A Scanning Fabry-Perot Interferometer*

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A simple method of photoelectrically scanning a Fabry-Perot interferometer pattern is described. Scanning is accomplished by parallel displacement of the incident beam of light across the face of an interferometer whose plate separation varies in the direction of the displacement. This method of scanning allows a slightly distorted plot of the line profile to be continuously displayed on an oscilloscope.

THE Fabry-Perot interferometer has been a favorite instrument in the field of high-resolution spectroscopy for many years. The development of multilayer dielectric mirrors increased the possible resolving power to the limit set by imperfections in the surfaces of the plates. Recent techniques,[1–3] which involve varying the gas pressure inside the interferometer chamber in order to scan the fringe system across a photomultiplier tube, eliminate the photographic process[4] and yield an almost linear wavelength scale. However, these techniques cannot shorten the exposure time beyond certain limits since the changes in pressure must be made slowly so as not to disturb the delicate adjustments of the interferometer. For many purposes it is advantageous to scan a Fabry-Perot pattern rapidly. A simple method of repeatedly scanning the interferometer at a rate of about 10 times per second is currently in use in our laboratory as an aid in diagnosing the characteristics of a plasma.

Although this method is capable neither of extremely short scanning times nor of extremely high resolution, it does have the advantage of scanning continuously. Figure 1 shows how the scanning is accomplished. The interferometer is adjusted so that at the wavelength of interest the interference pattern produced in the upper part of the interferometer shows an intensity maximum at the center of the pattern, the pattern produced in the central part shows a minimum at the center and the pattern produced near the bottom shows the next maximum.[5] Thus, changing the vertical position of the incident beam of light has the same effect as changing the spacing between the flats (or of changing the pressure and hence the index of refraction of the gas between the flats).

The problem of how to displace the incident beam without changing the angle of incidence, was solved by the use of a large cube of Lucite as shown in the figure. Using 1.49 for the refractive index of Lucite, one can easily show that the rotation of a 4-in. cube will sweep the beam across a 6-cm diam. If the cube is large enough so that the accepted light makes only a small angle with the normal to a cube face, then the scanning rate is more nearly constant. With the 4-in. cube, the scanning rate is 35% greater at a displacement of ±2 cm than it is at zero displacement.

Figure 2 is a schematic diagram showing the important features of the apparatus. The entrance aperture determines both the amount of light entering the system and the limit of resolution of the system. The limit of resolution can be evaluated as follows. The order of interference, n (not necessarily an integer), at the center of the fringe pattern is given by

$$n=2t\mu/\lambda,$$

where t is the spacer thickness, μ is the refractive index of the material between the mirrors, and λ is the wavelength. Thus,

$$\delta n/n=\delta\lambda/\lambda.$$

The free spectral range $\Delta\lambda$ is the wavelength interval corresponding to unit change in order number. In terms of $\Delta\lambda$ then, $\delta\lambda=\Delta\lambda\delta n$. The quantity δn is given by the

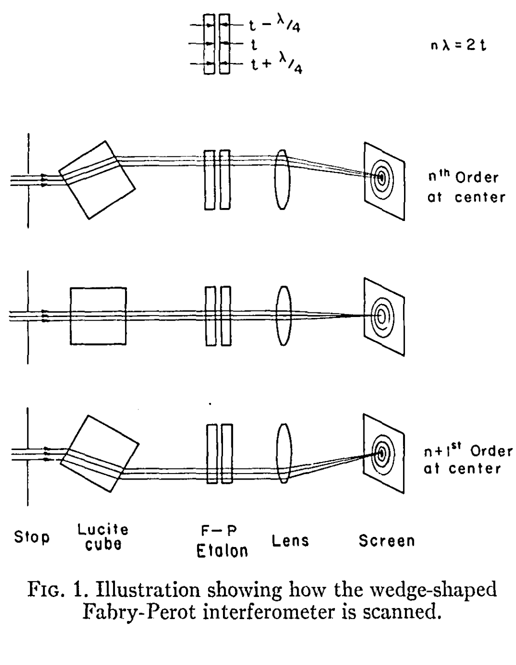

FIG. 1. Illustration showing how the wedge-shaped Fabry-Perot interferometer is scanned.

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1 M. A. Biondi, Rev. Sci. Instr. 27, 36 (1956).

2 J. H. Jaffe, D. H. Rank, and T. A. Wiggins, J. Opt. Soc. Am. 45, 636 (1955).

3 C. Dufour and P. Jacquinot, J. recherches centre nat. recherche sci., Labs. Bellevue (Paris) 6, 91 (1948).

4 For a comparison of the optical speeds of the several types of spectrometers when used with photoelectric detection, see P. Jacquinot, J. Opt. Soc. Am. 44, 761 (1954).

5 The wedge angle is given by the ratio of half a wavelength to the diameter of the plate. Because this is a very small angle the Airy summation is valid, and the fringes are essentially localized at infinity.

ratio of the vertical thickness of the beam of light entering the interferometer to the distance (measured vertically along the interferometer) over which n changes by one unit (see Fig. 1). Consequently, the limit of resolution $\delta\lambda$ is directly proportional to the vertical dimension of the entrance aperture.[6]

Just as with pressure scanning, provision must be made to change the size and position of the exit aperture through which the photomultiplier tube views the central spot. The choice of the size of the exit aperture depends on the size of the fringe pattern (i.e., on λ, t, and the focal length of the lens used to focus the fringes), and on the limit of resolution desired. It can be easily shown[1,2,7] that to obtain a limit of resolution $\delta\lambda$ the radius of the exit aperture, R, must satisfy the condition

$$R<f(2\delta\lambda/\lambda)^{\frac{1}{2}},$$

where f is the focal length of the lens.

