Promethium (Pm$^{3+}$) Solid State Laser

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SUMMARY

We have achieved stimulated emission from the trivalent promethium ion (Pm$^{3+}$) for the first time. Using a Pb-In-phosphate glass cylinder doped nominally with one percent promethium as the laser medium, laser action was obtained at ambient temperature at 933 and 1098 nm. The Pm gain medium was fashioned into an etalon one cm in length and was placed within a near concentric resonator of 20 cm length. The promethium gain medium was pumped through resonator mirrors at 570 nm using a pulsed dye laser (100 mJ/1 μsec/575 nm, 500 μ spot diameter). Laser performance data will be presented along with observations of radiation damage effects due to radioactive decay of $^{47}$Pm (224 keV beta).

The general features of a Pm laser can be understood in terms of the electronic energy level structure of Pm$^{3+}$ shown in Figure 1. The observed stimulated emission at 933 nm occurs in the $^5F_1 \rightarrow ^5I_{15}$ transition band and that at 1098 nm occurs in the $^5F_1 \rightarrow ^5I_{16}$ transition. Absorbed pump energy relaxes rapidly to the upper laser level, the $^5F_1$ J-manifold. This manifold is separated in energy from the next lower lying $^5I_{18}$ manifold by ~6000 cm$^{-1}$ and is expected to be extremely stable against multiphonon nonradiative decay. The 300 μsec $^5F_1$ fluorescence decay time measured for Pb-In-phosphate glass is equal to the radiative lifetime of this level calculated by the Judd-Ofelt transition probability model, and supports this expectation. Judd-Ofelt theory further predicts that excited state absorption from the $^5F_1$ manifold near 930 nm should be extremely small. The terminal $^5I_{15}$ and $^5I_{16}$ laser levels lie ~1600 cm$^{-1}$ and ~3200 cm$^{-1}$ above the ground level, respectively, and are thermally depopulated at 300 K, permitting the ambient four level laser action observed.
Earlier theoretical calculations predicted that the $^5F_1$ radiative lifetime of Pm$^{3+}$ in a given host material should be nominally equal to the radiative lifetime of the $^4F_{3/2}$ J-manifold of Nd$^{3+}$ in the same host, and also that the $^5F_1 \rightarrow ^5I_{15}$ transition strength of Pm at 920 nm should mirror that of the dominant $^4F_{3/2} \rightarrow ^4I_{11/2}$ transition of Nd at 1060 nm. We have measured $^5F_1$ fluorescence decay times, as well as absorption, excitation, and fluorescence spectra, of several oxide and fluoride glasses and crystals. Our measurements generally confirm the analogy between Pm and Nd as laser ions. Spectroscopic and kinetic data for Pb-In-phosphate glass and various other potential Pm laser host materials will be discussed in the presentation and correlated with laser measurements.

Finally, it should be noted that the Pm ion provides useful pump absorption bands at 770 and 805 nm (as well as an upper laser level with 250-1000 μsec metastable lifetime). This circumstance allows for a Pm laser to be directly pumped by AlGaAs semiconductor laser diode arrays, efficiently producing laser emission in the 910-930 nm and in the 455-465 nm region by harmonic doubling.

References:


FIGURE CAPTION

Figure 1. Energy levels of Pm$^{3+}$; dominant pump, fluorescence, and laser transitions (wavelengths in nm).

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