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SOME REMARKS ON STRONG RESONANCE ABSORPTION OF LASER LIGHT IN RUBY AMPLIFIER ROD

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Strong absorption of plane-polarized laser beam in ruby crystal as dependent on orientation of its $\vec{E}$ vector with respect to the optic axis of the ruby is illustrated by means of cross-sectional beam patterns visualized on photographic paper.

In the course of experiments on the amplifying of a giant light pulse in a second ruby rod, strong absorption of the coherent beam was observed as a function of mutual orientation of both optic axes, in the oscillator and in the amplifier. Fig. 1 presents the setup used in these experiments. Q-switching in the generator was accomplished by means of a cryptocyanine cell (Q). The generated output pulse was 30 ns in duration (measured at halfwidth) and had a power of several MW (Fig. 2). This pulse was then directed through a polarizer to a 20-cm ruby amplifying rod.

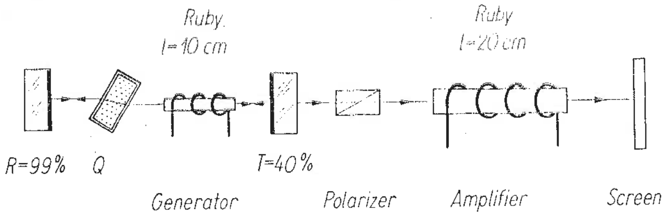

Fig. 1. Ruby laser (generator) and "one-pass" quantum amplifier

Triggering of the pumping flashtubes was electronically matched to give maximum population inversion in the second rod when the giant pulse from the generator was present. The flat surfaces of the generator and of the amplifier rods were not parallel to each other to avoid backward coupling. The maximum measured energetic amplification ratio was about 10.

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If the light from the generator passes through the not optically pumped ruby rod ("Passive case") its absorption depends strongly on the mutual orientation of both optic axes. In our experiments both ruby rods were of 90°-orientation; such a crystal generates a plane-polarized light beam. Orientation of the amplifying crystal was arranged to be parallel or perpendicular to the optic axis of the generator ruby rod.

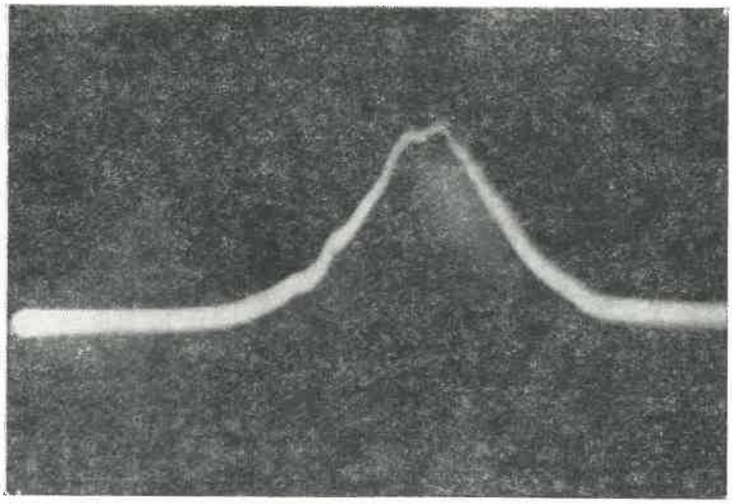

Fig. 2. Oscillogram of the light pulse emitted from the generator (measured halfwidth —30 ns)

Fig. 3 presents cross-sectional patterns of the beam depending on orientation of the second crystal in passive or active régime. The generated light beam was practically completely plane-polarized, as seen in Fig. 3. It was almost totally absorbed (Figs 3b and 3e) in the second ruby crystal, when both optic axes were parallel to each other and the amplifier crystal was not optically pumped ("Passive régime"). In the perpendicular case, absorption of the light in the ruby crystal is rather small (Fig. 3c or 3d). Strong amplification of the beam can be obtained if both optic axes are parallel to each other and the amplification rod is optically pumped to exhibit high population inversion of the appropriate energy levels (Figs 3f and 3g). However, a decrease in amplification in the active case was observed when these axes were perpendicular (Fig. 3i). It should be pointed out that no loss in the degree of polarization during beam amplification was observed (Figs 3h and 3g).

