Analysis of γ-ray lasers

Narender Kumar
Department of Physics, Manav Bharti University, Solan, India-173229
Email: narendersharma323@gmail.com

Abstract- The idea of generating X-ray lasers dates back to the 1970s, when scientists realized that laser beams amplified with ions would have much higher energies than beams amplified using gases. Generally, jumping of electrons between the orbits or their energy loss when passing through the strong electric field resulted in X-rays formation. The X-rays can be "turned off" at anytime by simply disconnecting the high voltage. Gamma rays are quanta of electromagnetic radiation resulted from spontaneous re-¬arrangements within unstable nuclei of very short wavelength and very high energy (at least 10 times more energetic than x-ray photons). As de-excitation of excited atom emit more visible photons, like that nucleus undergoes a spontaneous transition from an excited state to a lower-energy state to emit gamma rays. When a nucleus is in long-lived excited states, it stores excitation energy, which is spontaneously released in the form of gamma rays. To put this energy into use as a gamma ray laser or gaser, a process is required to release the energy quickly in a controllable manner as per demand. The energy gain by γ emission is an exciting area of research. This paper reviews the literature which has potential to work as γ-ray lasers.

Index Terms- X-rays, Gamma rays, Laser, Gaser

1. INTRODUCTION

For the visible laser the characteristics energy of the order of ev and the time 10^{-9} seconds so that fast electrical circuitry feeding for weakly ionized discharge can be used as a lasing medium. Furthermore transparent and reflecting material allows the isolation of the lasant and construction of resonant cavities. In contrast, in the X-ray region energies ~ KeV and times scale 10-15 seconds require either inner cell electronic transition or highly stripped ions as medium, pumped by a source of duration much less than a Pico second. Transmission and reflection properties of materials are general poor at these wavelengths, which together with limitations due to gain life time impose severe constraints on cavity design [1, 2].

Lasing action in a very short wavelength will be very difficult to achieve because of four main difficulties which were not found at higher wavelengths [3].

1. Matter has high opacity at short wavelength. The nearest analogue to transparent optical medium such as glass is hot fully stripped plasma where the opacity only due to Compton scattering.
2. The stimulated emission cross-section, upper bounded by $\lambda^2/8\pi$, will in general the smaller at shorter wavelengths. This implies that rather high density of population inversion state are required to produce the lasing action .This in terns that to achieve high population inversion enormous pumping power will be required.
3. Pump power density of the order of 1015 W/cm^2 are required. In view of this all devices proposed so far use either a subsidiary laser or particular beam as a pump.
4. A laser operating at very short wavelength must do so without the benefit of mirrors. This is due to both the fact that all materials have low reflectivity for $\lambda <$ 10 A^o and also to the fact an X-ray laser or γ-ray laser would operate at such a high flux level that any mirrors would be destroyed.

The buildings up of the laser to operate on wavelengths much shorter than the ultraviolet part of the spectrum are very difficult indeed. For one thing, the pumping efficiency is likely to decrease sharply with decreasing wavelengths as was pointed out in the pumping of solid laser .The resonant mirror system is also likely to very difficult to construct. At present there is an emphasis on 10-200A^o and 200-2000A^o lasers where the pumping requirements are less stringent. Such things as X-ray laser might prove extremely useful in research work and many fields of applications.

2. DREAM FOR γ-RAY LASER

A laser that emitted γ rays would have tremendous power efforts being made in this direction to have a γ ray laser. Carl B. Collin [4] of the University of Texas at Dallas estimates that such a laser might yield as much as 10-20 watts. This surpasses the total power production of the United State and is respectable 0.03% of the total energy output of the sun. Then it will enter totally new energy state for power sources generated in the laboratory. There are many difficulties from the physics of atomic nuclei, which are sources of the γ-rays “the hardest (of shortest wavelength) and greatest energy per quantum form of electromagnetic radiations". Collim's power estimate is for a wavelength of 1 A°. If we compare the wavelength of feasible light that ranges from about 3000-9000A°, whereas for infrared, the first laser were made, wavelength starts around 10000A°.

