On creating a gamma laser

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The problem is discussed on producing population inversion in a system of long-lived isomer nuclei by growing whiskers from a mixture enriched with them. Such whiskers are planned to serve an active medium for a gamma laser. This method of producing population inversion in an active medium opens a new way of obtaining induced gamma emission. Some isomer nuclei that may serve as a basis for designing the gamma laser are proposed.

1. Method of producing the population inversion in the isomer nuclear gamma lasers

Creation of a *gamma laser* (*gaser*) employing a system of excited atomic nuclei as an active medium faces a lot of complicated problems, which are still to be solved. The possibility of using transitions of atomic nuclei for designing a laser emitting gamma rays was first shown by Soviet physicist L.A. Rivlin as early as in 1961 even before the advent of an optical laser.[1]

One of the problems in designing gamma lasers is creation of the population inversion in a system of atomic nuclei, which could serve an active medium for a gamma laser.

As known, atomic nuclei emitting gamma quanta experience recoil, which decreases the energy of the emitted gamma quantum as compared with the absorbing one. As a result, the emission line shifts. The recoil grows with the increasing quantum energy. In the gamma spectral region the line shift can be beyond the absorption line width. Therefore, emission from nuclei experiencing recoil makes it impossible the creation of a gamma laser operating on such nuclei.

This problem can be solved with the use of the Mössbauer effect, under which atomic nuclei in a crystal emit, as known, without a recoil,[2] so that no line shift occurs. Therefore, it was proposed to use this effect to eliminate the line shift in a gamma laser.

We proposed *whiskers*, in which it was assumed to implement the *Mössbauer effect*, to be used as an active medium for gamma lasers.[3]

Whiskers have some important advantages, which allow one to use them as matrices for active nuclei. They practically have neither point defects nor dislocations. This is an essential circumstance, because the wavelength of a gamma quantum under the Mössbauer effect is highly sensitive to small distortions introduced by defects in crystals. The defects can lead to broadening of the line profile, what decreases the probability of emission without a recoil. It was shown[4] that for the stimulated emission from the isomers to occur, the concentration of dislocations should not exceed $3\cdot10^{-5}$ cm^{-3}, and that of point defects should be below 10^{14} cm^{-3}.

It is especially important that whiskers can be grown to the size needed for a short time: from several hours to several tens of hours.[5,6] Because of the fast growth, the inversion of population can be created in the whiskers if those are grown from a mixture of atoms already having the population inversion. That means that the concentration of atoms with the excited gamma-radioactive nuclei exceeds the concentration of atoms whose nuclei are in the lower energy state. The higher is the inversion in the mixture and the shorter is the time of crystal growth, the easier the population inversion can be obtained in it.[7]

Some specific gamma-radioactive isomers were proposed for use as a nuclear medium suitable for gamma lasers[8,9]; see also Ref. 10.

The mixture from which the working crystal is grown can be obtained using a laser-based technology of enrichment. In Ref. 11 it was proposed to use optical lasers to enrich the mixture of radioactive nuclei for gamma lasers. Then this method of creating the population inversion was considered in Refs. 12–15. A more detailed consideration of the laser separation of nuclides can be found in Ref. 16.

The whisker grown in such a way can serve as an active medium with the population inversion existing during the time when the concentration of active isomer exceeds some critical value. This time depends on the half-life of the nuclei intended for use in the gamma laser and on their initial concentration after growing whiskers.

In spite of obvious disadvantages, the above-described method of obtaining the population inversion for gamma lasers is the only one which can be realized in practice nowadays.

We shall call this method the *inherent inversion* method.

2. Peculiarities of the gamma lasers with inherent inversion

Unfortunately, it is impossible now to design cavities that can operate in the gamma region. So, the whisker active medium of a gamma laser with the inherent inversion could be used only in the single-pass mode. This makes the operation of gamma lasers expensive and inconvenient.

Another one peculiarity of such lasers is that no intermediate level is used, or it is absent at all, through which “usualB lasers are pumped. As a result, the three-level scheme in gamma lasers with inherent inversion degenerates into the two-level one, and the four-level scheme is reduced to the three-level one.

Such a laser can be called a *laser without an intermediate level.*[6]

Specific arrangements for the gamma laser which can be implemented to practice can make a subject of a separate consideration.

3. Isomers suitable for the gamma lasers

The following conditions should necessarily be fulfilled in creating the population inversion in the active medium of a gamma laser to obtain stimulated gamma emission.

1. High rate of whisker growth from the atoms, whose nuclei are the working isomers. This condition is usually easily fulfilled.
2. The half-life of the isomers ought to exceed far the time of whisker growth. This condition can be fulfilled only for some specific isomers.
3. The conditions for occurrence of the Mössbauer effect in the whiskers obtained in such a way should be technically realizable.
4. It is desirable to have a sufficiently cheap source of natural or (and) artificial isomers suitable for gamma lasers. Different nuclear reactions, for example, with the participation of neutrons and other particles can serve as such sources.

Let us consider specific isomers which can be used in gamma lasers.

The gamma radioactive isomers are needed with the half-life from several hours and longer. Other channels of radioactivity are undesirable, but if this is the case, the total probability of their occurrence should be at least an order of magnitude lower. Additional emission lines of an isomer are also undesirable. If there are some, their total probability also should be at least an order of magnitude lower than the probability of emission at the working line of a gamma laser.

Table 1. Isomers suitable for gamma lasers

Isomer	Half-life	Radiation energy, MeV
$_{27}$Co^{58m}	9.15 h	0.0249
$_{35}$Br^{80m}	4,42 h	0.086
$_{41}$Nb^{92m}	13.6 year	0.030
$_{52}$Te^{123m}	119.7 day	0.159
$_{65}$Tb^{156m}	5.0 h	0.088
$_{56}$Ba^{135m}	52.7 h	0.268
$_{76}$Os^{191m}	13.10 h	0.074
$_{78}$Pt^{193m}	4.33 day	0.150

Table 1 presents some isomers which have only one emission line with no additional channels of the radioactive decay. These isomers can be considered as candidates for an actual gamma laser.[8–10]

Let us also consider some isomers having some disadvantages in comparison with those presented in Table 1. They have only one emission line in the gamma region, but the radioactive decay in them is possible through more than one channel.

The presence of additional channels complicates the problem of creating gamma lasers, but the atoms with these isomers may have better properties for growing whiskers in them. It may also be the case that the Mössbauer effect is easier realized in them. All this is of principal importance in creating gamma lasers. Besides, these isomers may have more favorable half-lifes (Table 2) (Refs. 9 and 10).

Table 2

Isomer	Half-life, h	Additional channels of decay and their fraction in ratio to the spontaneous decay, %	Laser line energy, MeV, and its part in the spontaneous emission, %
$_{30}$Z^{69m}	13.76	β(0.033)	0.4399 (> 99)
$_{39}$Y^{87m}	12.9	electronic trapping (~2)	0.381 (98)
$_{41}$Nb^{95m}	86.6	β(2.5)	0.235 (97.5)

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