Absorption of ruby laser light in a second ruby rod as function of mutual orientation of the optic axes is a consequence of the difference in their absorption coefficients $\alpha_{||}$ and $\alpha_{\perp}$ [1, 2]. However, the difference $\alpha_{||}-\alpha_{\perp}$ when measured with a weak light beam is not very large and can not explain the strong absorption, as observed in Fig. 3b. Absorption of a strong coherent beam in ruby was earlier investigated by Nielson and Struge [2]. Assuming the light beam propagating along the geometric axis of the crystal (Fig. 4) we have to consider two main absorption spectra: $\sigma(\vec{E}\perp$ to the optic axis) or $\pi(\vec{E}||$ to the optic axis). Applying a temperature tunable ruby laser Nielson and Struge had measured the resonance absorption responsible for the transition from the ground state $^4A_2$ to the excited ^2E-state (this state is represented by two lines, R_1 and R_2, separated by about 39 cm^{-1}). These transitions are spin-forbidden and can be characterized by a very small oscillator strength of the order of 10^{-6}. The normal line width of the R_1 line is 6 cm^{-1} and decreases to about 0.2 cm^{-1} when observed in induced emission régime. Furthermore, both lines are almost equal in intensity during spontaneous emission.

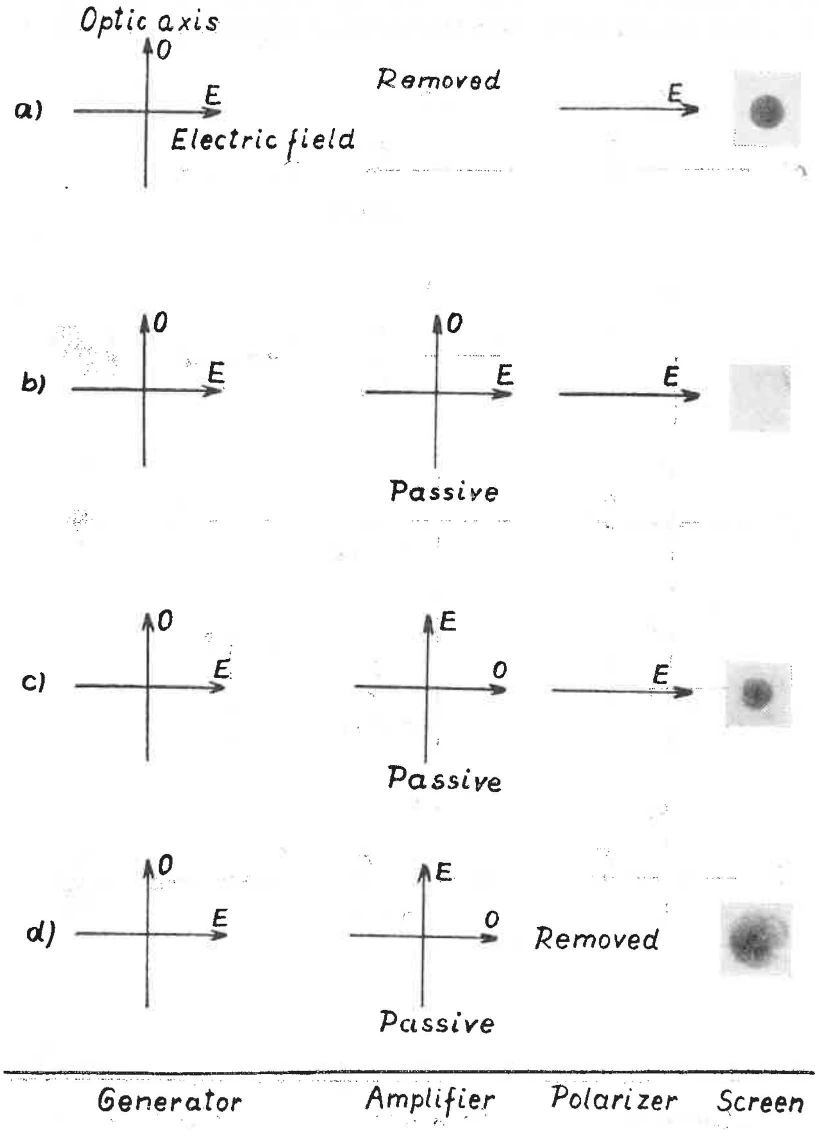

Fig. 3

The integrated absorption coefficients measured by [2] were (at 300°K):

$$\left.\begin{aligned}\int \sigma_{||} d\nu &= 0.2 \cdot 10^{-19}\ \text{cm}^2 \\ \int \sigma_{\perp} d\nu &= 3.5 \cdot 10^{-19}\ \text{cm}^2\end{aligned}\right\} \text{ for } R_1 \text{ line.} \qquad (1)$$

This gives a factor of 17.5 for the $\sigma_{\perp} : \sigma_{||}$ ratio. Figs 3b and 3c fully certify the validity of relation (1). If the ground state is highly depopulated as a result of strong optical pumping then amplification in the second ruby rod is very pronounced if both optic axes are parallel to each other (Figs 3f). Mitchell and Izaat [3] had also observed that absorp-