2.1. *How to make a γ-ray laser*

Lasing comes from a "population inversion in the nuclei of the lasing material. A large number of nuclei must be raised to a particular higher energy level where few or none of them would be found, and then induced ti drop from that energy level to lower one. To achieve the population inversion, scientist must pump the material with energy from outside source in such a way that it will invest the energy, for part of it, in the level from which a lasing transition takes place. This energy level last long enough without emitting spontaneously to permit the pumping to be accomplished.

2.2. *Difficulties to have a γ -ray laser*

1. It is generally believed that levels of nuclear excitation that might be efficiently stimulated in a gamma ray laser a very difficult to pump, because absorption width in nuclei are too narrow to permit effective pumping with X-rays.
2. The process of Compton scattering of γ-ray is dominant over the gain factor that is also a great difficulty in this direction.

2.3. *Materials tried for γ ray gain Medium*

Samples of ^{79}Br and ^{77}Se both in natural he isotropic abundance, were excited with 20ns pulses of bremsstrahlung radiations produced by an electron beam machine. The spectral energy density developed at tungsten converter was the order of 10^{13} KeV per pulses. Samples were positioned in a pneumatic shuttle tube directly behind the target foil and automatically transfer to the counting chamber after each short. The nuclear fluorescence spectra absorbed showed that a λ ray laser definitely feasible if an appropriate isotope exists. The laser workers are now looking for suitable nuclear species. As 1886 nuclei have been counted as all the isotopes of all the elements. Present knowledge indicates that out of 1886 nuclei only 29 are best suitable candidates. Among them are few of them are listed in the Table 1.

Table 1: Nuclear isomers considered most promising for the production of a gently pumped γ- ray laser.

Isomer	**k (γ-energy in MeV)**	**ʎ (A°)**	**σ_{max} (barns)**	**σ_{abs} (barns /atoms)**	**α**	**$\tau_{1/2}$ (min)**	**τ**
Co^{60}	0.059	0.21	$1.8.10_5$	120	41	10.7	37
Se^{79}	0.096		5.10^4	84	7	3.9	112
Se^{81}	0.103	0.12	$5.8.10^4$	70	9	57	92
Br^{77}	0.108	0.15	$5.2.10^4$	70	6	4.2	124
Tc^{99}	0.143		3.10^4	70	30	350	14

Where, k is gamma energy in MeV, **λ** is corresponding wavelength; σ_{max} is maximum stimulated emission cross-section in barns, σ_{abs} is photoelectric absorption plus Compton Scattering per atom, α is total internal conversion co-efficient, $\tau_{1/2}$ is excited state half-life, τ is figure of the merit of isotope which is $\sigma_{max} / (1+\alpha)\, \sigma_{abs.}$

The multi-polarity of the radiative decay and the most promising means of production of the isomer , including the fractional natural abundance and thermal neutron capture cross section (in barn) to the isomeric state of its precursor Co^{60}, Se^{79} and Tc^{99} are considered especially interesting as they are formed substantially population-inverted.

3. POSSIBLE SOLUTIONS

There are difficulties of effective pumping due to narrow absorption widths of nuclei. The threshold condition for the net population inversion density (N^*) in case of x-rays and γ-rays laser is given in Eq. (1).

$$N^* = N_2 - \left(\frac{g_2}{g_1}\right) N_1 \tag{1}$$

Where g_1, and g_2 are statistical weights of level N_1 and N_2 and known as degeneracy of the states. But

$$N^* > \frac{\Delta\upsilon(eV)}{l(cm)} 10^{18}\, cm^{-3} \tag{2}$$

Where, $\Delta\upsilon(eV)$ is the frequency width of the transition and l is length of gain medium.

