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Many application of the ruby laser require that the overall spectral breadth of the emission be less than 0.1 Å and the appearance of extra spectral components even if they are also narrow is objectionable. In applications where synchronization with an external event is not essential the use of a passive Q-switch consisting of a bleachable dye in the laser cavity serves to produce a single, extremely narrow line. The time jitter of the occurrence of the giant pulse frequency makes this technique inapplicable to experimental situations where precise timing of the laser emission is critical.

For such applications either an electro-optic shutter or a rotating reflector are used for Q-switching. The use of a single or compound Fabry-Perot resonator of low finessse as one of the cavity mirrors with the possible addition of a dilute solution of a bleachable dye has been used by us and others[(1)] to produce a single, narrow, emission line. We have found the adjustment of the laser necessary to achieve this condition to be extremely critical as to pumping, dye concentration, ruby temperature, and indeed the temperature of the resonant reflector itself, and the inevitable drifts in all of these quantities make it difficult to obtain the desired spectral emission reproducibly over many shots.

This letter describes an alternative method of controlling the spectral emission of a ruby laser that is simple, straightforward, and very reproducible.

A standard Korad Q-1 ruby laser which is Q-switched with a Pockels Cell is modified as follows. A calcite plate 3 mm thick, flat to a fringe, with its optic axis in the plane of a face is inserted into the laser cavity between the ruby and the totally reflecting mirror. The latter is a 99% dielectric mirror which replaces the totally internally reflecting prism originally installed to eliminate the addition phase shift introduced by such a prism between components polarized parallel to the principal directions of the plate. The plate is oriented so that its optic axis is at 45^0 to the C axis of the ruby.

The birefringent plate has the following effect: as is well known the dichroism of the ruby makes the gain from stimulated emission several times greater for light polarized perpendicular to the C axis of the ruby as compared with light polarized parallel to this axis. When plane polarized light is incident upon a birefringent plate so that the plane of polarization is at 45^0 to the optic axis of the plate the light emerges in general in an arbitrary state of elliptic polarization. Only for those wavelengths for which the difference in optical path for the ordinary and extraordinary ray is an integer multiple of a wavelength will the polarization state be unaltered. The separation $\Delta\lambda$ in wavelength for adjacent wavelengths for which this is so is given by:

$$\Delta\lambda = \frac{\lambda^2}{d(n_e - n_o)} \qquad \ldots (1)$$

where λ is the incident wavelength, d the thickness of the plate and n_e and n_o the extraordinary and ordinary indices of refraction of the plate.

In the experimental arrangement described here the thickness of the calcite plate was 3 mm. For the difference of indices of refraction for calcite of 0.17 at 6943 Å , $\Delta\lambda$ = 5 Å. (Since the light passes twice through the plate before re-entering the ruby its effective thickness is double its actual thickness.)

Fig.1A shows a Fabry-Perot interferogram of the giant pulse produced by the laser under these conditions. The free spectral range of the Fabry-Perot etalon was 0.2 Å. The power level of the giant pulse is ~ 20 MW. This spectrum was found to be reproducible for over 200 shots of the laser.

A brief comparison of the birefringent plate with a resonant reflector shows the former to be superior in two respects. Both are essentially two-beam interferometers in which the intensity of light transmitted varies as $\cos^2 \pi m$ where m is the difference in optical paths measured in wavelengths between the two beams. m is in general a function not only of wavelength λ but also θ, the angle of incidence of light upon the plate or reflector. In assessing the wavelength discrimination produced by either of the two types of interferometer it is necessary to consider the effect of a range of angles of incidence upon the interferometer. For a resonant reflector the optical path difference is given by:

$$m = m_o \left(1 - \frac{\theta^2}{2}\right) \qquad \ldots (2)$$

where m_o is the optical path difference at normal incidence.

