



Performance of Nd³⁺ Doped Waveguide LASER using Continuous Wave Excitation

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Abstract: Neodymium-doped waveguide Lasers and amplifiers are of interest for applications at +ve ion's specific emission wavelengths and have been widely studied. The trivalent Neodymium ion (Nd³⁺) is the most important active rare earth ion for the demonstration of significant gain and laser operation. In the present work Nd³⁺ complex doped polymer waveguide amplifiers with high gain at transitions 4F_{3/2} 4I_{11/2} and 4F_{3/2} 4I_{9/2} have been demonstrated. In this paper, Continuous Wave Laser operation of Nd³⁺ complex doped 6-FDA/UVR channel waveguides near 880nm and 1060nm will be reported. This work represents simultaneously the first demonstration of a rare-earth-ion-doped polymer waveguide Laser and a CW solid-state polymer Laser.

Keywords: Polymer waveguide, Optical Loss, CW Laser operation, optical amplification, Nd³⁺ (Neodymium ion).

I. Laser Experiment

Laser performance was investigated in Nd³⁺ complex-doped polymer channel waveguide for the optional Nd concentration of 1.03*10cm determined from gain measurement. Laser test of the Nd³⁺ doped 6-FDA/UVR channel waveguides around 880 and 1060nm were performed at room temperature by longitudinally pumping at 800nm with a CW Ti: Sapphire Laser. The Laser cavity was formed by attaching light weight then dielectric mirrors to the polished end faces of the waveguide using the surface-tension of a small amount of Fluorinated liquid(Fluorinent-FC-70) for adhesion. The mirrors used for incoupling were high reflective(R-99.8%) at the Lasing wavelength and had a transmission of 94% at the pump wavelength. A mirror with high reflectivity and a set of mirrors with different reflectivities at the Laser wavelengths of 880nm and 1060nm respectively, were used as output couplers. The microscope objectives used for in-and outcoupling had a magnification of x4 and x10 respectively. The pump Laser beam was expanded using a telescope consisting of two spherical lenses with focal lengths of f=40 and 200mm respectively, in order to fill the aperture of incoupling objective. The outcoupled waveguide mode, after passing through a RG1000 or RG850 filter(for 1060-nm or 878-nm lasing respectively). To block the residual transmitted pump light, was directed onto a power meter or a spectrometer as required. The coupling efficiency was optimized by adjusting the position of the waveguide and tuning the pump laser to find the lowest threshold power at the onset of lasing or by imaging the laser mode on a CCD camera.

II. Laser Results

Laser oscillation was obtained for all the channels investigated at a wavelength near 1060nm, which corresponds to the most intense peak of the waveguide luminescence spectrum. For a 16mm long cavity formed by two high reflective mirrors a laser threshold of 84mW absorbed pump power was obtained.

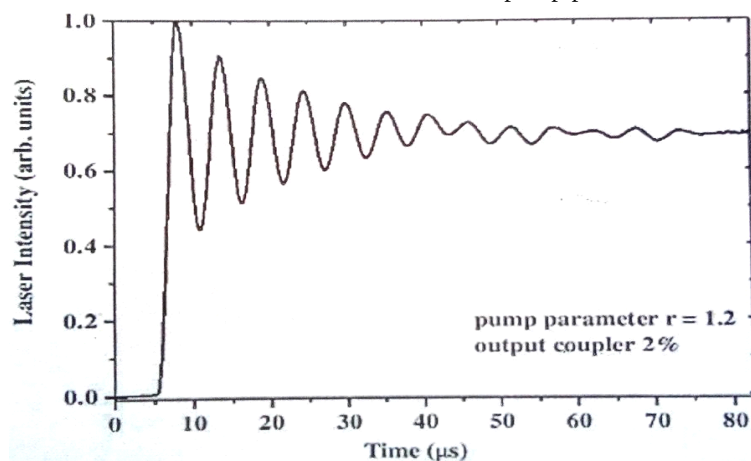


Fig.1

Fig.1 shows damped relaxation oscillations obtained by a modulation of the pump laser at an absorbed pump power of 100mW.