The actual threshold inversion densities will be determined by the achievable line widths **$\Delta\upsilon$,** which **γ** ray transitions are fortunately not strongly affected by their atomic environments. Indeed, in most circumstances **γ**-ray line width are equal to the Doppler width. For a "Vigorously" pumped γ-ray laser medium, we would have $\Delta\upsilon = (\Delta\upsilon)_{Doppler}$ where

$$\left(\frac{\Delta\upsilon}{\upsilon}\right)_{Doppler} = 10^{-3}\left[\frac{T}{A}\right]^{\frac{1}{2}} \qquad (3)$$

Where , T is the temperature of the emitting nuclei in Kilovolts and A is the mass number of the nuclei unfortunately because γ-rays transitions are extremely weak relative to x-rays transitions the gain implied by Eq. (3) are going to be small even at low temperatures. In fact, at temperatures that one can realistically expect in a vigorously pumped γ-rays medium the gain would not be high enough to overcome Compton scattering. To satisfy this condition there are no known γ-rays transitions with energy, hω<200 KeV which satisfy this condition. There are strong transitions at energies ~15 MeV (the Goldaber-Teller effect) but the threshold inversion density implied by Eq. (2) (multiplied by $\tau_{spon}/\tau_{allowed}$) would be unattainable high [5]. The γ-ray laser appear feasible t this time due to some way of improvement on the Doppler line width can be found if the γ ray laser medium can be properly pumped [6]. As has been pointed out by several people there is one possible way of improvement of the Doppler width by use of phenomenon of recoilless emission in the crystals. Infact, line widths as 10^5 Hz have been demonstrated experimentally using short lived $\tau \sim 10^{-6}$s isomers .The line width that needs be achieved depends upon the spontaneous radioactive life time: longer life time requires smaller widths. Thus we would like to use an isomer with as short a life time as possible.

Recent research **γ-** ray laser reported that molecules have been absorbed in the laboratory by firing an intense bursts of positrons into a thin film of porous silica .In this process the slowing down positrons were captured by ordinary electrons to form positronium atoms. Positronium atoms by nature are extremely short lived .The stability of positronium atom is questionable when the atom (positronium) collides with another positronium atom .Such a collision of two positronium atoms can result in there annihilation accompanied by the production of powerful and energetic type of electromagnetic radiation called **γ-** radiation or creation of molecules of positronium. Physicists suggested by a new apparatus and methods for generating **γ-** ray laser [7]. On the basis of the above mentioned research, in future, it is possible to have a monochromatic **γ-** ray laser named as GASER, having photon energy more than several MeV. The present research will also contribute in the fields of a fusion nuclear reactor, particle physics and high energy physics. As the present research of positronium molecule and positrium atom is based on the earlier idea of electron and positron annihilation known for many years in nuclear and particle physics.

4. CONCLUSIONS

In the present course of investigation the laboratory status of x-ray laser and **γ**-ray laser have been studied. In recent years of x-ray many different schemes have been proposed. Most successful is the collisionally pumped x-ray laser, which are produced plasma containing ions in highly charged state. Collisionally pumped x-ray lasers are highly useful because they can operate over a wide range of pump conditions and with a verity of targets. For **γ**-ray laser suitable nuclear species have been identified from all the available isotopes. But their effective pumping could not have been possible due to narrow absorption width in nuclei. By having an improvement in the Doppler line width, the **γ**-ray laser appears to be feasible. In last I would like to mention that in the future we would be having a monochromatic **γ**-ray laser named as GASER, having photon energy of more than several MeV.

REFERENCES

[1] Silfast, W. T. (2003): Laser fundamentals.
[2] Thyagaragan, K.; Ghatak, A.K. (2005): Laser theory and applications.
[3] Elton, R.C. (1990): X-ray lasers, New York, academic press.
[4] Carl B. Collins (1989: Proof of the feasibility of coherent and incoherent schemes for pumping a gamma ray laser. University of Texas at Dallas, pp. 1-54.
[5] Wood, L.; Chapline, G. (1974): Towards gamma-ray lasers. Nature, 252, pp. 447-450.
[6] Chapline, G; Wood, L. (1975): X-ray and γ-ray lasers. Progress in lasers and laser fusion studies in the natural sciences, 8, pp. 269-280.
[7] Hidetsugu, I. (1997): Method and apparatus for generating gamma-ray laser. Patent number-5617443.