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## IMPROVED OPERATION OF A CW YLF LASER

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**Abstract** - We developed a cw laser in the  $2\mu\text{m}$  region operating at liquid-nitrogen (77 K) and at dry ice temperature (210K) pumped by the  $514\ \mu\text{m}$  line of  $\text{Ar}^+$  laser. Also we observed two wavelenghts (670 nm, 890 nm) that are significantly correlated with laser emission.

## Introduction.

The Holmium emission at  $2.06\ \mu\text{m}$  has long been the basis for the development of efficient solid-state lasers. Laser action has been reported for different host crystals, both in pulsed and in cw regime; room temperature as well as 77 K operation has been described /1 - 8/.

Recently we developed a highly efficient cw laser employing a  $\text{LiYF}_4$  crystal doped with Er, Tm and Ho, with the purpose of obtaining a low-noise tunable source for spectroscopic applications in the  $2\ \mu\text{m}$  wavelength region. The main results achieved in the improvement of our laser are described in the first part of this paper while in the second part we studied the visible and infrared fluorescence from the higher energy levels of Ho and Er, which are populated by upconversion processes.

The motivation of this work was to improve the understanding of the basic mechanisms of energy transfer and eventually to provide guidelines for the design of a better laser device.

## Experimental Apparatus.

The  $\text{LiYF}_4$  crystal, doped with 0.72 Er, 0.072 Tm and 0.003 Ho, is placed in a cryostat inside an astigmatically compensated resonator.

The pump light is the 514 nm line of an Ar laser, which is injected into the YLF resonator by a ZnSe beam splitter. The crystal is placed with its "C" axis parallel to both the pump and the infrared polarization.

Its dimensions are  $7 \times 3.5\ \text{mm}$  and it is 2.5 mm thick. The absorption coefficient at 514 nm is about  $6\ \text{cm}^{-1}$  (at the temperature of 77 K).

The resonator has a total length of about 1 meter and a folded structure with two concave mirrors ( $R = 5$  and  $8\ \text{cm}$ ) and a flat output mirror, all clamped to a super-invar base to insure a good thermal and mechanical stability /9/. The curved mirrors and the crystal are kept inside the vacuum chamber of the cryostat, which is terminated by a Brewster window. An additional side window allows the direct observation of the fluorescence from the crystal in a direction orthogonal to the laser propagation. The fluorescence at 670 or 890 nm is selected by a small monochromator and detected by a cooled photomultiplier with Si spectral response. A mechanical chopper and lock-in amplifier are used for signal processing.

## Results.

In the Fig.1 the best performances of the laser are displayed for two different operating conditions.

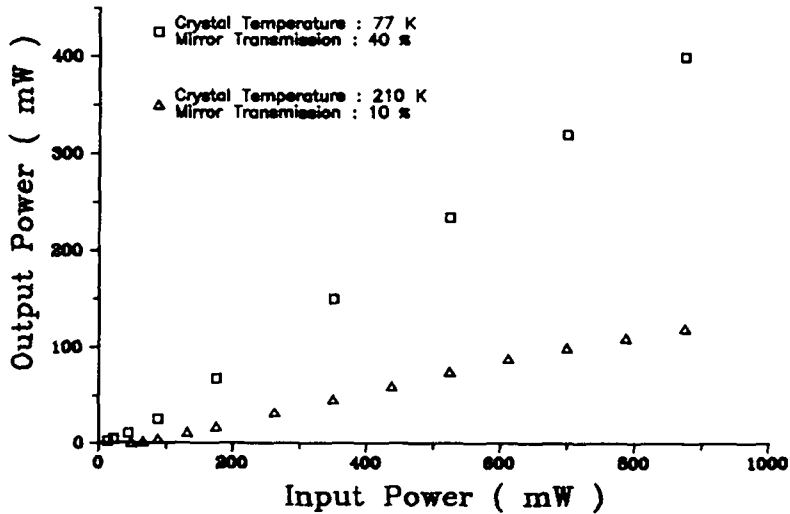


Fig.1 Maximum output power of the YLF Laser versus input power for 77 K and 210 K crystal temperature at two different transmissions of the output coupler.

The highest power is obtained with the crystal at 77 K and an outcoupler transmission of 40%. With an incident power of 870 mW on the crystal, we obtained an output of 400 mW at 2.06  $\mu\text{m}$ . The remarkable slope efficiency of 48% is maintained up to 3.1 Watt of incident power where an output of 1.46 Watt was observed/10/. We measured a pump power threshold of 15 mW.

In the second case the crystal is operated at dry-ice temperature (210 K) and the optimum outcoupler transmission is 10%. Now the maximum output power is 130 mW, the threshold is about 60 mW and the slope efficiency is 15%.

In Fig.2 we plot the intensity of the infrared fluorescence at 890 nm as a function of pump power: a non-linear behaviour is clearly visible. The crystal temperature is 77 K and laser action is inhibited by an intracavity shutter. We assign this fluorescence to the emission from the  $^5I_5$  level of Ho and the tentative explanation of non-linearity is given as the follows.

