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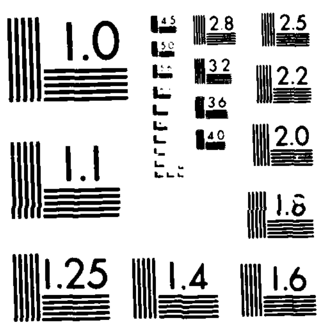

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IDA MEMORANDUM REPORT M-141

APPLICATIONS OF GAMMA-RAY LASERS

Bohdan Balko
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November 1985

Prepared for
Strategic Defense Initiative Organization
Innovative Science and Technology Office
James Ionson, *Director*

IDA
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As a result of the IST/IDA Gamma-Ray Laser Workshop held in May 1985, a general picture of the gamma-ray laser has emerged. The characteristics of the radiation from this source are contrasted with those from other coherent sources; these include energy, bandwidth, intensity, and coherence length. Potential nonmilitary applications are listed; and two classes of military applications are suggested. Those characteristics which drive a specific application are spelled out.

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APPLICATIONS OF GAMMA-RAY LASERS

Bohdan Balko
Leslie Cohen
Francis X. Hartmann

November 1985

INSTITUTE FOR DEFENSE ANALYSES

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PREFACE

As an outgrowth of the IST/IDA Gamma-Ray Laser Workshop held on 21-22 May 1985 (reported in IDA Memorandum Report M-122), the Director of the Innovative Science and Technology Office (IST) of the Strategic Defense Initiative Organization (SDIO), requested that IDA summarize the possible civilian and military applications of these devices. These potential applications are based on work to be reported elsewhere and on discussions with various participants in the workshop.

This document has not been subjected to an IDA review.

INTRODUCTION

The SDI/IST program is actively pursuing new and innovative ways of producing and delivering energy. The associated development of shorter wavelength and higher power lasers has generally been encouraged and funded. The IST program in this area includes investigations of the feasibility of developing a gamma-ray laser. Such a device will operate in the keV energy regime, with unprecedented intensity and high penetrability. The program could therefore provide a new and powerful technique for probing and modifying materials.

In this report we summarize some potential military (strategic) and non-military applications of gamma-ray lasers.

General Characteristics

Although it is difficult at this stage to predict precisely the characteristics of gamma-ray lasers, the deliberations at the recent IST/IDA workshop on gamma-ray lasers permit us to put some reasonable bounds on the operational characteristics. We conclude that gamma-ray lasers very probably [1,2]:

a. will have photon energies in the range of 10 to 100 keV (about 1.0 to 0.1Å),
b. will use recoilless nuclear resonant transitions (Mossbauer effect),
c. will be single-pulse devices, most likely operating in the Dicke superradiant mode,
d. will operate without conventional mirrors,
e. will be highly monochromatic with linewidths on the order of 10^{-8} eV to 10^{-18} eV,

f. will have intensity and power output that could be very high and variable, ranging from 10^{-1} W at threshold to over 10^{14} W, and

g. will have a beam divergence on the order of 10^{-6} rad.

As a source of high-energy, coherent electromagnetic radiation, a gamma-ray laser is inherently different from an x-ray laser and a filtered synchrotron source [2,3,4]. Synchrotron radiation is currently available from large immobile sources. It emits light over a broad spectrum. Therefore, to make it useful for the applications under consideration, a slice of energy (or frequency) has to be filtered out of the beam. This problem has not yet been resolved, although major efforts have been expended [2].

Synchrotron radiation in the x-ray region will illuminate a spot 10 m away from the source with 10^7 photons/sec/cm^2, assuming it can be filtered to 10^{-8} eV linewidth so as to be comparable with the energy resolution available from nuclear resonant transitions. This illumination is about 10^4 times higher than the illumination by natural radioactive sources but it is much less than the estimated 10^{14} photons/sec from gamma-ray lasers [2].

The potential energy resolution and coherence achievable from gamma-ray lasers is much higher than from x-ray lasers. Thus, the magnitude of the energy resolution of gamma-ray lasers could approach the order of magnitude of the natural nuclear transition linewidths (10^{-8} eV to 10^{-18} eV). Coherence lengths on the order of centimeters and longer are expected, whereas x-ray lasers are limited to an energy resolution of about 0.01 eV and to a coherence length of only about 10^{-3} cm [1]. Furthermore, the potentially useful wavelength range of 1 to 10Å [3], which a few years ago was considered to be easily accessible with x-ray lasers, is now thought to be impractical.

In general, the higher the energy of the radiation, the deeper the penetration of materials. For example, in nickel, photons with energies of 1 keV, 10 keV, and 100 keV have absorption, cross sections of the order of 10^6, 2×10^4, and 40 b/atom, respectively. This characteristic, together with high coherence (which would permit good focusing), high intensity, high-energy resolution, and the ability to ionize atoms and molecules, could provide a new powerful technique for probing and modifying materials.

