OPTICAL QUANTUM GENERATOR WITH A COMBINED ACTIVE MEDIUM

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OPTICAL QUANTUM GENERATOR WITH A COMBINED ACTIVE MEDIUM

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The results of studies of the processes of autoresonant energy transfer in mixed-type crystals, characterized by a multiplicity of optical centers (o.c.) ([1]), have led to the creation of an optical quantum generator (OQG) with a combined active medium (c.a.m.). Below we consider some characteristics of OQGs with c.a.m. that use combinations of simple crystals ($Y_3Al_5O_{12} - Nd^{3+}$, $CaWO_4 - Nd^{3+}$) and mixed-type crystals ($CaF_2 - YF_3 - Nd^{3+}$) and glass (LGS-6).

OQGs with c.a.m. differ from ordinary quantum generators in that they possess controllable selective gain (this is determined by the spectroscopic properties of simple crystals) over a broad frequency characteristic (determined by the properties of an active medium with a multiplicity of o.c.) while the parameters of the optical resonator remain unchanged. OQGs with c.a.m. have low threshold excitation energies (E_{p}) and narrow generation lines—qualities they have inherited from simple crystals—as well as a sufficiently high efficiency, imparted to them by active media with a multiplicity of o.c.

Figure 1A shows the scheme of an OQG with c.a.m., and Fig. 1B shows diagrams of conditionally distinguished energy levels of the crystal $Y_3Al_5O_{12} - Nd^{3+}$ and of neodymium glass of grade LGS-6. The first substance differs by one type of generating o.c. ([2]), the second by their multiplicity ([3]). Whereas for garnet with Nd^{3+} ions the positions of the Stark components of the terms $^4F_{3/2}$ and $^4I_{11/2}$ ([3]), between which induced transitions can occur, are known, for glass the construction of such a level scheme for each o.c. is practically impossible. The luminescence spectrum of the crystal $Y_3Al_5O_{12} - Nd^{3+}$, corresponding to the transition $^4F_{3/2} \rightarrow {}^4I_{11/2}$, has a distinct Stark structure of the levels, while for glass it is an inhomogeneously broadened wide line, representing a superposition of the spectra of different centers ([3]). These luminescence spectra are shown in Fig. 1B. The generation spectrum of an ordinary OQG based on LGS-6 at 300° K is a broad band with $\lambda_{\mathrm{center}} = 1.06\,\mu$ (indicated on the luminescence spectrum), whereas that based on garnet is characterized by a narrow line with $\lambda = 10\,641$ Å. In glasses, as also in mixed-type crystals, in the excited state autoresonant energy transfer occurs between different o.c. ([3]).

Fig. 1

Figure 1: Fig. 1

The condition for the onset of generation in an OQG with c.a.m. at the frequency $h\nu_i$ can be written

$$\exp\{-2[(\alpha_{\mathrm{p}}^1-\alpha_{\mathrm{g}}^1)l_1+(\alpha_{\mathrm{p}}^2-\alpha_{\mathrm{g}}^2)l_2]_{h\nu_i}\}R_1R_2=1;$$

here α_{p}^1 and α_{p}^2 are the absorption coefficients of the simple and mixed-type active media per unit length; α_{g}^1 and α_{g}^2 are the gain coefficients; l_1 and l_2 are the crystal lengths, and R_1 and R_2 are the reflection coefficients of the mirrors of the optical resonator. If α_{p}^1 and α_{p}^2 are the same over a broad frequency interval, then upon excitation of the c.a.m. generation will arise at the same

frequency at which the effective gain coefficient will be greatest.

In our case, when exciting an OQG with a combined active medium based on $Y_3Al_5O_{12}$—Nd^{3+}+ LGS-6, a field of induced radiation (i.r.) first arises at the frequency $h\nu_1$ (10 641 Å), i.e., at the generation frequency of an ordinary OQG based on only one garnet ([2]) (Fig. 2a). In this case the value of E_{p} is somewhat smaller than the threshold of this line in an OQG with a combined active medium with "switched-on" gain α_y^2 (when only one garnet is excited).

Fig. 1. **A** –block diagram of an OQG with a combined active medium (**a** –spherical mirrors, **b** –pump lamps, **c** –simple-type crystals, **g** –mixed-type crystals, **d** –illuminating chambers). **B** –luminescence spectra at 300° K of $Y_3Al_5O_{12}$—Nd^{3+} and LGS-6 glass (dashed line) and schematic diagrams of the energy levels of the Nd^{3+} ion in garnet and glass. The positions of the levels are indicated in cm^{-1}. Induced transitions are indicated by bold arrows; radiationless transitions, by wavy lines.

With a further increase of E_{exc}, a second narrow line appears in the generation spectrum of the OQG with a combined active medium based on $Y_3Al_5O_{12}$—Nd^{3+}+ LGS-6 at the frequency $h\nu_2$ (10 614 Å), which in an ordinary OQG based on garnet at 300° K is not excited at all. A further increase of E_{exc} up to the value $E_{\mathrm{p\,LGS-6}}$ in an OQG with a combined active medium at $\alpha_y^1=0$ does not lead to the onset of generation at the frequency $h\nu_{\mathrm{LGS-6}}$ (see Fig. 2c). And only at considerable E_{exc}, exceeding $E_{\mathrm{p\,LGS-6}}$ severalfold (this depends on the total α_y at the frequency $h\nu_{\mathrm{LGS-6}}$), does the i.r. of LGS-6 glass with its characteristic broad line arise simultaneously with two lines of $Y_3Al_5O_{12}$—Nd^{3+} (see Fig. 2e).

