	0.009255	0.002859	0.000264	0.000518
1.35194	917.2005	0	9.35E-08	0	0.000526	0	0.009239	0.002853	0.000263	0.000517
1.34962	918.7771	0	9.20E-08	0	0.000525	0	0.009222	0.002848	0.000262	0.000516
1.3473	920.3592	0	9.06E-08	0	0.000524	0	0.009205	0.002843	0.000261	0.000515
1.34498	921.9468	0	8.92E-08	0	0.000523	0	0.009189	0.002837	0.00026	0.000514
1.34268	923.5261	0	8.77E-08	0	0.000522	0	0.009172	0.002832	0.000259	0.000513
1.34039	925.1039	0	8.63E-08	0	0.000521	0	0.009156	0.002827	0.000258	0.000512
1.3381	926.6871	0	8.49E-08	0	0.00052	0	0.00914	0.002821	0.000256	0.000511
1.33582	928.2688	0	8.36E-08	0	0.000519	0	0.009123	0.002816	0.000255	0.00051
1.33356	929.8419	0	8.22E-08	0	0.000518	0	0.009107	0.002811	0.000254	0.000509
1.33129	931.4274	0	8.09E-08	0	0.000517	0	0.009091	0.002806	0.000253	0.000508
1.32904	933.0043	0	7.95E-08	0	0.000516	0	0.009075	0.0028	0.000252	0.000507
1.3268	934.5794	0	7.82E-08	0	0.000515	0	0.009059	0.002795	0.000251	0.000506
1.32456	936.1599	0	7.69E-08	0	0.000514	0	0.009043	0.00279	0.00025	0.000505
1.32234	937.7316	0	7.56E-08	0	0.000513	0	0.009027	0.002785	0.000249	0.000504

E (eV)	λ (nm)	ThO2 050429 -- 10.468 nm -- 0 V k (oscillators)	ThO2 050503 -- 19.112 nm -- 50 V k (oscillators)	ThO2 050505 -- 14.062 nm -- 70 V k (oscillators)	ThO2 050520 -- 54.194nm -- 68 V k (oscillators)	ThO2 050526 -- 53.005nm -- 0 V k (oscillators)	ThO2 050527 -- 51.349nm -- 0 V k (oscillators)	ThO2 050604 -- 9.981nm -- 64 V k (oscillators)	ThO2 050604-2 -- 336.938nm -- 0 V k (oscillators)	ThO2 050818 -- 538.033nm -- 65 V k (oscillators)
1.32012	939.3085	0	7.44E-08	0	0.000512	0	0.009011	0.00278	0.000248	0.000503
1.31791	940.8837	0	7.31E-08	0	0.000511	0	0.008996	0.002775	0.000247	0.000502
1.3157	942.4641	0	7.19E-08	0	0.00051	0	0.00898	0.00277	0.000245	0.000501
1.31351	944.0354	0	7.06E-08	0	0.000509	0	0.008964	0.002765	0.000244	0.0005
1.31132	945.6121	0	6.94E-08	0	0.000508	0	0.008949	0.002759	0.000243	0.0005
1.30915	947.1795	0	6.82E-08	0	0.000507	0	0.008933	0.002754	0.000242	0.000499
1.30698	948.7521	0	6.70E-08	0	0.000506	0	0.008918	0.002749	0.000241	0.000498
1.30481	950.3299	0	6.58E-08	0	0.000505	0	0.008902	0.002744	0.00024	0.000497
1.30266	951.8984	0	6.47E-08	0	0.000504	0	0.008887	0.00274	0.000239	0.000496
1.30051	953.4721	0	6.35E-08	0	0.000503	0	0.008872	0.002735	0.000238	0.000495
1.29837	955.0436	0	6.24E-08	0	0.000502	0	0.008857	0.00273	0.000237	0.000494
