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PHYSICS

1967

SovietRxiv

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UDC 621.378.325

PHYSICS

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QUANTUM YIELD OF LUMINESCENCE AND ENERGY YIELD OF STIMULATED EMISSION IN NEODYMIUM GLASS

(Presented by Academician A. A. Lebedev, 11 VI 1966)

The quantum yield of luminescence of neodymium glass has been measured in a number of works (^{1,2}). However, as is known (see, for example, (^{3})), the value of the quantum yield is not directly related to the energy yield (efficiency) of an optical quantum generator, which is determined by the relations (for a pump-pulse duration shorter than the lifetime τ of the upper working level)

$$\frac{W}{W} \cong \omega \frac{\ln(1/R)}{\ln(1/R)+\sigma}\left(1-\frac{1}{n^2}\right)\sum_i \frac{\lambda}{\lambda}\eta_1^i\theta^i F^i$$

single-pulse regime;

$$\frac{W}{W} = \omega \frac{\ln(1/R)}{\ln(1/R)+\sigma}\left(1-\frac{1}{n}\right)\sum_i \frac{\lambda}{\lambda}\eta_1^i\theta^i F^i$$

quasi-stationary pulsed regime.

Here W and W are the generation energy and the electrical energy supplied to the pump source, respectively; ω is the effectiveness of the optical system for concentrating the pump radiation on the active rod; R and σ are the mirror reflection coefficient and the resonator losses; n is the excess above threshold in pump energy; λ and λ are the wavelengths of generation and of the i-th excitation band; η_1^i is the quantum yield of excitation of the upper working level when pumping in the i-th band; F^i and θ^i are the energy yield of the radiation of the pump source and the fraction of the light flux incident on the rod that is absorbed in it for the i-th band.

Fig. 1. P—total probability (excluding the probabilities d) of transitions from a level; d—probabilities of radiationless transitions between levels corresponding to the excitation bands; A (sec^{-1})—probability of spontaneous emission on the working transition 3—2.

A simplified scheme of the levels of the Nd^{3+} ion in glass is shown in Fig. 1. It is not difficult to show that the quantities η_1^i are determined by the expression $\eta_1^i = \eta^i/\eta^3$, where $\eta_1^3 = 1$; $\eta_1^4 = d_{43}/(d_{43} + P_4)$, etc., where η^i is the quantum yield of luminescence upon excitation in the i-th band.

In the present work, measurements were carried out of the quantum yield of luminescence upon excitation in the four most intense absorption bands (see Fig. 1) of the Nd^{3+} ion in glass of complex composition (^{4}), at an activator concentration of $2 \div 6\%$, and the value of η_1 was found from the quantum-yield values. Excitation of luminescence was carried out by monochromatized radiation from an iodine incandescent lamp; measurement of the power of excitation and luminescence was carried out with a calorimeter and a calibrated photomultiplier and photoresistor. The results of measuring the total (η_0) quantum yield of luminescence and that in the working band with $\lambda = 1.06\,\mu$m (η), as well as the values of η_1, are given in Table 1.

As can be seen from the data presented, the quantum-yield values depend strongly on the excitation wavelength; correspondingly, the value of η_1 for short-wavelength excitation bands is considerably less than 1.

Let us note that the situation is analogous in crystals of $CaWO_4 : Nd^{3+}$ and $CaF_2 : Dy^{2+}$; in particular, for the principal excitation bands of $CaF_2 : Dy^{2+}$ crystals the quantum yield of luminescence η_0 is $0.03 \div 0.12$, and $\eta_1 \simeq 0.2$.

Table 1

Excitation band λ_H, μm	2% Nd^{3+}, $\tau = 670\,\mu$sec			6% Nd^{3+}, $\tau = 440\,\mu$sec		
	η_0	η	η_1	η_0	η	η_1
0.88	0.6	0.3	1	0.42	0.21	1
0.81	0.46	0.23	0.77	0.26	0.13	0.62
0.74	0.2	0.1	0.33	0.13	0.07	0.34
0.58	0.2	0.1	0.33	0.11	0.05	0.25

The experimental and calculated dependence of the threshold and efficiency of a glass generator on the activator concentration is shown in Fig. 2 (the values of the losses in the resonator necessary for the calculation were determined by the method described in (^{3})).

Of greatest interest is the question of the limiting efficiency of an optical quantum generator, determined by the conditions $\omega = 1$, $\theta^i = 1$, $n \gg 1$, $\ln(1/R) \gg \sigma$. In this case

$$\left(\frac{W}{W_H}\right)_{\text{lim}} = \sum_i \frac{\lambda_H^i}{\lambda_g} \eta_1^i F^i.$$

Fig. 2. 1—threshold pump energy; 2—generation energy. Rod diameter 0.5 cm, length 8.0 cm

Using data on the energy yield of pulsed xenon lamps ([5],[6]), we find that the limiting efficiency of a generator based on neodymium glass is $3.0 \div 4.0\%$ for small xenon lamps and $5 \div 7\%$ for large lamps ($D \gtrsim 1.5$ cm; $L \gtrsim 15$ cm). It may be noted that the limiting efficiency values found agree well with experimental data (see, for example, ([7])).

If one uses the data of the table, as well as the values P_3 and P_4 measured in ([1]), then it is possible to estimate the probabilities of certain transitions: $P_3 = 2.3 \cdot 10^3$ sec^{-1}; $P_4 = 10^4$ sec^{-1}; $d_{43} = 1.6 \cdot 10^4$ sec^{-1}; $A = 5 \cdot 10^2$ sec^{-1}. As can be seen, the quantity d_{43}, which determines the rate of relaxation between levels 3 and 4, is only slightly greater than P_3. It can be shown that saturation of the generation intensity with increasing pumping, due to the low rate of relaxation between levels 3 and 4, is reached at

$$n_{\mathrm{M}} > \frac{d_{43}}{2P_3}\frac{N_0}{N_{\mathrm{p}}},$$

where n_{M} is the excess over threshold in pump power, N_0 and $N_{\mathrm{p}} = N_3 - N_2$ are the activator concentration and the threshold inversion.

In neodymium glass $N_0/N_{\mathrm{p}} \simeq 10^2$. In this case saturation is reached at $n_{\mathrm{M}} > 350$. Such excesses over threshold are difficult to realize with existing pump sources, and, consequently, the relaxation time between the excited levels is not a limiting factor for increasing the generation power.

Thus, the following has been established in this work:

1. There is a strong dependence of the quantum yield of luminescence of neodymium glass on the wavelength of the exciting radiation. The quantum yield for excitation of the upper working level for the short-wavelength pump bands is 0.25–0.33, which substantially reduces the contribution of these bands to the energy yield of stimulated emission.
2. The limiting efficiency of a quantum generator on neodymium glass is 3-7% when pulsed xenon lamps are used as the pump source.
3. The linear dependence of the generation power on the pump intensity should be observed for threshold exceedances not greater than ~ 350.

Received3 VI 1966

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