M. Sc Final (IV Semester)

Course: Paper 4104 (Section A), Inorganic Materials

Course Instructor: Professor S. Uma

Topic: Optical materials

Content: Introduction to colors in gemstones (Ruby), Ruby laser, and Nd-YAG laser

Color of Ruby

Ruby is (α-Al_2O_3 containing 0.5 Cr %). Cr^{3+} dopant ions are randomly distributed in place of Al^{3+} ions in the lattice.

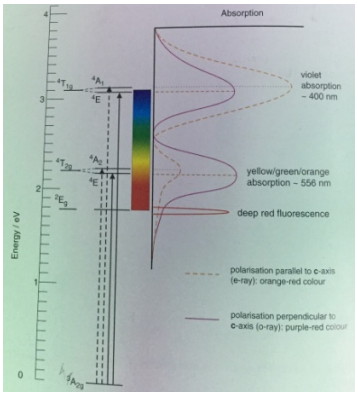
In Al_{1-x} Cr_xO_3, when x = 0, it is colorless and it is corundum mineral. For small values of x (0.005), the color is intense ruby red. With increase of Cr^{3+} ion concentration, the color turns grey, light green and green of Cr_2O_3.

Both the end members are isostructural and the trivalent ions have slightly distorted oxygen octahedral. The color is from crystal filed splitting of Cr^{3+} (d^3) ions.

The absorption bands are

1. $^4T_{2g} \leftarrow {}^4A_{2g}$ 556 nm (2.23 eV, 3.58×10^{-19} J, 18 000 cm^{-1}) = 10 Dq
2. $^4T_{1g}$ (from ^4F) $\leftarrow {}^4A_{2g}$ 400 nm (3.10 eV, 4.97×10^{-19} J, 25 000 cm^{-1}) = 18 Dq – interaction energy
3. $^4T_{1g}$ (from ^4P) $\leftarrow {}^4A_{2g}$ 270 nm (4.59 eV, 7.35×10^{-19} J, 37 000 cm^{-1}).

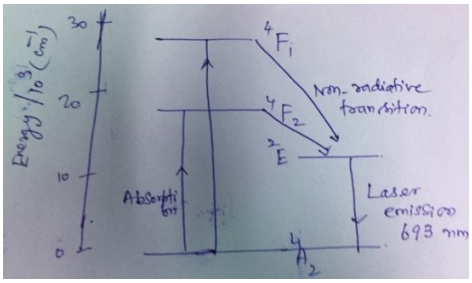
The first two transitions are responsible for the color ruby. Between the absorption (at 556 nm and at 400 nm), there is a transmission window (at 680 nm). The electronic transitions (d-d) are shown in the figure below.

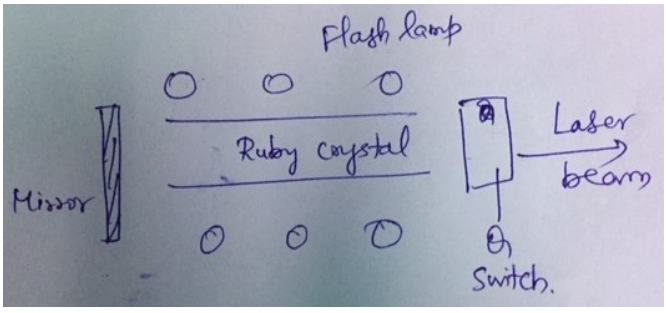


(Ref. R.J.D. Tilley)

Ruby laser (Light Amplification by Stimulated Emission of Radiation) **(three level laser):** The first laser (Ruby laser, in 1960) is formed from (~$Al_{1.995}Cr_{0.005}O_3$) crystal. The transitions (shown below) of Cr^{3+} ions are responsible for the laser action. The construction of Ruby laser is also shown below. When the Xe (Xenon) flash lamp is shined on the ruby crystal, d electron of Cr^{3+} ions absorb the energy and promoted from the ground ($^4A_2$) state to the upper states ($^4F_1$ and $^4F_2$) by absorbing the blue-green region. The electrons decay non-radiatively to ^2E level. The lifetime of this excited state is long (~$5x10^{-3}$ s), allowing the population to build up causing **population inversion.** Laser action occurs by transition from ^2E level to the ground state, giving intense, coherent pulse of red light (6934 Å) with a duration of ~250μs.

The Ruby laser is three level laser based on the three energy levels employed.





The design of Ruy laser is made up of a ruby crystal rod with a flash lamp around and they are arranged in a reflection cavity. At one end, a mirror is placed to reflect the pulse. At the other end a Q switch is used either to allow the laser to pass or to reflect it back through the cavity for another cycle.

Nd-YAG (**four level laser**)

This is a four level laser (Figure) because laser emission does not correspond to the ground state energy level but another involves another intermediate energy level.

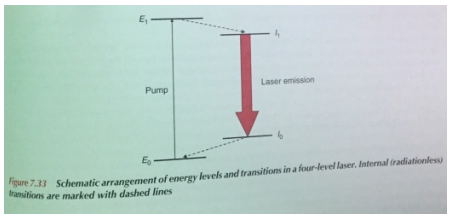
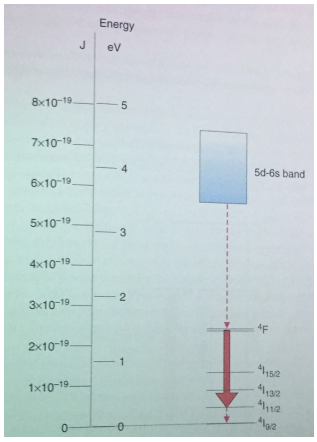


Figure 7.33 Schematic arrangement of energy levels and transitions in a four-level laser. Internal (radiationless) transitions are marked with dashed lines

The host solid is yttrium aluminium garnet (YAG, $Y_3Al_5O_{12}$), in which a small amount of Nd^{3+} ions are substituted for Y^{3+} ions. The transition are shown below. Several absorption transitions re possible after light irradiation. The excited states decay non radiatively to the $^4F_{3/2}$ level, from which laser emission occurs to the $^4I_{11/2}$ level with a wavelength of 1064 nm. The $^4F_{3/2}$ level is long lived (~10^{-4} s). The four level lasers are useful in high power lasers as compared to the three level lasers.



(Ref. R. J. D. Tilley)