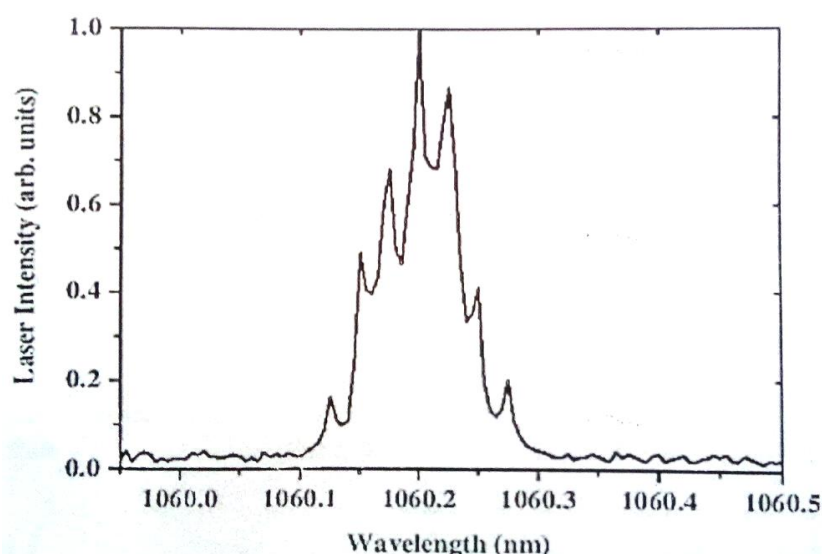


Fig.2

Fig.2 shows a laser spectrum obtained for an absorbed pump power just above the laser threshold. The separation of the peaks observed in the spectrum, which correspond to the longitudinal cavity modes, can be calculated for the cavity length $l=16\text{mm}$ using the equation:

$$\Delta\lambda (\lambda^2 / 2.L.n)$$

The calculated peak separation is 0.023nm, which fits well with the value of 0.025nm observed from the measured laser spectrum.

By replacing the high reflectivity outcoupling mirror with one having a transmission of 2% at the lasing wavelength the threshold value increased to 101mW. Fig.3 shows the laser output power as a function of absorbed pump power. The maximum output power was 440 μW at 1060nm for 148mW of absorbed pump power and a slope efficiency η of 0.95% with respect to absorbed pump power was derived.

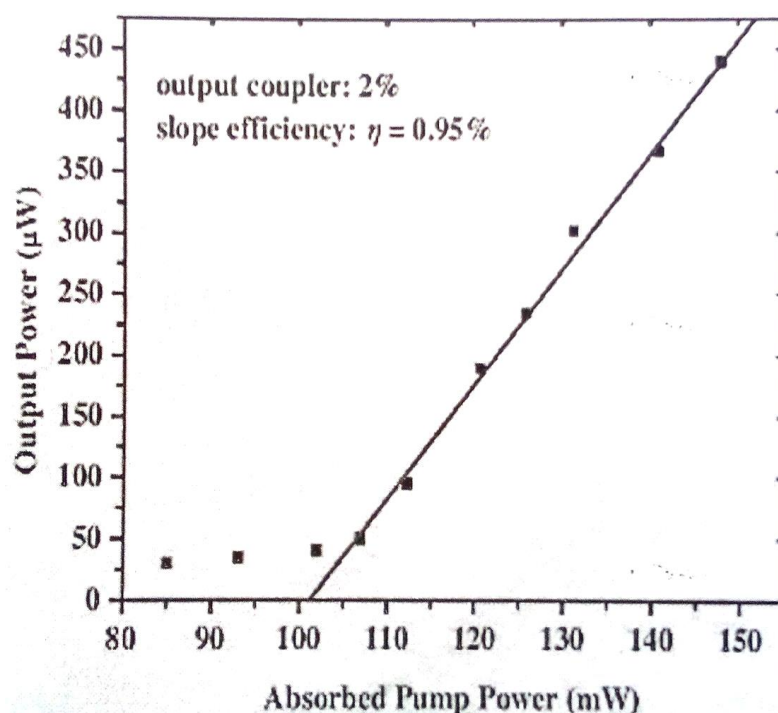


Fig.3 Laser output power in a 16-nm-long Nd^{3+} complex-doped 6-FDA/UVR channel waveguide as a function of absorbed pump power for the four-level transition at 1060.2nm.

The laser performance at 1060nm was further studied in a shorter channel waveguide sample of length of 7.5mm, using successively a set of four outcoupling mirrors with transmission values of 1.8%, 3%, 4% and 5% at the laser wavelength. Fig.4 shows the laser spectrum at high pump power. The output vs input power

characteristics obtained for each of them is shown in Fig.5. The highest slope efficiency η of 2.15% and the maximum output power of 0.9mW for 129mW of absorbed power were obtained using a 5% outcoupling mirror. Lasing could not be achieved using the outcoupling mirror with the next highest transmission available ($T=10\%$), as the pump intensity is required were destructive for the channels.