1.29624	956.613	0	6.12E-08	0	0.000501	0	0.008841	0.002725	0.000236	0.000493
1.29412	958.1801	0	6.01E-08	0	0.0005	0	0.008826	0.00272	0.000235	0.000492
1.292	959.7523	0	5.90E-08	0	0.0005	0	0.008811	0.002715	0.000234	0.000491
1.2899	961.3148	0	5.79E-08	0	0.000499	0	0.008796	0.00271	0.000233	0.00049
1.2878	962.8824	0	5.69E-08	0	0.000498	0	0.008781	0.002705	0.000232	0.00049
1.28571	964.4477	0	5.58E-08	0	0.000497	0	0.008767	0.002701	0.000231	0.000489
1.28362	966.018	0	5.48E-08	0	0.000496	0	0.008752	0.002696	0.00023	0.000488
1.28154	967.5859	0	5.37E-08	0	0.000495	0	0.008737	0.002691	0.000229	0.000487
1.27948	969.1437	0	5.27E-08	0	0.000494	0	0.008722	0.002686	0.000228	0.000486
1.27741	970.7142	0	5.17E-08	0	0.000493	0	0.008708	0.002682	0.000227	0.000485
1.27536	972.2745	0	5.07E-08	0	0.000492	0	0.008693	0.002677	0.000226	0.000484
1.27331	973.8398	0	4.97E-08	0	0.000491	0	0.008679	0.002672	0.000225	0.000483
1.27127	975.4026	0	4.87E-08	0	0.000491	0	0.008664	0.002668	0.000224	0.000483
1.26924	976.9626	0	4.77E-08	0	0.00049	0	0.00865	0.002663	0.000223	0.000482
1.26722	978.5199	0	4.68E-08	0	0.000489	0	0.008635	0.002658	0.000222	0.000481
1.2652	980.0822	0	4.59E-08	0	0.000488	0	0.008621	0.002654	0.000221	0.00048
1.26319	981.6417	0	4.49E-08	0	0.000487	0	0.008607	0.002649	0.00022	0.000479

E (eV)	λ (nm)	ThO2 050429 -- 10.468 nm -- 0 V k (oscillators)	ThO2 050503 -- 19.112 nm -- 50 V k (oscillators)	ThO2 050505 -- 14.062 nm -- 70 V k (oscillators)	ThO2 050520 -- 54.194nm -- 68 V k (oscillators)	ThO2 050526 -- 53.005nm -- 0 V k (oscillators)	ThO2 050527 -- 51.349nm -- 0 V k (oscillators)	ThO2 050604 -- 9.981nm -- 64 V k (oscillators)	ThO2 050604-2 -- 336.938nm -- 0 V k (oscillators)	ThO2 050818 -- 538.033nm -- 65 V k (oscillators)
1.26119	983.1984	0	4.40E-08	0	0.000486	0	0.008593	0.002645	0.000219	0.000478
1.25919	984.76	0	4.31E-08	0	0.000485	0	0.008578	0.00264	0.000218	0.000478
1.2572	986.3188	0	4.22E-08	0	0.000484	0	0.008564	0.002636	0.000217	0.000477
1.25522	987.8746	0	4.13E-08	0	0.000484	0	0.00855	0.002631	0.000216	0.000476
1.25325	989.4275	0	4.05E-08	0	0.000483	0	0.008536	0.002627	0.000216	0.000475

B.4. Our Values of k fit Point-by-Point

(Note also that the thicknesses listed (nm) are the thicknesses of the film as fit by ellipsometry, and the voltages listed (V) are the voltages at which each sample was sputtered.)