The Ho  $^5I_5$  level is populated through an upconversion process where an excited Er ion ( $^4I_{13/2}$ ) transfers its energy to an excited Ho ion ( $^5I_7$ ) /11, 12/. The Ho  $^5I_5$  population is therefore determined by both the Ho  $^5I_7$  and the Er  $^4I_{13/2}$  populations since the upconversion rate is proportional to the product of the populations.

A different result is shown in Fig.3: now the IR fluorescence is measured when the crystal is lasing, while all other conditions are the same as above. A linear behaviour is observed and the fluorescence has a much smaller intensity. This happens because Ho  $^5I_5$  population is clamped to threshold by laser action. If a lower transmission is used for the outcoupler, the smaller losses will clamp the threshold population at a lower amount; thus this modal also explains the very small fluorescence observed at  $T = 5\%$ .

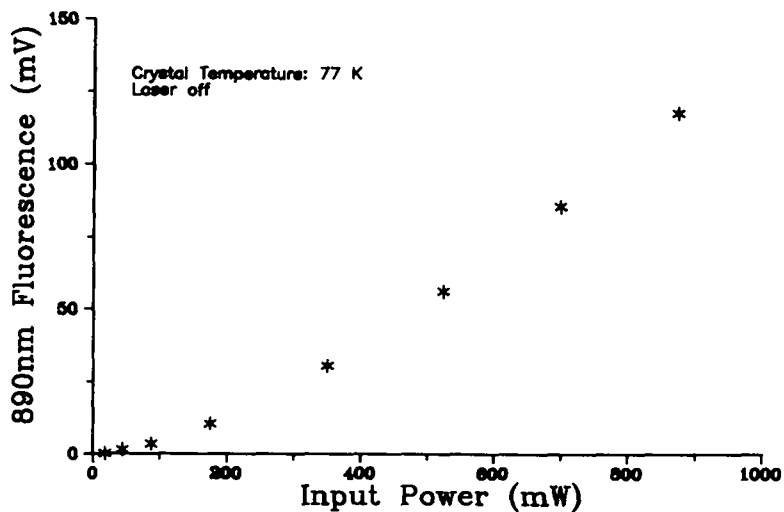


Fig.2 Intensity of the infrared fluorescence versus input power with the laser not operating

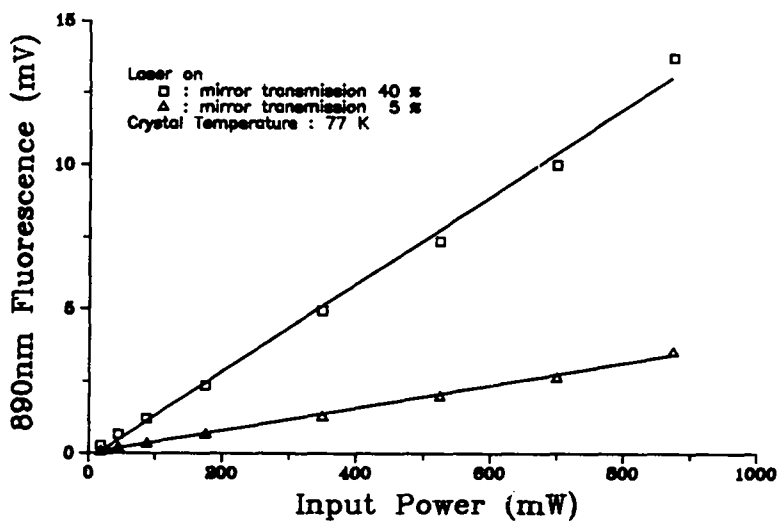


Fig.3 Intensity of the infrared fluorescence versus input power with the laser operating at two different transmissions of the output coupler

We studied a second fluorescence line in the visible, at 670 nm and here too we compared lasing and non-lasing intensities. This emission can be assigned either to the Ho  $^5F_5$  or the Er  $^4I_{9/2}$  levels which are almost exactly resonant.

The most likely process is where one excited Er ion in  $^4I_{11/2}$  combines with one excited Ho ion in  $^5I_7$  resulting in one excited Er ion in  $^4F_{9/2}$  or one excited Ho ion in  $^5F_5$ . In this case too we found that the fluorescence is remarkably increased when laser action is inhibited, a behaviour similar to that of the infrared fluorescence. Since upconversion presents a loss for the laser and since Er is identified as being responsible for both of the processes, the 2.06  $\mu\text{m}$  laser should work better when only Tm is used as a sensitizer. This is possible when laser diodes are used for pumping.

As a conclusion we can state that we have obtained a powerful and stable laser source in the 2  $\mu\text{m}$  region and we have reported a preliminary study of the connections between crystal fluorescence and laser action.

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