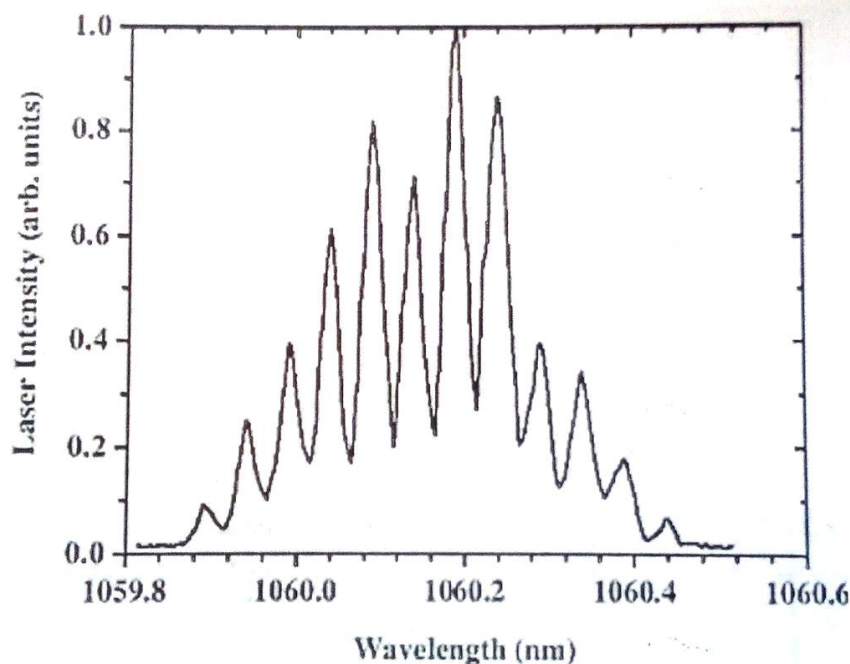


Fig. 4 Typical laser emission spectrum at 1060.2nm in a 7.5-mm-long Nd^{3+} -complex-doped 6-FDA/UVR channel waveguide at high pump power.

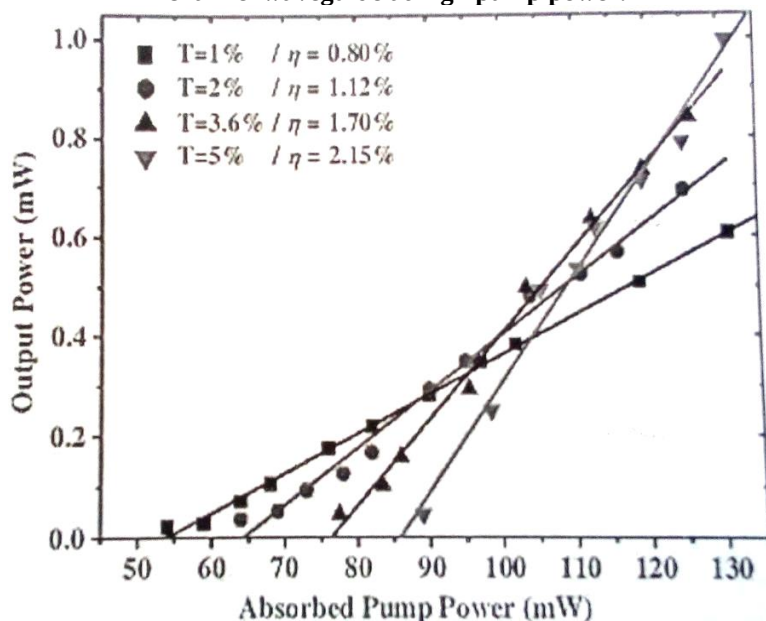


Fig. 5 Laser output power in a 7.5-mm-long Nd^{3+} -complex-doped 6FDA/UVR channel waveguide as a function of absorbed pump power for the four-level-transition at 1060.2nm using a set of outcoupling mirrors.

A result that exceeded our expectations was the laser operation of the quasi-three-level transition near 870nm. Re-absorption losses combined with the relatively low stimulated-emission cross section at this wavelength ($\sigma_e \sim 1.2 \times 10^{-20} \text{cm}^2$ as compared to $\sigma_e \sim 4.4 \times 10^{-20} \text{cm}^2$ for the dominant four-level transition), require high pump powers, which however counter-poses the need to maintain the pump power at a low level to avoid detrimental effects on the laser performance induced by thermal degradation of the material. Using 2HR mirrors as input and output couplers lasing was observed at an absorbed pump power threshold of 67mW (Fig.6). Fig.7 shows the laser output as a function of absorbed pump power for 2.2% outcoupling, which yields a slope efficiency of 0.35% and a laser threshold of 74.5mW.

