PRISM TUNER FOR SINGLE FREQUENCY OPERATION OF A CW DYE LASER

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A cw dye laser capable of single longitudinal mode operation and linear reproducible wavelength tuning over a relatively wide spectral range is described. By employing a novel scheme of four intracavity highly dispersive Abbe prisms output powers of 5 mW with a linewidth less than 30 MHz for an input power of 700 mW have been obtained.

The development of tunable single frequency cw dye lasers has recently received considerable interest. Most of the methods reported [1–3] require multiple wavelength selective components, such as intracavity dispersive prisms, one or more additional Fabry Perot etalons, and at times a Fox–Smith mode selector [4] in order to force the dye laser to oscillate in a single longitudinal mode, and hence with narrow linewidths in the MHz-range. Continuous frequency tuning over a large spectral range is complicated by the need of simultaneous and synchronous tuning of all the wavelength selective components, and which in the case of tilted etalons may be complicated by different individual nonlinear characteristics. In this paper we describe a cw dye laser which employs a novel scheme for wavelength selection and tuning, consisting of a multiple prism array. With an arrangement of four highly dispersive Abbe prisms it is possible to achieve single frequency operation and semi-continuous tuning over a range of about 5 nm with one single linear translational control.

The optical arrangement of such a cw dye laser is shown schematically in fig. 1. The basic dye laser cavity composed of reflectors M_1 through M_3 or M_4 is similar to the astigmatically compensated design of Dienes et al. [5] and uses optics capable of very tight focusing of the pump radiation [6]. A dye cell with channel dimensions of $0.1 \times 0.1 \times 0.5$ cm is employed. The dye solution utilized in our experiments was a 3×10^{-4} molar solution of Rhodamine 6G in water with 6% by volume ammonyx LO added. The flow circulation system was designed to minimize impurities, bubbles and vibrations and allowed variable flow rates up to 25 m sec^{-1}. The pump radiation may be either coupled in by a prism, applied non-collinearly or focussed directly into the dye cell with a short focal length lens. In the case of Rhodamine 6G it was found desirable to pump with the 514.5 nm argon laser line in order to reduce the initial bandwidth of the dye laser gain profile and to maintain reliable single frequency operation. For alignment purposes the dye laser cavity can be at first terminated with an optional reflector M_3. The beam coupled out by M_3 can then be used to optimize the adjustments of the wavelength selector and the final output mirror M_4. The wavelength selector is unlike previous multiple prism tuners [7] and consists of four Brewster angle Abbe or Pellin Broca prisms which are capable of 90° constant deviation of the incident beam at maximum dispersion. The prisms are made of highly dispersive glass (Schott type SF 59) with a dispersion of 4×10^{-4} nm^{-1} and refractive index of 1.9521 at λ_D = 589.3 nm and acceptable absorption (0.2% per cm). The prisms are cut and mounted, so that the incident and emerging beams always enter and exit the prism as close to the Brewster angle as possible (see insert at upper left of fig. 1). For the wavelength range 400 to 1000 nm this corresponds to an internal angle i that varies from 71.5° to 72.5°;

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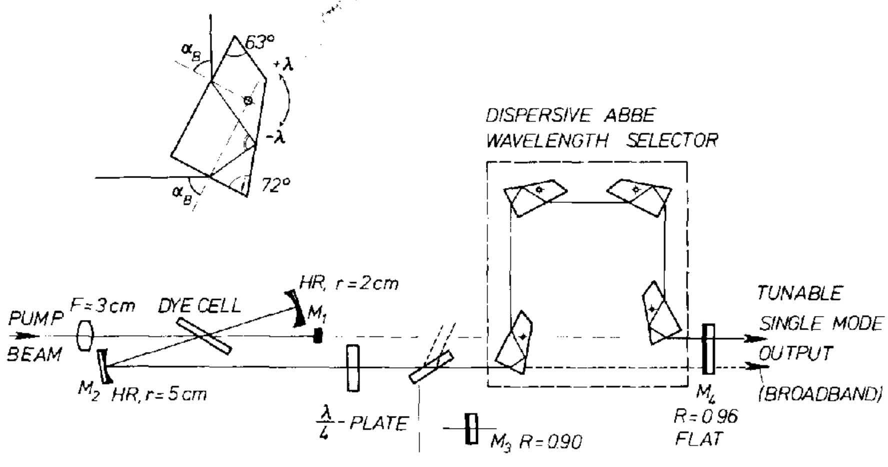

Fig. 1. Optical schematic of cw dye laser with prism wavelength selector. Insert at upper left shows geometrical details of individual Abbe prism construction.