E (eV)	λ (nm)	ThO2 050429	ThO2 050503	ThO2 050520	ThO2 050527	ThO2 050604	ThO2 050604-2	ThO2 050818
		-- 0 V -- 10.468 nm Eg (eV) (α^2) = 6.31 Eg (eV) ($\alpha^{1/2}$) = 3.10 k (pt-by-pt)	-- 50 V -- 8.906 nm Eg (eV) (α^2) = 6.28 Eg (eV) ($\alpha^{1/2}$) = 2.10 k (pt-by-pt)	-- 68 V -- 52.617 nm Eg (eV) (α^2) = 6.09 Eg (eV) ($\alpha^{1/2}$) = -6.58 k (pt-by-pt)	-- 0 V -- 50.423 nm Eg (eV) (α^2) = 6.19 Eg (eV) ($\alpha^{1/2}$) = -7.02 k (pt-by-pt)	-- 64 V -- 6.589 nm Eg (eV) (α^2) = 6.12 Eg (eV) ($\alpha^{1/2}$) = 2.55 k (pt-by-pt)	-- 0 V -- 334.591 nm Eg (eV) (α^2) = 6.00 Eg (eV) ($\alpha^{1/2}$) = 2.46 k (pt-by-pt)	-- 65 V -- 539.281 nm Eg (eV) (α^2) = 5.93 Eg (eV) ($\alpha^{1/2}$) = 3.16 k (pt-by-pt)
6.50868	190.5148	0.22873	0	0.085209	0.090278	0.83603	0.011695	0
6.45406	192.1271	1.2459	0.3714	0.17567	0.064601	0.10569	0.029083	0.010605
6.40035	193.7394	0.20713	0.55107	0.18025	0.24307	0	0.016282	0.017811
6.34751	195.3522	0.31342	0.37217	0.14771	0.178	0.023475	0.072331	0.052532
6.29554	196.9648	0.028014	0.22358	0.15178	0.036471	0.51038	0.094356	0.049062
6.24441	198.5776	0.19411	0.2317	0.087213	0.11512	0.11255	0.12012	0.067833
6.1941	200.1905	0.29389	0.22817	0.11543	0.071129	0.38955	0.089108	0.058334
6.14459	201.8035	0.25067	0.19029	0.071341	0.063375	0.30299	0.079908	0.047255
6.09586	203.4167	0.16735	0.19052	0.041072	0.077858	0.28835	0.076342	0.050006
6.04789	205.0302	0.25212	0.21955	0.078291	0.055243	0.29719	0.054392	0.036791
6.00067	206.6436	0.1893	0.22399	0.044139	0.04532	0.2537	0.053365	0.030852
5.95418	208.2571	0.19155	0.22547	0.053648	0.066749	0.22308	0.0465	0.026628
5.90839	209.871	0.22314	0.15512	0.049463	0.029183	0.30498	0.04162	0.021144
5.86331	211.4846	0.13995	0.14696	0.034789	0.03499	0.23403	0.039001	0.018832
5.8189	213.0987	0.15974	0.16677	0.038351	0.057751	0.26542	0.037742	0.020046
5.77516	214.7127	0.16249	0.16663	0.018096	0.036884	0.23179	0.035507	0.01818
5.73207	216.3267	0.16433	0.16095	0.036297	0.048415	0.20724	0.033935	0.017746

		ThO2 050429	ThO2 050503	ThO2 050520	ThO2 050527	ThO2 050604	ThO2 050604-2	ThO2 050818
		-- 0 V	-- 50 V	-- 68 V	-- 0 V	-- 64 V	-- 0 V	-- 65 V
		-- 10.468 nm	-- 8.906 nm	-- 52.617 nm	-- 50.423 nm	-- 6.589 nm	-- 334.591 nm	-- 539.281 nm
		Eg (eV)	Eg (eV)	Eg (eV)	Eg (eV)	Eg (eV)	Eg (eV)	Eg (eV)
		(alpha^2) = 6.31	(alpha^2) = 6.28	(alpha^2) = 6.09	(alpha^2) = 6.19	(alpha^2) = 6.12	(alpha^2) = 6.00	(alpha^2) = 5.93