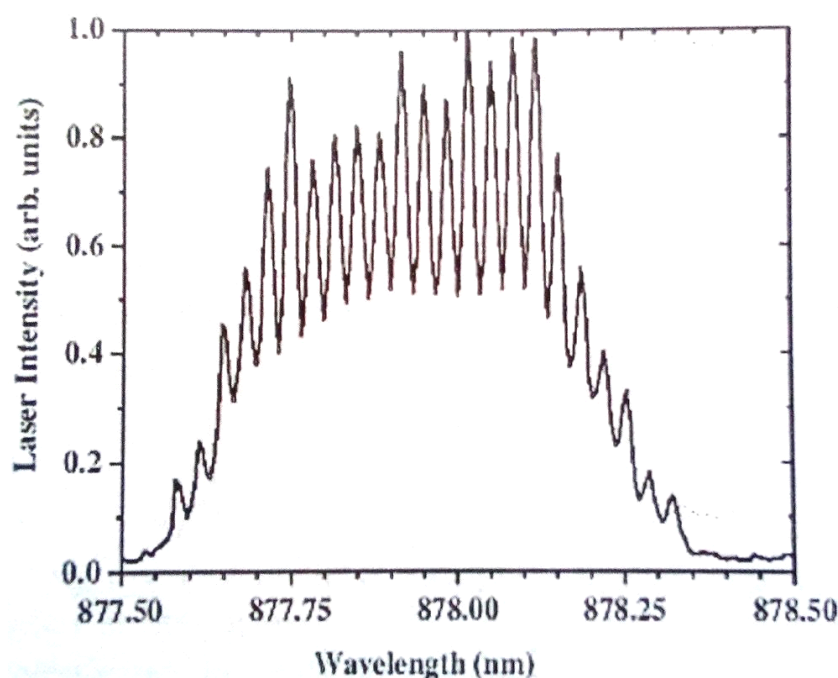


Fig. 6 Typical laser emission spectrum at 878nm in a 7.5-mm-long Nd³⁺-complex-doped 6-FDA/UVR channel waveguide at high pump power.

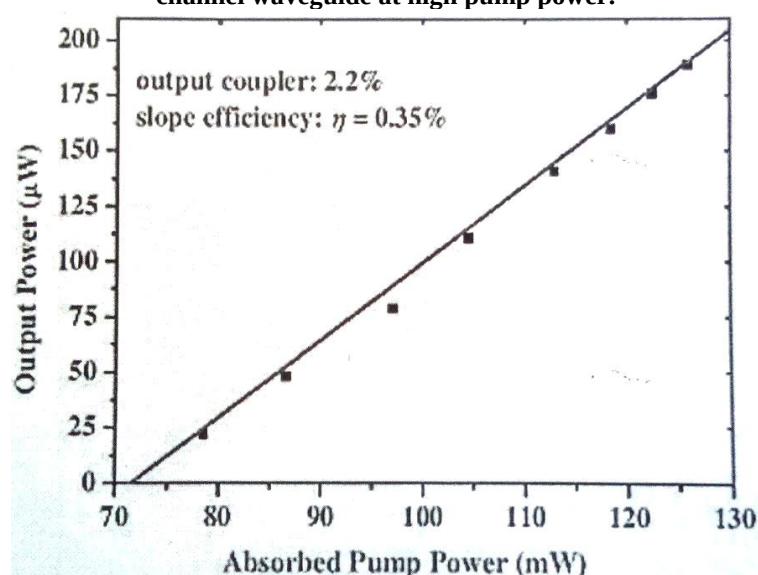


Fig. 7 Laser output power in a 7.5-mm-long Nd³⁺-complex-doped 6-FDA/UVR channel waveguide as function of absorbed pump power for three level transition at 878nm.

An upper limit for the propagation loss in the waveguide at 1060nm was obtained using the Findlay-Clay method. The latter is applicable to four-level laser system showing negligible depopulation of the ground state, for which the absorbed power threshold P_{th} is dependent on the outcoupling level is given by:

$$P_{th} = K \cdot [(2 \cdot a \cdot I - \ln((R_1 R_2)))]$$

References

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