For a birefringent plate the optical path difference between components polarized parallel and perpendicular to the optic axis depends upon the azimuthal angle as well as the angle of incidence. The expression for this is given by Evans[(2)]. If the equation (III.19) of his paper be averaged over all azimuthal angles the resulting expression for the path difference is:

$$m = m_o \; 1 - \frac{\theta^2}{2} \left\{ \frac{n_e - n_o}{2 \, n_o^2 \, n_e} \right\} \qquad \ldots (3)$$

The expression in curly brackets is 0.024 for calcite. Hence such a polarizing interferometer is an order of magnitude less sensitive to variations in θ than a Fabry-Perot. Accordingly one would expect its wavelength discrimination characteristic to follow more nearly a cosine squared law independently of the way it is illuminated.

A second advantage of the birefringent plate over the resonant reflector is the relatively large spectral separation of the interference maxima, which is 5 Å for the former. As this separation is comparable to the width of the ruby fluorescence line, laser action can occur at only one of these maxima even if there are small drifts in the centre frequency of the fluorescent line relative to the frequency of maximum gain of the plate that arise from temperature variations. A resonant reflector having such a wide spectral separation would require a spacing of its reflecting surfaces ~ 0.3 mm.

The addition of the birefringent plate effected an improvement in the beam divergence of the laser from 11.5 to 7.5 milliradians measured using the technique of Winer[(3)]. The results are shown in Fig.2. We have no direct explanation for this improvement except that the restriction in wavelength must imply a corresponding limitation in the number of off-axis modes which can oscillate in the cavity.

No radiation damage to the calcite plate has been noted in over 1000 shots of the laser at a power level of 20 MW. If greater power is desired a laser amplifier can be added which increases the output power without changing the spectral emission. Fig.1B shows a Fabry-Perot interferogram of the previous laser emission amplified to a level of 100 MW with a single stage amplifier. The free spectral range is the same as 1A. The line width is essentially unchanged.

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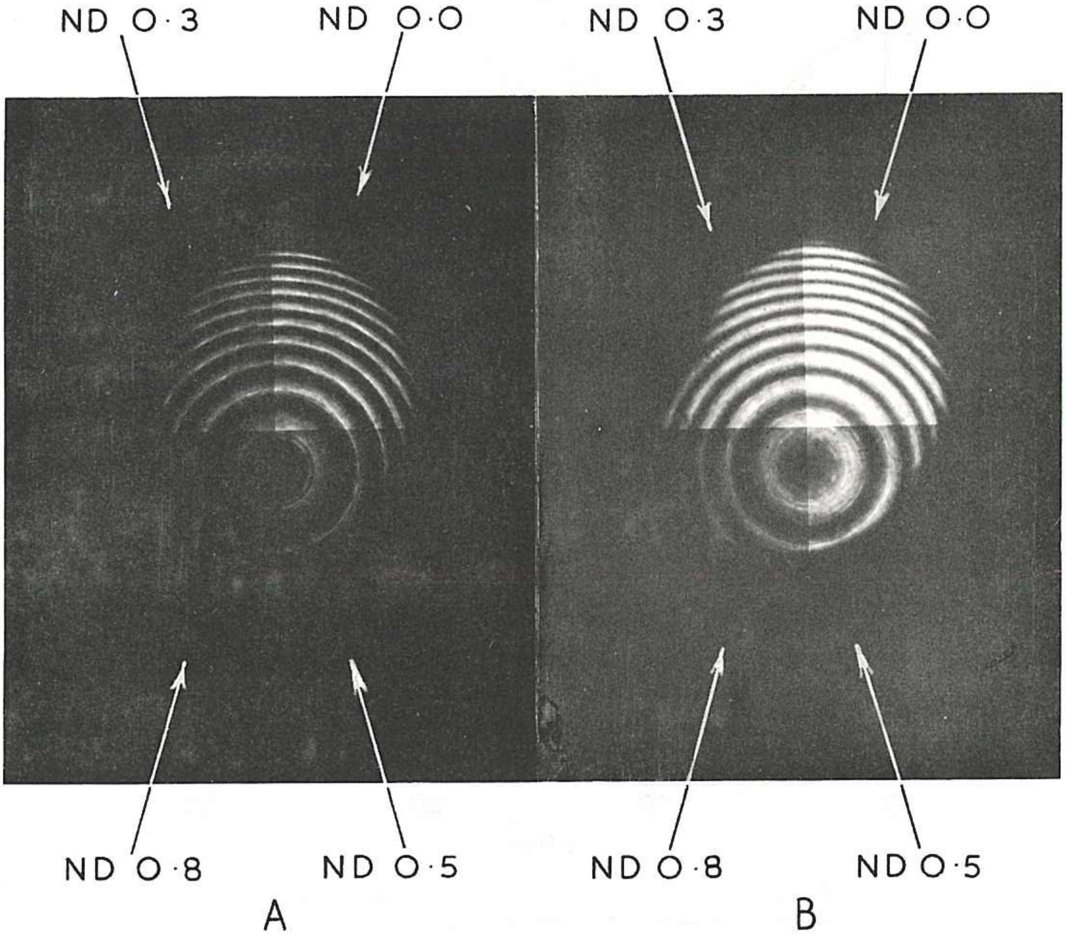

