not be obtained there, since no account was taken in [8] of the two-phonon state, which must be present in the diagrams of the figure.

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CONCERNING THE FEASIBILITY OF A γ LASER BASED ON RADIOACTIVE CRYSTALS

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The feasibility of a γ laser based on Mossbauer radiation without transfer of energy to the nuclei in crystals has been discussed in the literature many times [1 - 7]. This discussion has revealed serious difficulties that stand in the path of realization of a γ laser, and consequently, in so far as the author knows, no serious attempts at its realization have been made so far.

The present article is an extension of [1 - 7] and shows that in principle it is possible to produce a γ laser based on crystals consisting of long-lived nuclear isomers.

When a resonant γ quantum is incident on an excited nucleus, the effective cross section σ of the stimulated emission by the nucleus of a new γ quantum coherent with the incident one is described by the Breit-Wigner formula [1 - 3]

$$\sigma = \frac{\lambda^2}{2\pi} \frac{1 + 2I_2}{1 + 2I_1} f \frac{1}{\Gamma\tau} \frac{1}{1 + \alpha}, \qquad (1)$$

where λ is the radiation wavelength, I_2 and I_1 are the spins of the upper and lower states of the nucleus, f is the probability of emitting a γ quantum without transferring energy to the nucleus, Γ is the width of the emission length, τ is the lifetime of the excited state, and α is the internal-conversion coefficient.

The gain β of the radiation is equal to

$$\beta = \sigma N, \qquad (2)$$

where N is the difference between the number of excited nuclei and the nuclei in the lower working level.

Let us estimate the factors that determine the gain.

When the crystal enrichment with excited nuclei greatly exceeds 50%, the order of magnitude of N is 10^{22} cm^{-3}. With recoilless transitions in mind, λ should be chosen to be on the order of $(1 - 3) \times 10^{-9}$ cm, and f on the order of unity. Assuming also that the transition is not strongly converted, we can assume as estimates

$$\beta = (10^3 - 10^4)\frac{1}{\Gamma\tau} . \tag{3}$$

In order for the stimulated emission of the γ quantum to take place, it is necessary that the gain β exceed the absorption coefficient δ, the order of magnitude of which is 1 cm^{-1}. Thus, to obtain stimulated γ radiation it is necessary that the emission line width Γ exceed the natural width $1/\tau$ by not more than 3 - 4 orders of magnitude.

To prepare a crystal satisfying the conditions formulated below, it is apparently necessary to have a time on the order of several days, which imposes the requirement $\tau \gtrsim 10^6$ sec on the lifetimes of the excited states.

In Mossbauer spectroscopy, in which short-lived excited states with $\tau < 10^{-6}$ sec are used, the parameter $\Gamma\tau$ is of the order of unity. For long-lived states, the line broadens and ceases to depend on the lifetime. There are practically no experimental studies on the broadening of spectral lines of long-lived states. The only exception is [8], in which a value $\Gamma\tau \simeq 10^6$ was measured indirectly for the 93-keV transition of Ag^{107} with lifetime 44 sec.

It should be noted that measurements of relatively small broadenings of long-lived transitions cannot be carried out by usual Mossbauer-spectroscopy methods. It is therefore necessary to develop new methods, one of which has been proposed in [9]. It is based on the difference between the emission probabilities, due to the gravitational frequency shifts in vertical and horizontal directions, of nuclei located in the same crystal.

Just as in optics, it is necessary to distinguish between homogeneous and inhomogeneous line broadening. The different quasi-static random conditions obtaining in the different sections of the crystal (temperature, mechanical stresses, gravitational potential, etc.) lead to an inhomogeneous line broadening. In the experiments of [8], the line broadening was apparently inhomogeneous. Such a broadening can be eliminated, at least in principle. Therefore the first conditions to be satisfied by a crystal for a γ laser are the absence (or minimum) of defects, homogeneity of the temperature, etc. Rapid fluctuations of the electronic states of the atoms, the vibrations of the atoms in the crystal lattice, etc. are causes of homogeneous broadening. Theoretical investigations of homogeneous broadenings [10 - 14] show that in a defect-free crystal at low temperatures the broadening can be reduced to $\Gamma\tau = 10 - 10^2$ or even less.

Thus, theoretical estimates show that in principle it is possible to produce γ lasers by using long-lived isomers. To find the nuclear transitions needed for this purpose it is necessary to perform systematic experimental investigations of ultranarrow γ-radiation lines by methods other than the Mossbauer effect.

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