		Eg (eV)	Eg (eV)	Eg (eV)	Eg (eV)	Eg (eV)	Eg (eV)	Eg (eV)
		(alpha^(1/2)) = 3.10	(alpha^(1/2)) = 2.10	(alpha^(1/2)) = -6.58	(alpha^(1/2)) = -7.02	(alpha^(1/2)) = 2.55	(alpha^(1/2)) = 2.46	(alpha^(1/2)) = 3.16
E (eV)	λ (nm)	k (pt-by-pt)	k (pt-by-pt)	k (pt-by-pt)	k (pt-by-pt)	k (pt-by-pt)	k (pt-by-pt)	k (pt-by-pt)
5.68961	217.9411	0.16144	0.14306	0	0.047093	0.19949	0.027366	0.016243
5.64777	219.5557	0.1477	0.15325	0.012808	0.050772	0.11025	0.025394	0.013776
5.60655	221.1699	0.11749	0.14261	0.01786	0.042507	0.13764	0.021843	0.012535
5.56591	222.7848	0.13843	0.15017	0.01021	0.060967	0.1306	0.015761	0.012092
5.52586	224.3995	0.14401	0.13373	0.017808	0.04583	0.15919	0.013337	0.012035
5.48638	226.0142	0.10423	0.15585	0.008166	0.06534	0.13128	0.011464	0.01184
5.44746	227.629	0.10839	0.14848	0.001507	0.060036	0.13976	0.010893	0.012376
5.40909	229.2437	0.12088	0.11472	0.005479	0.079476	0.13686	0.012671	0.013678
5.37124	230.8592	0.10519	0.13734	0.010161	0.060688	0.14326	0.011382	0.013832
5.33393	232.474	0.12526	0.14424	0.006584	0.070691	0.14291	0.013197	0.012837
5.29712	234.0895	0.11118	0.13623	0.000362	0.07068	0.16797	0.014854	0.010984
5.26082	235.7047	0.13418	0.12325	0.003602	0.061261	0.1455	0.014874	0.009853
5.22501	237.3201	0.10889	0.14203	0.015693	0.085885	0.13784	0.017846	0.008761
5.18968	238.9357	0.12191	0.14666	0.006984	0.079073	0.20114	0.016905	0.007922
5.15483	240.5511	0.1017	0.1385	0.009754	0.071568	0.11562	0.01851	0.009631
5.12044	242.1667	0.1222	0.14455	0.012988	0.073467	0.15137	0.018571	0.010081
5.0865	243.7826	0.1348	0.13537	0.002165	0.06359	0.15422	0.018496	0.011006
5.05301	245.3983	0.11696	0.1608	0.0127	0.080052	0.14598	0.016988	0.010802
5.01996	247.0139	0.11886	0.13897	0.020014	0.080945	0.064941	0.016734	0.012716
4.98733	248.63	0.1101	0.12996	0.020531	0.067069	0.11696	0.016265	0.013065
4.95512	250.2462	0.12055	0.13293	0.014208	0.080136	0.10541	0.01359	0.011577
4.92333	251.8621	0.087728	0.13076	0	0.091642	0.098761	0.010643	0.012815
4.89194	253.4782	0.12095	0.12712	0.002724	0.067132	0.16179	0.010655	0.011017
4.86095	255.0942	0.10264	0.16	0.006745	0.069027	0.069189	0.008524	0.01003
4.83034	256.7107	0.11113	0.14553	0.023173	0.076238	0.11211	0.005038	0.009103

		ThO2 050429	ThO2 050503	ThO2 050520	ThO2 050527	ThO2 050604	ThO2 050604-2	ThO2 050818
		-- 0 V	-- 50 V	-- 68 V	-- 0 V	-- 64 V	-- 0 V	-- 65 V
		-- 10.468 nm	-- 8.906 nm	-- 52.617 nm	-- 50.423 nm	-- 6.589 nm	-- 334.591 nm	-- 539.281 nm
