LINE WIDTH OF A RUBY LASER WITH A LIQUID SWITCH

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A Fabry-Perot interferometer is used in the wedge mode to examine the line width with a passive Q switch. The width is found to fall from 0.2 cm\(^{-1}\) in free oscillation to 0.005 cm\(^{-1}\) in the single-pulse mode.

It is of interest to produce high-power laser radiation with the narrowest possible line width. Q-switching provides a considerable increase in output power, but the line width is rather dependent on the method used. A rotating prism gives a total width of 0.6-1.5 cm\(^{-1}\), the pumping power then being the decisive factor [1]. A width of 0.02 cm\(^{-1}\) has [2] been attained by the use of a cryptocyanin solution.

We have examined the spectrum of a ruby laser under various conditions with a liquid switch.

**Experimental.** Figure 1 shows the block diagram of the apparatus. The laser consists of a cavity of semiconfocal type enclosing the ruby 1 and the liquid cell 2, the cavity being formed by the spherical mirror 3 (radius of curvature 2000 mm) and the set of plane-parallel plates 4 at the focal point of the mirror. The ruby rod was 120 mm long and 10 mm in diameter, with plane-parallel ends and polished sides. The pumping was provided by two IFP-2000 lamps, pumping energy 2 to 4 kJ. The filter was gallium phthalocyanin chloride in quinoline, which has its peak absorption at 6925 Å and a molar extinction coefficient of \(2.4 \times 10^5\) at \(\lambda_{\text{max}}\). This solution was used in a 5 mm glass cell between the ruby and the spherical mirror, the latter having a reflection coefficient of about 97% at 6943 Å. This cell was placed at a small angle to the axis. Tests were done with solutions whose transmissions (as measured with an SF-4 spectrophotometer) were 25, 40, and 50%.

The number of giant flashes was determined with the photomultiplier 5 (type FEU-28) and the oscilloscope 6. The interferometer 8 was a standard Fabry-Perot operating in the wedge mode [3]; the plates had multilayer dielectric coatings with \(R = 94\%\) at 6943 Å. Tests were done with plate separations \(h = 10\) and 30 mm. The resolution is [3] defined by

\[
\delta v = \frac{1 - R}{2\pi h V R}
\]

and was \(3.3 \times 10^{-3}\) cm\(^{-1}\) for \(h = 30\) mm. The interferometer was illuminated by the parallel beam formed by the collimator 7 taken from an OSK-3 optical bench; parts liable to be damaged by the flashes were removed or replaced. The output from the interferometer was recorded by a film placed in the camera 9.

It is very difficult to adjust the interferometer directly with a pulsed ruby laser, but a continuous-running laser obviates this difficulty. The beam from the He-Ne laser 10 is taken via the beam splitter 11 and the stops 12. The collimator was adjusted to give roughly uniform intensity. The angle of the interferometer wedge was chosen to bring rather more than one order of interference within the diameter of the plates. The correct inclination of the plates to the beam was determined from the change in the direction of motion of the fringes on turning the interferometer as a whole. Adjustment of the length of the collimator gave straight interference fringes. The pattern was tested for stability by altering the inclination of the laser beam within the limits allowed by the stops. Then the spectrum of the pulsed laser was obtained on the ground glass when the beam passed through both stops.
Results and Discussions. Free oscillation gave a total width of about 0.2 cm⁻¹, as measured with h = 10 mm; Fig. 2 shows the result and the result for Q switching with h = 30 mm. Free oscillation (Fig. 2a) led to overlap of orders, but it is clear that there are many lines. Estimates of the frequency differences for the clearer parts indicate that these correspond to modes differing in longitudinal parameters. Figure 2b shows that Q switching reduces the spectrum to a single component, whose width (as measured with an MF-2 microphotometer) was 0.005 cm⁻¹, which is close to the limit of resolution of the interferometer. A similar spectral width for giant pulses has been reported [4] for Q switching by means of a rotating prism, with mode selection by plane-parallel plates and a cell containing cryptocyanin. Figure 3 shows interference patterns for this laser under various conditions.

Fig. 2. Interferograms for laser radiation: a) free oscillation; b) with Q-switching by phthalocyanin (50% transmission, pumping energy 2300 J). A single component is seen in each order (Fig. 3a) in single-pulse working, so only one longitudinal mode is generated. More lines appear as the pumping energy is raised; in the two-pulse mode we get two lines (Fig. 3b), and we may suppose that each pulse corresponds to its own line. The frequency shift of about 0.03 cm⁻¹ between pulses (Fig. 3b) may be due to change in optical length of the cavity caused by heating of the ruby. Three pulses occur at higher pumping energies, and three lines are seen.

Fig. 3. Interferograms for pumping energies of: a) 2380 J; b) 3100 J; c) 3420 J (40% transmission); d) 3600 J (25% transmission).

The number of lines does not always equal the number of pulses, e.g., for the two-pulse mode of Fig. 3c, where the pumping energy was about 10% above that for Fig. 3b, there are five lines. Here the heating effect is accompanied by the occurrence of several axial modes separated by several times the interval between types of oscillation.

Figure 3d shows the pattern in the single-pulse condition with a cell of 25% transmission; the pumping energy is about 1.5 times that for Fig. 3a, which causes excitation of two modes whose longitudinal parameters differ by one unit, while the transverse ones coincide, as is evident from the line doubling, which is clear in the right-hand line. The components of the double line have a separation of 0.0043 cm⁻¹. The frequency difference between two modes whose axial parameters differ by unity is

\[ \Delta v = \left(2 \left[ L + l_1 (n_1 - 1) + l_2 (n_2 - 1) \right] \right)^{-1}, \]

in which \( L \) is the distance between the mirrors; \( l_1 \) and \( n_1 \) are the length and refractive index of the rod, while \( l_2 \) and \( n_2 \) are the same for the cell. The result is \( \Delta v = 0.0045 \) cm⁻¹, which agrees with the result from Fig. 3d.

Different ruby rods gave no essentially different interference pattern; but the rods did differ considerably when a plane-parallel cavity was used. Even the single-pulse condition gave several widely separated lines with certain rods. Here crystal inhomogeneity distorts the cavity and produces large differences of Q between modes, whereas the crystal produces only small perturbations in a spherical cavity [5].

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