hence we selected $i = 72°$. The angle opposite to i is chosen to be 63°, so that the prism surface containing this angle runs approximately parallel to the deviated beam inside the prism. To accomodate typical beam diameters of 2.5 mm, prism dimensions were chosen to be 11 X 7 X 10 mm. Then the optical path length in each prism is about 10 mm. This corresponds to an intracavity absorption loss of less than 1% for the four prism array in the Rhodamine 6G spectral range. The individual prisms are arranged in a mirror symmetrical array in order to constructively enhance the overall dispersion. Wavelength tuning requires synchronous counter-rotation of the four prisms as described in ref. [8]. The center of rotation for each prism was selected so as to minimize the changes in the optical path lengths and beam displacement when tuning the dye laser. Both of these conditions cannot be met simultaneously according to ref. [9]. The prism supporting tables are located precisely with two ball bearings on a common mounting plate. These four tables can then be rotated simultaneously is such a way that wavelength tuning can be accomplished by a single micrometer-driven precision translation assembly. Since the prism wavelength selector is built as a single compact unit, it is possible to align and calibrate it conveniently with a He–Ne laser prior to placing it into the dye laser cavity formed by mirrors M_1, M_2, and M_4. In this manner it is possible to operate the dye laser either in a free running mode with a bandwidth in the Å range or with very narrow linewidth in single frequency operation. By suitable choice of the four prism geometrical arrangement it is possible to make the tunable output from the wavelength selector collinear with the argon pump beam either in a vertical or horizontal configuration.

The linewidth in single mode operation was measured to be less than 30 MHz with an analyzing Fabry–Perot interferometer of 1.5 GHz free spectral range with long-term fluctuations within ±20 MHz. Fig. 2 shows on the left hand side a single mode dye laser interferogram and to the right for comparison the mode structure of a He–Ne laser with 600 MHz mode spacing. The above linewidth – not corrected for the finite resolving power of the interferometer – can probably be considerably reduced by paying careful attention to stability of the overall dye laser design, in particular to the cavity and dye flow parameters. In principle it should be possible to wavelength-tune the single mode laser line over most of the dye gain profile. Due to the limited pump power available (700 mW) and the reflection losses, the set of four SF 59 prisms allowed tunability only over a 5 nm interval near the gain maximum of Rhodamine 6G. The dye laser is modulated by laser cavity mode "jumps", which can be eliminated by synchronized tracking of the resonator length with a piezoelectrically mounted end mirror (say, M_4).