		Eg (eV)	Eg (eV)	Eg (eV)	Eg (eV)	Eg (eV)	Eg (eV)	Eg (eV)
		(alpha^2) = 6.31	(alpha^2) = 6.28	(alpha^2) = 6.09	(alpha^2) = 6.19	(alpha^2) = 6.12	(alpha^2) = 6.00	(alpha^2) = 5.93
		Eg (eV)	Eg (eV)	Eg (eV)	Eg (eV)	Eg (eV)	Eg (eV)	Eg (eV)
		(alpha^(1/2)) = 3.10	(alpha^(1/2)) = 2.10	(alpha^(1/2)) = -6.58	(alpha^(1/2)) = -7.02	(alpha^(1/2)) = 2.55	(alpha^(1/2)) = 2.46	(alpha^(1/2)) = 3.16
E (eV)	λ (nm)	k (pt-by-pt)	k (pt-by-pt)	k (pt-by-pt)	k (pt-by-pt)	k (pt-by-pt)	k (pt-by-pt)	k (pt-by-pt)
4.80012	258.3269	0.09143	0.10835	0.022171	0.073455	0.050771	0.005756	0.008493
4.77027	259.9434	0.037531	0.14425	0.010055	0.071754	0.08156	0.007342	0.005965
4.74079	261.5598	0.063187	0.10279	0.016407	0.078332	0.11196	0.004182	0.006758
4.71168	263.1758	0.08071	0.093361	0.028917	0.04945	0.058822	0.005288	0.005393
4.68291	264.7926	0.051273	0.062528	0.030814	0.05003	0.12786	0.006418	0.006429
4.6545	266.4089	0.051682	0.087613	0.036258	0.054472	0.11761	0.006442	0.005274
4.62642	268.0258	0.032473	0.092705	0.014047	0.071399	0.12757	0.005744	0.008416
4.59869	269.642	0.055621	0.092677	0.023941	0.07131	0.097102	0.009428	0.007756
4.57128	271.2588	0.052417	0.079513	0.010668	0.067743	0.083382	0.008142	0.010531
4.54419	272.8759	0.040282	0.094684	0.021678	0.073023	0.12488	0.009086	0.008298
4.51743	274.4924	0.048669	0.081664	0.025741	0.08184	0.03717	0.011048	0.010454
4.49098	276.109	0.041802	0.1035	0.023128	0.070119	0.0647	0.009195	0.009427
4.46483	277.7261	0.039397	0.073393	0.032115	0.070815	0.10411	0.014062	0.008606
4.43899	279.3428	0.057161	0.076979	0.04218	0.083234	0.080638	0.011108	0.009943
4.41344	280.96	0.041573	0.072506	0.047467	0.092108	0.087748	0.010662	0.007987
4.38819	282.5766	0.031743	0.089192	0.037689	0.069193	0.095867	0.013204	0.008042
4.36322	284.1938	0.043828	0.10545	0.042287	0.053607	0.090224	0.012545	0.009687
4.33853	285.8111	0.039086	0.049468	0.039018	0.074757	0.10957	0.011466	0.007016
4.31413	287.4276	0.018983	0.065568	0.032387	0.071523	0.11699	0.011685	0.005359
4.28999	289.045	0.075339	0.10259	0.045191	0.078105	0.065259	0.010165	0.006468
4.26612	290.6622	0.064423	0.098829	0.043972	0.084776	0.13056	0.010224	0.005372
4.24252	292.2791	0.032094	0.095771	0.041818	0.073482	0.1053	0.008909	0.00518
4.21918	293.896	0.033284	0.094675	0.047252	0.072329	0.090744	0.008557	0.00587
4.19609	295.5132	0.081991	0.079489	0.039943	0.072514	0.11298	0.008821	0.004998
