EFFICIENCY OF STIMULATED R-LINE EMISSION IN RUBY

X.A. SHEN

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Shock Dynamics Laboratory

Department of Physics

Washington State University

Pullman, WA 99164

This report is concerned with stimulated R-line emission in ruby. It estimates the maximum obtainable power of the stimulated emission in a pump-and-probe experiment and under various conditions. This calculation is based on the following assumptions: a) a 100 % population inversion in ruby is achieved by exposing ruby to a high-power light pulse from a pump laser (*e.g.*, Candala dye laser operating at 514.5 nm) prior to shock impact and remains unchanged throughout the experiment, b) a dye laser, providing a uniform photon flux in a wavelength region between 692 and 698 nm, is used to initiate the emission.

Consider the interaction of a monochromatic wave (frequency ν) and an assembly of two-level systems, in which N_2 electrons are in level 2 and N_1 electrons are in level 1. The net transitions per unit volume per unit time gives rise to an induced emission power[1]

$$\frac{\text{Power}}{\text{Volume}} = (N_2 W_{21} - N_1 W_{12}) h\nu = (N_2 - N_1 \frac{g_2}{g_1}) \frac{\lambda^2 g(\nu) I}{8\pi n^2 t_{spont}}, \tag{1}$$

where $W_{21} = W_{12} g_1 / g_2$ is the rate of transition from level 2 to level 1 and the spontaneous transitions are ignored. Since $dI/dz = (\text{Power/Volume})$, we obtain

$$\frac{dI(\nu)}{dz} = \gamma I(\nu), \tag{2}$$

where

$$\gamma = (N_2 - N_1 \frac{g_2}{g_1}) \frac{\lambda^2 g(\nu)}{8\pi n^2 t_{spont}}. \tag{3}$$

Integrating Equation (2) yields the following relation

$$I = I_0 \exp(\gamma d), \tag{4}$$

where d is the thickness of the ruby sample.

For a ruby crystal with 0.5 % Cr_2O_3 by weight, *i.e.*, 2.4×10^{19} Cr atoms/cm^3, we have

$$N_1 - N_2 \frac{g_2}{g_1} = 2.4 \times 10^{19},$$

$$t_{spont} = 3 \times 10^{-3} sec,$$

$$\lambda = 6943 \times 10^{-8} cm,$$

$$n = 1.77,$$

and

$$d\nu = 1/g(\nu) = 2 \times 10^{11} \ Hz \quad \text{at 300 K,}$$

which yields

$$\gamma = 2.45 \ cm^{-1}. \tag{5}$$

In general γ is not constant. It decreases with time because of the reduction of N_2 during the emission. The value in Equation (5) provides only an upper limit for the efficiency of the stimulated emission. Thus, for d=250 μm, we obtain

$$\frac{I}{I_0} = \exp(\gamma d) = \exp(2.45 \times 0.025) = 1.06.$$

Only 6 % of signal stems from stimulated emission and the rest is just straight laser light. The equivalent signal-to-noise is therefore only 0.06, too small to obtain any useful signal.

If, instead, we use a 1 cm thick ruby crystal, then the contribution from stimulated emission increases to

$$I - I_0 = \left(\exp(2.45 \times 1) - 1 \right) I_0 = 10.6 I_0.$$

A much improved S/N ratio of 10.6 will be obtained.

If we increase Cr concentration by a factor of 10, from 2.4×10^{19} to 2.4×10^{20} cm^{-3} and thickness by a fact of 2, to 500 μm, then the equivalent S/N ratio becomes

$$(I - I_0)/I_0 = \exp(24.5 \times 0.05) - 1 = 2.4.$$

In conclusion, under current experimental conditions, *i.e.*, $d=250$ μm and 0.5 % Cr concentration, the stimulated R-line emission will be too weak to measure. Increasing sample thickness is not feasible because it will affect significantly the temporal resolution. One possibility is to use heavily doped ruby crystals. However, it is not clear as to how high the Cr concentration one can obtain. Powell has studied heavily doped ruby with Cr concentrations up to 2.1 %.[2]

References

1. A. Yariv, in *Quantum Electronics*, (John Wiley and Sons, New York, 1975) p. 161.

2. R. C. Powell, J. Appl. Phys. **37**, 4973 (1966).