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LASERS AND THEIR APPLICATION

Special Features of Amplification of UV at the Electronic Transition of the Cu^+ Ion in an NaCl Crystal

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Abstract—The spectral and luminescent properties of the Cu^+ ion in an NaCl crystal are studied and the amplification is obtained at the $3d^{10} \longrightarrow 3d^9 4P$ transition, which is under excitation by the fourth harmonic of an Nd:YAG laser (λ = 266 nm). It is found that the short–lived absorption is related to an uncontrollable nickel impurity in the crystal. © *2000 MAIK "Nauka/Interperiodica".*

INTRODUCTION

The possibility of realizing solid-state UV lasers has recently stimulated growing interest in intense luminescence of Cu^+ ions in cubic crystals [1, 2]. In this paper, we study spectral and luminescent properties and special features of amplification of UV radiation at the $3d^{10} \longrightarrow 3d^9 4P$ transition of the Cu^+ ion in an NaCl crystal.

EXPERIMENTAL

We studied samples grown by the Stockbarger technique with copper content of about 0.1 mol %. The short–lived absorption was measured with an S1-93 oscilloscope by the change in the crystal transmission in the presence and absence of laser pumping. Absorption spectra of the samples were recorded with an MPS-50L spectrometer. The absorption spectrum in the near UV region represents a band with λ_m = 250 nm, which is assigned to the $3d^{10} \longrightarrow 3d^9 4P$ electronic transition in the Cu^+ ion [3]. This absorption band is convenient for excitation of copper ions by the fourth harmonic of an Nd:YAG laser.

The absorption coefficient at the pumping wavelength λ = 266 nm was 8 cm^{-1}, and the loss at the emission wavelength λ = 360 nm of Cu^+ ions was 0.016 cm^{-1}. Transverse excitation was used. The faces of the crystal of size $1.0 \times 0.5 \times 0.2$ cm were carefully polished. The $3d^{10} \longrightarrow 3d^9 4P$ electronic transition of the ion Cu^+ was excited by the fourth harmonic of pulsed Nd:YAG laser (ν = 12.5 Hz, τ = 10 ns, P = 0.03 W). Then, the probe beam from a halogen lamp (λ = 360 nm) was passed through the crystal at 300 K. The amplification effect was detected by the change in the transmission of the Cu : NaCl crystal in the presence or absence of laser pumping. The measurement of the gain was complicated by the poor energy stability of the Nd:YAG laser, which was about 10–20%. The gain found from exprimments was α = 0.68 cm^{-1}.

RESULTS AND DISCUSSION

The possibility of using Cu : NaCl crystals for lasing can be evaluated from the Einstein coefficients for the stimulated emission. Experimentally, the spectral profile of the absorption coefficient $k(\nu)$ was determined. The lifetime of the excited state is τ = 1 μs [4]. The quantities B_{21}^{ν} and B_{12}^{ν} were calculated from the expressions

$$B_{21}^{\nu} = (c^3/4h\nu^3)A_{21}^{\nu}, \quad A_{21}^{\nu} = g_1(\nu)/\tau,$$

$$B_{12}^{\nu} = c^3 k(\nu) g_a(\nu_0)/4h\nu\nu_0^2 k(\nu_0)\tau,$$

where ν_0 is the frequency of the purely electronic transition; $g_1(\nu)$ and $g_a(\nu)$ are the luminescence and absorption band shapes, respectively. The Einstein coefficients at the band centers were found to be $B_{21}^{\nu} = 0.88 \times 10^4$ m^3 J^{-1} s^{-1} and $B_{12}^{\nu} = 1.02 \times 10^5$ m^3 J^{-1} s^{-1}. In

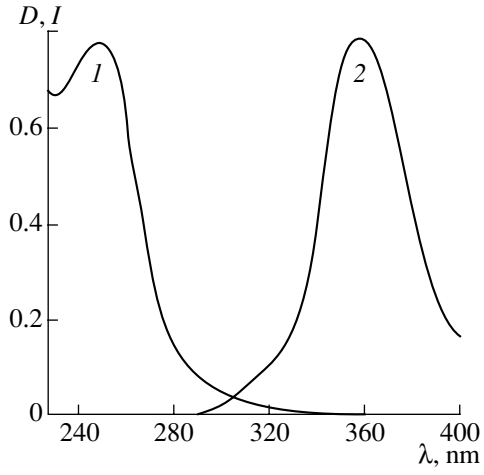

Fig. 1. (*1*) Absorption and (*2*) luminescence spectra of the Cu^+ ion (0.1 mol %) in an NaCl crystal.

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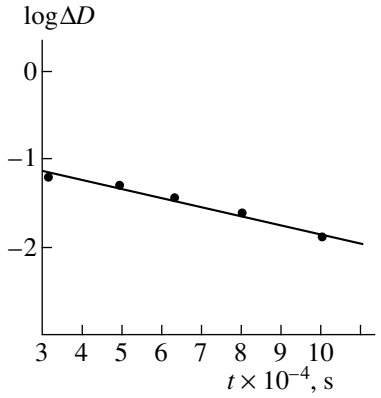

Fig. 2. Relaxation kinetics of the induced absorption at λ = 380 nm under excitation by the fourth harmonic of an Nd : YAG laser.

quantum electronics, it is common to use the stimulated–emission cross section $\sigma_{21} = h\nu B_{21}^{\nu}/c^3\sqrt{2\pi}$ instead of the Einstein coefficient B_{21}^{ν}. Its value is $\sigma_{21} = 8.5 \times 10^{-20}$ cm^2. By using the experimental gain $\alpha = 0.68$ cm^{-1}, we estimated the concentration of the excited Cu^+ centers to be $n = \alpha/\sigma_{21} = 8 \times 10^{18}$ cm^{-3}. Comparison of the properties of the Cu^+ : NaCl crystal with those of a Ce^{3+} : BaY_2F_8 crystal in which the amplification of coherent radiation at λ = 345 nm was reported [5] shows that the effective stimulated–emission cross section of the former is an order of magnitude smaller than that of the latter. However, the gain achieved in the Cu^+ : NaCl crystal is almost two times larger and the concentration of impurity Cu^+ ions in this crystal is high.

We detected the time dependence of the probe-beam intensity passed through the crystal upon pumping switched on at the moment $t = 0$. The amplification in the medium reduced to zero in 90 s, i.e., after absorption of 10^3 pulses of the Nd:YAG laser. Because analysis of the absorption spectra before and after action of coherent radiation showed no evident losses, we measured the short–lived absorption. Figure 2 shows the relaxation kinetics of the induced absorption at λ = 380 nm upon excitation by the fourth harmonic of the Nd : YAG laser. We observed a component of the bleaching relaxation with τ = 0.37 + 0.03 ms. It is known that the luminescence lifetime of a Ni : NaCl crystal is τ = 0.4 ms upon excitation into the 360-nm band. Therefore, the short–lived absorption can be related to the Ni^+ ions, which are present as uncontrollable impurities in the crystal. Indeed, the measurement of the luminescence spectrum in the red–orange region confirmed this assumption.

CONCLUSION

Thus, the amplification observed at the electronic transition in the Cu^+ ions suggests that they can be used for lasing in the 340–380 nm region. The induced absorption from the excited state of the Ni^+ ions should be taken into account when growing Cu : NaCl crystals.

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