4.17325	297.1305	0.054283	0.084538	0.036141	0.082166	0.11277	0.009587	0.006121

		ThO2 050429	ThO2 050503	ThO2 050520	ThO2 050527	ThO2 050604	ThO2 050604-2	ThO2 050818
		-- 0 V	-- 50 V	-- 68 V	-- 0 V	-- 64 V	-- 0 V	-- 65 V
		-- 10.468 nm	-- 8.906 nm	-- 52.617 nm	-- 50.423 nm	-- 6.589 nm	-- 334.591 nm	-- 539.281 nm
		Eg (eV)	Eg (eV)	Eg (eV)	Eg (eV)	Eg (eV)	Eg (eV)	Eg (eV)
		(α^2) = 6.31	(α^2) = 6.28	(α^2) = 6.09	(α^2) = 6.19	(α^2) = 6.12	(α^2) = 6.00	(α^2) = 5.93
		Eg (eV)	Eg (eV)	Eg (eV)	Eg (eV)	Eg (eV)	Eg (eV)	Eg (eV)
		($\alpha^{1/2}$) = 3.10	($\alpha^{1/2}$) = 2.10	($\alpha^{1/2}$) = -6.58	($\alpha^{1/2}$) = -7.02	($\alpha^{1/2}$) = 2.55	($\alpha^{1/2}$) = 2.46	($\alpha^{1/2}$) = 3.16
E (eV)	λ (nm)	k (pt-by-pt)	k (pt-by-pt)	k (pt-by-pt)	k (pt-by-pt)	k (pt-by-pt)	k (pt-by-pt)	k (pt-by-pt)
4.15066	298.7477	0.046922	0.090137	0.024963	0.068199	0.10071	0.007411	0.00657
4.12831	300.365	0.040208	0.072839	0.044291	0.072286	0.057506	0.005392	0.007758
4.1062	301.9824	0.056778	0.071934	0.045965	0.078479	0.086874	0.004999	0.007466
4.08433	303.5994	0.068499	0.065993	0.048177	0.077276	0.061069	0.003719	0.008423
4.06269	305.2165	0.030567	0.08029	0.042066	0.089073	0.035838	0.004897	0.008785
4.04127	306.8342	0.048626	0.083235	0.041197	0.089212	0.066175	0.002207	0.008665
4.02008	308.4516	0.026963	0.075531	0.042386	0.064611	0.11132	0.00125	0.010032
3.99911	310.069	0.042515						
3.97836	311.6862	0.026223						
3.95782	313.3038	0.021954						
3.9375	314.9206	0.031305						
3.91738	316.5381	0.039665						
3.89746	318.1559	0.032971						
3.87775	319.7731	0.034156						
3.85824	321.3901	0.033525						
3.83892	323.0075	0.0085146						
3.81979	324.6252	0.02194						
3.80085	326.2428	0.0072072						
3.7821	327.8602	0.031301						
3.76354	329.477	0.026515						
3.74515	331.0949	0.022606						
3.72694	332.7126	0.0040248						
3.70891	334.33	0.017865						
3.69106	335.9469	0.035849						
3.67337	337.5647	0.015268						

		ThO2 050429	ThO2 050503	ThO2 050520	ThO2 050527	ThO2 050604	ThO2 050604-2	ThO2 050818
		-- 0 V	-- 50 V	-- 68 V	-- 0 V	-- 64 V	-- 0 V	-- 65 V
		-- 10.468 nm	-- 8.906 nm	-- 52.617 nm	-- 50.423 nm	-- 6.589 nm	-- 334.591 nm	-- 539.281 nm
		Eg (eV)	Eg (eV)	Eg (eV)	Eg (eV)	Eg (eV)	Eg (eV)	Eg (eV)
		(alpha^2) = 6.31	(alpha^2) = 6.28	(alpha^2) = 6.09	(alpha^2) = 6.19	(alpha^2) = 6.12	(alpha^2) = 6.00	(alpha^2) = 5.93
		Eg (eV)	Eg (eV)	Eg (eV)	Eg (eV)	Eg (eV)	Eg (eV)	Eg (eV)