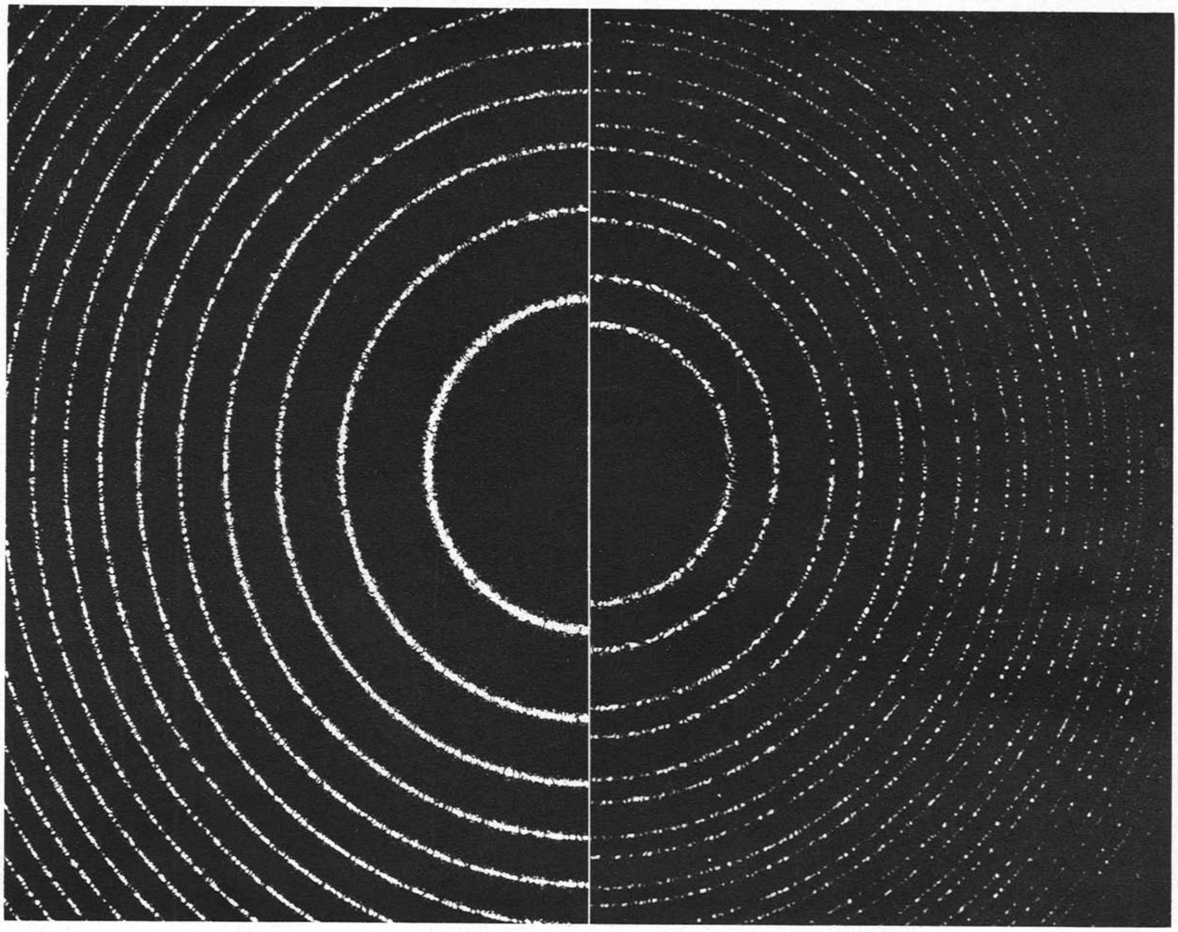

Fig. 2. Interferogram of single mode dye laser output (left) and for comparison interferogram of model structure of a He–Ne laser output (600 MHz mode spacing) taken with a 10 cm etalon and a long focal length lens (f = 160 cm).

The difficulties associated with such a multiple prism tuner, particularly its alignment, are due to the presence of an elliptical polarization component and intracavity absorption and reflection losses of the highly refractive prisms. Although such elliptical polarization can be compensated with an intracavity quarter wave plate, considerable reflection losses occur at the Brewster angled prism interfaces, even with completely linearly polarized light, as monitored by a fixed Brewster plate. Upon insertion of the four prism tuner into the dye laser cavity, the laser threshold increased from 240 mW to 600 mW while the output power dropped from 54 mW (free running system) to about 2 to 5 mW for single mode operation with an argon pump level of 700 mW. The reflection losses for linearly polarized light incident at the Brewster angle are strongly dependent on the surface quality of the glass [10] and are especially large for highly refractive glasses. Fig. 3 shows the reflection characteristics of two Schott glasses (type SF 59 and BK 7). Although linearly polarized light in the incident plane should not be reflected at the Brewster angle, there exists a considerable residual reflectivity for $\alpha = \alpha_B$, this value being higher by a factor of 100 for SF 59 than BK 7. With a set of four Brewster angle BK 7 glass prisms, a much smaller laser threshold was observed. However, single mode operation was obtained only near laser threshold, since the dispersion of this glass is about $\frac{1}{6}(7 \times 10^{-5}\ \mathrm{nm}^{-1})$ of the dispersion of SF 59 glass. It should be added that the reliability of single mode operation strongly de-

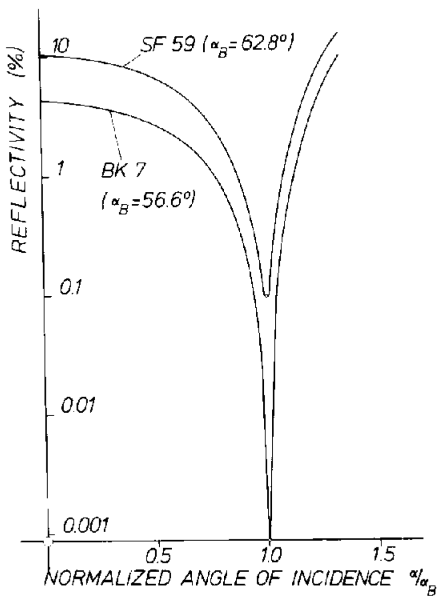

Fig. 3. Reflectivity of SF 59 and BK 7 glass surfaces versus normalized angle of incidence for light, linearly polarized in the plane of incidence.

pended on careful positioning of mirror M_1 relative to the resonator axis and an optimally adjusted quarter wave plate.

In conclusion, we have described a single frequency cw dye laser with a novel multiple prism tuner. This laser has the spectral and tuning characteristics necessary for high resolution spectroscopic measurements.

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