Fig. 1 (CLM-P 156)

A Fabry-Perot interferogram of oscillator output at a power level of 20 MW.

B Interferogram of the oscillator output amplified to a power level of 100 MW.

The etalon plate spacing was 1.3 cm corresponding to a free spectral range of 0.2 . Portions of the field labelled ND 0.3, ND 0.5, and ND 0.8 are covered with neutral density filters with the corresponding densities.

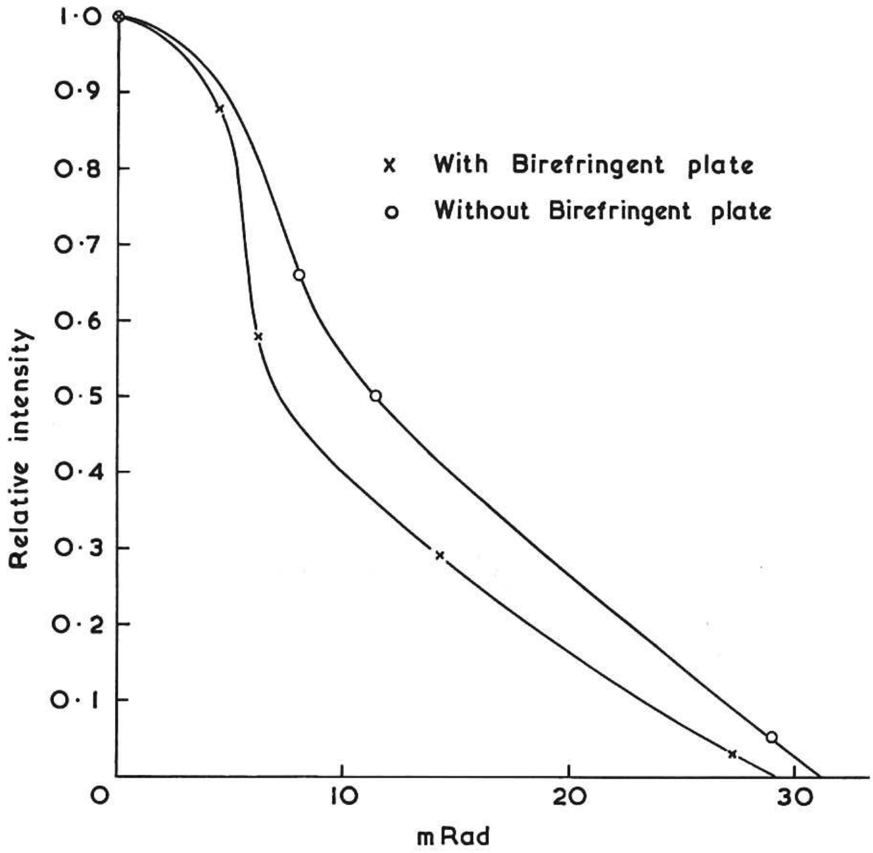

Fig. 2 (CLM-P 156)

Results of beam divergence measurements with and without the birefringent plate.