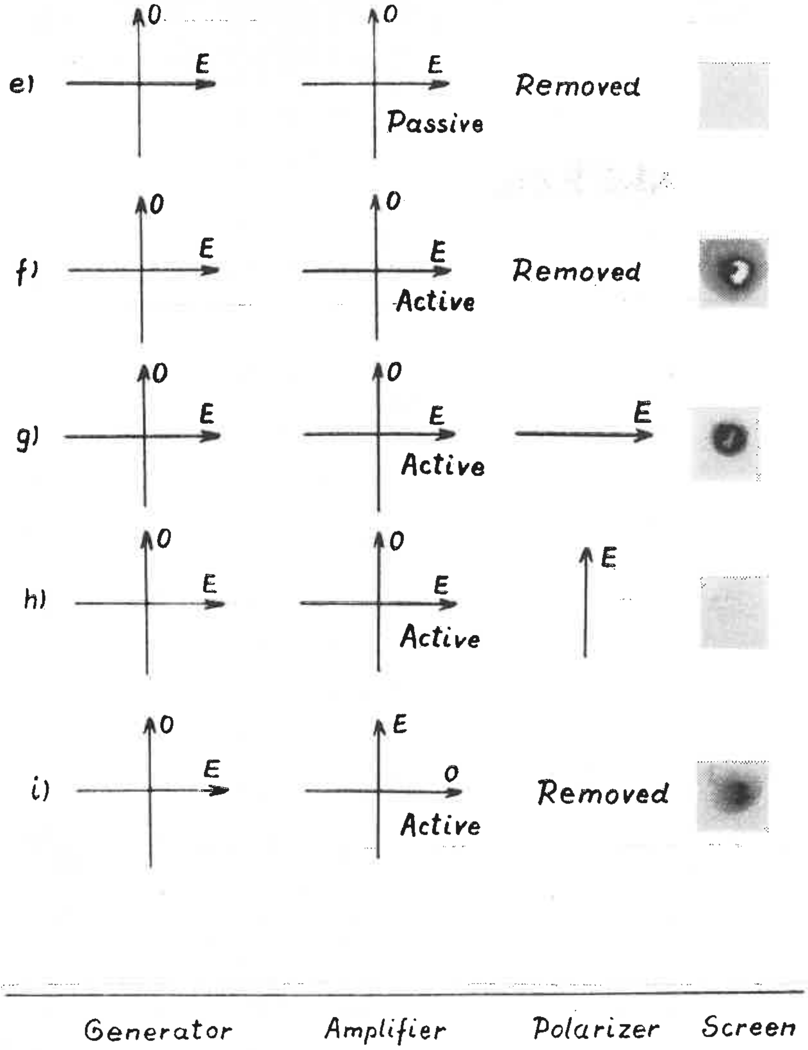

Fig. 3. Cross-sectional patterns of the light beams as dependent on the mutual orientation of optic axes of both ruby rods

tion in the second unpumped ruby rod decreases nonlinearly if the incident beam is very strong. This decrease in absorption is caused by strong depopulation of the ground state. In their experiments, the energy density of the incident, measuring beam was about 100 J/cm^2. In our experiments, this energy density was of the order of 10 J/cm^2. Thus, the nonlinear absorption is completely negligible. Of course, no distortion of the generated pulse shape in the second ruby rod was observed. The pictures presented in Fig. 3 indicate the importance of proper alignment of both ruby rods if the highest amplification ratio is desired. First of all — both ruby rod axes should be parallel to each other. Distribution of pumping energy in the amplifying rod will determine the efficiency of the device. In the case of parallel optic axes the absorption is very high in these ruby parts which remain unpumped. This is of special interest because the amplifier rod has usually a large diameter in order to reduce the flux density of the beam. Homogeneous distribution of pumping energy within a ruby amplifying rod is thus a very serious problem.

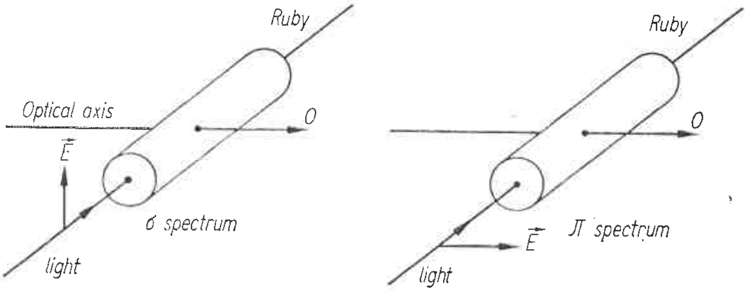

Fig. 4. Illustration of the two different methods in measurements of the absorption spectra of a ruby crystal. $\vec{E}$ — electric field vector of the plane-polarized incident beam

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