In addition to the above features, three of the five concepts presented at the workshop were based on the use of long-lived isomeric nuclear transitions. Such transitions would permit long-term storage of energy (seconds to years, depending on the nucleus) at high densities approaching 10^{12} J/L (10^9 J/cm^3).

Several mechanisms to release this energy were proposed at the workshop. The energy storage capacity of an isomer was emphasized. Thus, a large amount of energy stored in a "nuclear battery" could be released at will, thereby permitting a delay between pumping and emission not available with any other lasing system. This characteristic alone would be extremely useful for strategic applications.

Non-Military Applications

Some of the more obvious applications of gamma-ray lasers include:

- gamma-ray and x-ray spectroscopy with very high resolution, improved contrast, and deeper penetration for inspection of thick materials;
- holography with very-short-wavelength, coherent radiation for three-dimensional observations of the structures of molecules, crystals, proteins, genes, and *in vivo* cellular material;
- extension into the nuclear regime of precision-frequency and length (sub-nanometer) measurements based on interferometric techniques;

- imaging techniques (CAT scanners), with reduced doses and higher resolution for discrimination between molecular species;
- nonlinear effects at short wavelengths, with applications to nuclear studies;
- modifications of nuclear reactions by using highly monochromatic gamma-radiation for selective removal of electrons to produce charge-density modifications at nuclear dimensions;
- determination of microscopic structure with very short exposures and high collimation at Fresnel-limited resolution;
- microreplication and fabrication of microelectronic components with high intensity, excellent collimation, and short exposure times;
- possible advances in materials science using the high intensities of ionizing radiation at very small local scales;
- fusion research that is facilitated by deep penetration with gamma-rays to interrogate high-density matter.

Military Applications of Gamma-Ray Lasers

We foresee two classes of missions for the military application of gamma-ray lasers:

(1) nondestructive interrogation of enemy satellites to determine what is inside, and

(2) destruction of enemy satellites in orbit and ICBMs after launch.

For those military applications, gamma-ray lasers are superior to other proposed systems such as (1) optical wavelength laser weapons, (2) particle beam weapons, and (3) x-ray laser weapons.

The gamma-ray laser will penetrate materials more effectively than optical lasers and x-ray lasers. This can be seen from a consideration of the energy dependence of the reflection coefficient α_R and the linear extinction coefficient $\mu(E)$ for metallic or non-metallic materials. The penetration of photons in the x-ray laser range is orders of magnitude lower than of photons in the gamma-ray laser range because of the energy dependence of the Compton and photoelectric cross sections.

For the nondestructive interrogation of satellites, one could operate either in the transmission mode, which would require separate source and detector platforms, or a backscatter mode using only a single platform. The data reconstruction procedures for both modes would be based on techniques already developed for x-ray computerized axial tomography (CAT) scanners. With a gamma-ray laser, however, there are two important advantages:

(1) the higher photon energy would permit deeper penetration and more efficient analysis of metallic objects, and

(2) the higher energy resolution, assuming turnability, would permit discrimination (and identification of parts) on the basis of isotopic resonances as well as density variations; thus, finer details could be studied.

For ICBM destruction, the advantages in using the gamma-ray laser as opposed to the longer wavelength devices, are based on material penetration and the type of material modification. Greater penetration of the atmosphere from a satellite by a gamma-ray laser beam permits earlier destruction of the missile than would be possible with an x-ray laser. For example, calculations show that a gamma-ray laser in geosynchronous orbit emitting at 100 keV will penetrate (transition of 67 percent of the energy of the beam) to about 35 km above the earth's surface. This should be compared with the expected x-ray laser penetration under the same condition to only about 100 km at 1 keV.

Once the beam gets to the surface of the ICBM, deeper penetration in metallic objects provides a faster and more efficient energy deposition. Thus, shorter wavelength lasers have a distinct advantage in this respect. Furthermore, the destruction of material by optical lasers requires multiple attack pulses on a particular area because of the low penetration of the beam. It may take as long as 100 sec to drill a hole through a piece of metal 1 cm thick. Gamma-ray lasers would need only one pass of the beam to deposit the energy. Thus, if enough energy is deposited, destruction could take place in a fraction of a second.

The destructive mechanism available to low-energy lasers is based solely on heating effects. With gamma-ray lasers, in addition to heating, there is a possibility of massive ionization on a microscopic scale in a short time. This could provide a more controlled and at the same time a more effective destructive mechanism. Because of the depth of penetration and the speed of energy deposition leading to a more efficient destruction, defense measures devised against optical lasers would be ineffective against the gamma-ray laser. Using a mirrored surface on the missile would not prevent penetration. An ablative coating would have to be too thick and, therefore, impractical. Finally, rotation of the missile about its axis to redistribute the deposited energy would require speeds that are too high for practical consideration.

Again, it should be emphasized that the use of long-lived nuclear isomeric levels for energy storage in the gamma-ray laser permits the use of low pumping fluxes for the inversion (not nuclear explosives but, for example, thermal neutrons from reactors) and allows the pumping and firing of the laser to be separated in time. This characteristic alone makes the gamma-ray laser a uniquely valuable potential device for strategic military applications.

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