		(alpha^(1/2)) =	(alpha^(1/2)) =	(alpha^(1/2)) =	(alpha^(1/2)) =	(alpha^(1/2)) =	(alpha^(1/2)) =	(alpha^(1/2)) =
		3.10	2.10	-6.58	-7.02	2.55	2.46	3.16
E (eV)	λ (nm)	k (pt-by-pt)	k (pt-by-pt)	k (pt-by-pt)	k (pt-by-pt)	k (pt-by-pt)	k (pt-by-pt)	k (pt-by-pt)
3.65586	339.1815	0.0049415						
3.63851	340.7988	0.011582						
3.62132	342.4166	0.0070282						
3.6043	344.0335	0.031097						
3.58743	345.6513	0.027892						
3.57072	347.2689	0.015509						
3.55417	348.886	0.011586						
3.53777	350.5033	0.028295						
3.52152	352.1207	0.0088706						
3.50542	353.7379	0.032796						
3.48946	355.3558	0.027363						
3.47365	356.9732	0.02147						
3.45799	358.5898	0.010186						
3.44246	360.2075	0.0097875						
3.42707	361.8251	0.01628						
3.41182	363.4424	0.0045429						
3.39671	365.0591	0						
3.38173	366.6762	0.032482						
3.36688	368.2935	0.016519						
3.35216	369.9107	0.0063853						
3.33757	371.5278	0.024768						
3.3231	373.1456	0.02558						
3.30876	374.7628	0.01018						
3.29454	376.3803	0.018103						
3.28045	377.9969	0.0028695						

		ThO2 050429	ThO2 050503	ThO2 050520	ThO2 050527	ThO2 050604	ThO2 050604-2	ThO2 050818
		-- 0 V	-- 50 V	-- 68 V	-- 0 V	-- 64 V	-- 0 V	-- 65 V
		-- 10.468 nm	-- 8.906 nm	-- 52.617 nm	-- 50.423 nm	-- 6.589 nm	-- 334.591 nm	-- 539.281 nm
		Eg (eV)	Eg (eV)	Eg (eV)	Eg (eV)	Eg (eV)	Eg (eV)	Eg (eV)
		(alpha^2) = 6.31	(alpha^2) = 6.28	(alpha^2) = 6.09	(alpha^2) = 6.19	(alpha^2) = 6.12	(alpha^2) = 6.00	(alpha^2) = 5.93
		Eg (eV)	Eg (eV)	Eg (eV)	Eg (eV)	Eg (eV)	Eg (eV)	Eg (eV)
		(alpha^(1/2)) =	(alpha^(1/2)) =	(alpha^(1/2)) =	(alpha^(1/2)) =	(alpha^(1/2)) =	(alpha^(1/2)) =	(alpha^(1/2)) =
		3.10	2.10	-6.58	-7.02	2.55	2.46	3.16
E (eV)	λ (nm)	k (pt-by-pt)	k (pt-by-pt)	k (pt-by-pt)	k (pt-by-pt)	k (pt-by-pt)	k (pt-by-pt)	k (pt-by-pt)
3.26647	379.6147	0						
3.25262	381.2311	0						
3.23888	382.8484	0						
3.22526	384.4651	0.017847						
3.21175	386.0824	0.016724						
3.19835	387.6999	0.0098702						
3.18507	389.3164	0						
3.17189	390.9341	0						
3.15883	392.5504	0						
3.14587	394.1676	0.0048132						
3.13302	395.7843	0						
3.12027	397.4015	0.005943						
3.10763	399.0179	0.0024966						
3.09508	400.6358	0						
3.08265	402.2513	0						
3.0703	403.8693	0						
3.05806	405.4858	0						
3.04592	407.102	0						
3.03387	408.7189	0.0019985						
3.02191	410.3365	0						
3.01005	411.9533	0.0064772						
2.99829	413.5691	0						