Other considerations are also important in the actual use of the instrument. The exit aperture and the photomultiplier assembly must be easily removable or other provisions must be made to allow visual adjustment of the interferometer and the centering of the apertures on

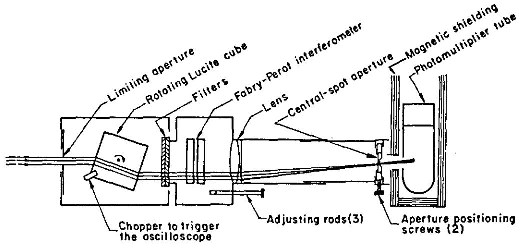

FIG. 2. Schematic diagram of the scanning interferometer, showing the important details.

the fringe system. In order to collect as much light as possible, the instrument may have to be located near regions of strong electric or magnetic fields, and shielding may be required around the photomultiplier. Especially if the light source is not steady, an external trigger may have to be supplied to the oscilloscope to obtain reproducibility of the trace. And finally, when a commercial interference filter is used in conjunction with auxiliary filters to isolate a spectral line, it may be necessary to search for a diameter across the filter over which its transmission characteristics are constant.

The apparatus in use at our laboratory has the following characteristics: Diameter of interferometer plates—6 cm; Vertical dimension of entrance aperture —4 mm; Spacer thickness, t—1.0 mm; Focal length of lens, f—188 mm; Radius of exit aperture, R—0.8 mm; Size of Lucite cube—4 in.; Speed of rotation of cube—$\sim$5 rps. These specifications were chosen to suit the He II λ4686 line and its $\sim$0.6A Doppler width in the P-4 plasma system at Livermore.[8] Other applications of

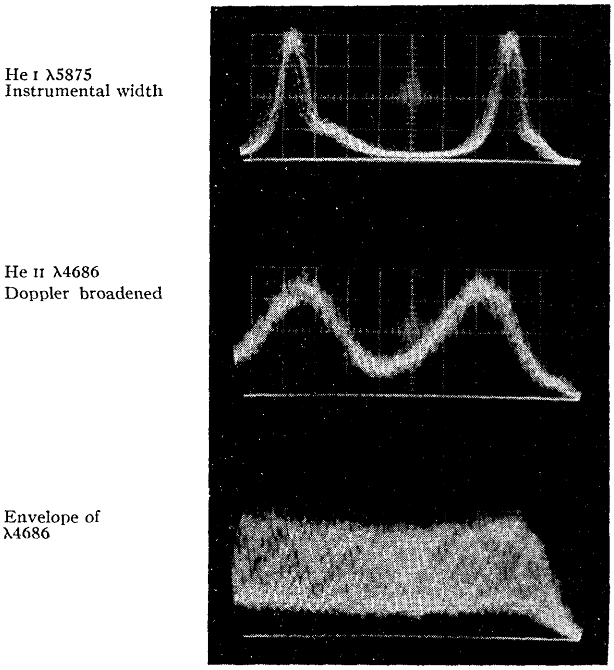

FIG. 3. Oscillograms taken with the scanning interferometer.

the instrument may require variations from the data listed.

Figure 3 shows three oscillograms taken with the P-4 system which provides a high-temperature, steady-state helium plasma as the source of light. The top trace was made by using filters to isolate the neutral helium triplet at 5875 A. Since these lines are known to be sharp in this plasma, the observed profile is due to the instrument. The center trace was made by using filters to isolate the helium ion lines at 4686 A. The interferometer adjustments were left the same for all three oscillograms, but the sweep speed of the trace was different for the top one. The spacer thickness was 1.0 mm which gave a free spectral range of 1.73 A at 5875 A and 1.10 A at 4686 A. The broadening of λ4686 is due in part to fine structure but mainly to the Doppler effect. Independent measurements show that the ion temperature here is about 10 ev. Since our apparatus is also equipped for pressure scanning, we can shift the line profile across the screen of the scope by varying the pressure. The third trace was made by changing the pressure in a series of small increments while scanning 4686 A. It is seen that the ratio of maximum-to-minimum intensity is nearly independent of their relative origins in the interferometer.

By observing the continuous display of a trace like the center one in Fig. 3, one can see any appreciable changes in the ion temperature that result from varying the operating conditions. This makes the instrument a convenient monitor of ion temperature in a steady-state plasma.

[6] Note that when used with a monochromator instead of filters, the entrance aperture will be determined by the exit slit of the monochromator. Then δn, and hence $\delta\lambda$, can be very small.

[7] D. H. Rank and J. M. Bennett, J. Opt. Soc. Am. **45**, 46 (1955).

[8] Andrew L. Gardner, William L. Barr, Daune M. Gall, Laurence S. Hall, Raymond L. Kelly, and Norman L. Oleson, UCRL-5904 (unpublished).