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Laser Physics of Nd³⁺-Doped Phosphate Glasses

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Laser Physics of Nd³⁺-doped Phosphate Glasses

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New data and analysis regarding the four fundamental processes that impact the laser performance of Nd-doped glasses will be discussed, including concentration quenching, Auger upconversion, the ⁴I_{11/2} lower level lifetime, and hole-burning.

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Nd-doped glasses have emerged as one of a handful of laser materials that are routinely employed in scientific and commercial applications. As a consequence, it is of interest to have access to a comprehensive evaluation of the crucial laser parameters. In this paper we present new information on the mechanisms that impact the pumping efficiency (concentration quenching and Auger upconversion) and the extraction process (⁴I_{11/2} terminal level lifetime and hole-burning). Most of our results concern phosphate glasses, although fluorides and silicates are addressed as well. The relevant processes are illustrated in Fig. 1.

Concentration quenching is seen to involve the ⁴F_{3/2} → ⁴I_{15/2} and ⁴I_{9/2} → ⁴I_{15/2} transitions on two nearby Nd³⁺ ions. Since this mechanism is sensitively dependent on the energy mismatch between the two transitions, a broadening of the spectral features in a Nd:glass may be expected to reduce this mismatch and enhance the quenching rate. This effect is illustrated in Fig. 2, where we plot the Nd³⁺ quenching constant characterizing numerous different phosphate glass compositions

against the 1.05 μm emission bandwidth. (We confirmed in a separate analysis that the broadening of all the absorption and emission features is strongly correlated.)

A second process that can reduce the pumping efficiency is Auger upconversion, where two excited Nd^{3+} ions interact to yield one ion in a higher-lying electronic state while the other neodymium is forced back to the ground state. The magnitude of this effect can be evaluated by measuring the emission lifetime as a function of excitation density. From these experiments we deduced that the Auger upconversion rate becomes equal to the emission rate at Nd excited state densities of about $0.7 \times 10^{20} \text{ cm}^{-3}$.

Next we considered the impact of the $^4\text{I}_{11/2}$ lower level lifetime. In order to obtain information regarding this relaxation rate, we utilized a novel pump/probe scheme where the $^4\text{I}_{9/2} \rightarrow ^4\text{I}_{13/2}$ transition is initially excited, followed by a probe pulse at 1.06 μm that induces the $^4\text{F}_{3/2}$ emission. An example of this experimental measurement appears in Fig. 3, for which the LG-750 phosphate glass lifetime is deduced to be 250–450 psec. If the extraction pulsewidth were ≤ 200 psec, the extraction efficiency could be reduced by as much as 25% due to a bottlenecking effect in the lower laser level.

Lastly, Nd-doped glasses can potentially incur a reduced extraction efficiency as a result of hole-burning at the laser wavelength. To examine this effect we compared the extraction efficiencies of two Nd-doped phosphate glasses: one with a narrow emission bandwidth of 25 nm and the other with a maximally broadened width of 31 nm. Although the inhomogeneity of the two glasses is expected to be significantly different, the extraction efficiency has been determined to be reduced by only $27\% \pm 10\%$ for the more inhomogeneous glass.

In summary we have assessed the impact of four processes that could be detrimental to the laser performance of Nd-doped phosphate glasses: concentration quenching, Auger upconversion, the lower level lifetime, and hole-burning.

Figure Captions

Fig. 1: Illustration of the mechanisms to be addressed in this paper.

Fig. 2: Plot of the quenching constant, C_q , against the bandwidth of the 1.05 μm emission feature [C_q is defined with $\tau_{\text{em}} = \tau_0 (1 - N_{\text{Nd}}/C_q)$, where τ_{em} is the emission lifetime and N_{Nd} is the Nd concentration].

Fig. 3: Example of the $^4\text{I}_{11/2}$ lower level lifetime data.

Concentration

Quenching

Anger Upconversion

⁴I_{11/2} Relaxation

Nd³⁺ Energy Levels

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