Measurements of the generation energy of an OQG with a combined active medium based on these media at such E_{exc}, when radiation at the line $h\nu_{\mathrm{LGS-6}}$ has not yet arisen, showed that amplification of the i.r. field occurs in comparison with the case of an ordinary OQG based only on $Y_3Al_5O_{12}$—Nd^{3+} at the

Figure 2. Generation spectra

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Fig. 3. Luminescence spectra at 300° K of $Y_3Al_5O_{12}$–Nd^{3+} and $CaWO_4$–Nd^{3+} crystals (dotted line) and conditional schemes of energy levels. The designations are the same as in Fig. 1

Figure 3: Fig. 3. Luminescence spectra at 300° K of $Y_3Al_5O_{12}$–Nd^{3+} and $CaWO_4$–Nd^{3+} crystals (dotted line) and conditional schemes of energy levels. The designations are the same as in Fig. 1

same E_{exc}. This is apparently explained by the fact that the i.r. field, first at the frequency $h\nu_1$, and then at $h\nu_2$, acts on certain optical centers of the excited quantum system LGS-6 and stimulates their emission. Owing to autoresonant transfer of energy between the optical centers of the glass, the energy stored during excitation is transferred

Fig. 2. Generation spectra: **a**–$Y_3Al_5O_{12}$—Nd^{3+} crystal, $E_{\text{exc}} = 150$ J; **b** –LGS-6 glass, $E_{\text{exc}} = 300$ J; **c**–$Y_3Al_5O_{12}$—Nd^{3+}+ LGS-6, $E_{\text{exc}} = 500$ J; **d** –$Y_3Al_5O_{12}$—Nd^{3+}+ LGS-6, $E_{\text{exc}} = 1200$ J; **e**–CaF_2—YF_3—Nd^{3+} crystal, $E_{\text{exc}} = 100$ J; **f**–$Y_3Al_5O_{12}$—Nd^{3+} + CaF_2—YF_3—Nd^{3+}, $E_{\text{exc}} = 100$ J; **g**–$CaWO_4$—Nd^{3+} crystal, $E_{\text{exc}} = 120$ J; **h**–$CaWO_4$—Nd^{3+} + $Y_3Al_5O_{12}$—Nd^{3+}, $E_{\text{exc}} = 300$ J. All spectra were obtained from a single generation pulse. The arrow indicates the reference line.

with the associates that had already "joined in" the generation process (here the main role should be played by those centers which, during generation, have time to transfer the stored energy to the emitting a.c.). Similar results were also obtained by us with an optical quantum generator with a combined active medium based on yttrium fluoride and garnet activated by Nd^{3+} ions.

Unfortunately, within the scope of this note it is impossible to discuss all the features of optical quantum generators with a combined active medium; they will be described in more detail in a special paper. Here we shall briefly touch upon only certain points. From Fig. 2 it is seen that the spectra of optical quantum generators with a combined active medium based on garnet and LGS-6 were enriched by a new line with $\lambda = 10\,614$ Å. The analysis carried out made it possible to

Fig. 3. Luminescence spectra at 300° K of $Y_3Al_5O_{12}$–Nd^{3+} and $CaWO_4$–Nd^{3+} crystals (dotted line) and schematic energy-level diagrams. The designations are the same as in Fig. 1.

identify it as a transition from the level 11 423 cm^{-1} to the lowest component of the term $^4I_{11/2}$. It is seen that in optical quantum generators with a combined active medium conditions arise that lead to the appearance of new induced transitions which do not occur in ordinary optical quantum generators (new generation lines were also recorded in the study of other substances). The excitation of new induced transitions makes it possible to carry out more complete studies of the kinetics of the processes occurring in the excited state in crystals of this simple type.

If two crystals with nonoverlapping frequency characteristics are placed in an optical quantum generator with a combined active medium, for example, $Y_3Al_5O_{12}$ –Nd^{3+} and $CaWO_4$–Nd^{3+}, then no noticeable interactions between them are observed, and they generate independently. This case is illustrated by Figs. 2 and 3.

In conclusion, we note that we have investigated optical quantum generators with combined active media based on more than 20 pairs and triples of substances activated by Nd^{3+} ions. The following simple crystals were used: $Y_3Al_5O_{12}$, CaF_2, SrF_2, LaF_3, CeF_3, $CaWO_4$, and YVO_4. As media characterized by a diversity

i.e., the following substances were used: α-$NaCaYF_6$ and α-$NaCaCeF_6$, CaF_2–YF_3 and $2CaF_2 \cdot 5YF_3$, CaF_2–CeF_3 and CaF_2–SrF_2–BaF_2–YF_2–LaF_3, BaF_2 –LaF_3 and SrF_2–LaF_3, LaF_3–SrF_2 and $LaNa(MoO_4)_2$, 9NaF$ 5YF_3, and glasses of the KGS and LGS grades. The results of preliminary studies showed that optical quantum generators with composite active media based on them possess, on the one hand, the spectral composition of generation and E_{th} characteristic of simple crystals (narrow lines and a low threshold), and, on the other hand, a sufficiently high efficiency characteristic of media with a diversity of active centers. If these properties are compared with the parameters of ordinary optical quantum generators, then, in comparison with generators based on substances of the first type, we have an increase in efficiency, and, in comparison with optical quantum generators based on media of the second type, an increase in spectral brightness and a decrease in E_{th}.

Active media for optical quantum generators with composite active media may be not only crystals and glasses, but also combinations of crystals with liquids and gases, of gases and liquids, as well as combinations of a larger number of different types of media.

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Note: Figure translations are in progress. See original paper for figures.