2.98661	415.1864	0						
2.97503	416.8025	0						
2.96353	418.4199	0						

		ThO2 050429	ThO2 050503	ThO2 050520	ThO2 050527	ThO2 050604	ThO2 050604-2	ThO2 050818
		-- 0 V	-- 50 V	-- 68 V	-- 0 V	-- 64 V	-- 0 V	-- 65 V
		-- 10.468 nm	-- 8.906 nm	-- 52.617 nm	-- 50.423 nm	-- 6.589 nm	-- 334.591 nm	-- 539.281 nm
		Eg (eV)	Eg (eV)	Eg (eV)	Eg (eV)	Eg (eV)	Eg (eV)	Eg (eV)
		(α^2) = 6.31	(α^2) = 6.28	(α^2) = 6.09	(α^2) = 6.19	(α^2) = 6.12	(α^2) = 6.00	(α^2) = 5.93
		Eg (eV)	Eg (eV)	Eg (eV)	Eg (eV)	Eg (eV)	Eg (eV)	Eg (eV)
		($\alpha^{1/2}$) = 3.10	($\alpha^{1/2}$) = 2.10	($\alpha^{1/2}$) = -6.58	($\alpha^{1/2}$) = -7.02	($\alpha^{1/2}$) = 2.55	($\alpha^{1/2}$) = 2.46	($\alpha^{1/2}$) = 3.16
E (eV)	λ (nm)	k (pt-by-pt)	k (pt-by-pt)	k (pt-by-pt)	k (pt-by-pt)	k (pt-by-pt)	k (pt-by-pt)	k (pt-by-pt)
2.95213	420.0357	0						
2.94081	421.6525	0						
2.92958	423.2689	0						
2.91843	424.886	0						
2.90737	426.5023	0						
2.89639	428.1191	0.0016619						
2.8855	429.7349	0						
2.87468	431.3524	0						
2.86395	432.9685	0						
2.8533	434.5845	0						
2.84273	436.2004	0.0009616						
2.83223	437.8176	0						
2.82181	439.4343	0						
2.81147	441.0504	0						
2.80121	442.6658	0						
2.79102	444.282	0						
2.7809	445.8988	0						
2.77086	447.5145	0						
2.76088	449.1322	0						
2.75099	450.7468	0						
2.74116	452.3632	0						
2.7314	453.9796	0						
2.72171	455.5959	0						
2.71209	457.212	0						
2.70254	458.8276	0						

		ThO2 050429	ThO2 050503	ThO2 050520	ThO2 050527	ThO2 050604	ThO2 050604-2	ThO2 050818
		-- 0 V	-- 50 V	-- 68 V	-- 0 V	-- 64 V	-- 0 V	-- 65 V
		-- 10.468 nm	-- 8.906 nm	-- 52.617 nm	-- 50.423 nm	-- 6.589 nm	-- 334.591 nm	-- 539.281 nm
		Eg (eV)	Eg (eV)	Eg (eV)	Eg (eV)	Eg (eV)	Eg (eV)	Eg (eV)
		(α^2) = 6.31	(α^2) = 6.28	(α^2) = 6.09	(α^2) = 6.19	(α^2) = 6.12	(α^2) = 6.00	(α^2) = 5.93
		Eg (eV)	Eg (eV)	Eg (eV)	Eg (eV)	Eg (eV)	Eg (eV)	Eg (eV)
		($\alpha^{1/2}$) =	($\alpha^{1/2}$) =	($\alpha^{1/2}$) =	($\alpha^{1/2}$) =	($\alpha^{1/2}$) =	($\alpha^{1/2}$) =	($\alpha^{1/2}$) =
		3.10	2.10	-6.58	-7.02	2.55	2.46	3.16
E (eV)	λ (nm)	k (pt-by-pt)	k (pt-by-pt)	k (pt-by-pt)	k (pt-by-pt)	k (pt-by-pt)	k (pt-by-pt)	k (pt-by-pt)
2.69305	460.4445	0						
2.68363	462.0607	0.0022162						
2.67428	463.6762	0						
2.66499	465.2926	0						
2.65577	466.9079	0						
		(Below this						
		energy, the						
		values for <i>k</i> are						
		essentially						
		all 0's)						
...	...							