Potential breakthrough in nuclear-powered lasers brings space-based systems closer

by Jon Gilbertson

The use of laser beams in either ground-based or space-based beam weapon systems requires a very large energy source. This will be relatively easy to obtain for a land-based laser weapons system (compared to a space-based system), but is likely to be very costly with the types of high-powered lasers now being developed. These lasers are usually either driven (or pumped, in laser lingo) by electrical discharges, chemical reactions, or electron beams, and therefore require large amounts of either electricity or chemicals as their energy source.

Because of the large volumes, space and weights of these energy sources, high-powered lasers driven by these methods are out of the question for space-based systems. A future requirement, then, for space-based lasers (advantageous for land-based lasers as well) is development of a far more dense and compact energy source. An obvious candidate for this task is nuclear energy from an advanced type of nuclear fission reactor—the most energy-dense non-explosive source available today.

History of nuclear lasers

When the first laser was demonstrated in the early 1960s, scientists and engineers began thinking of how lasers could be driven with nuclear energy. But instead of extracting energy from a nuclear reactor in the usual form—heat—ways had to be created to extract energy as light. To accomplish this in a radioactive environment, at acceptable conversion efficiencies and in a configuration that produces a practical laser beam, was, and still is, a formidable task.

Experimental work began on nuclear lasers in the late 1960s, but a demonstration of nuclear pumping wasn't achieved until 1974, almost simultaneously at two locations: Los Alamos Scientific Laboratory in a joint experiment with the University of Florida, and at Sandia Corporation. Both tests used fission fragments to excite different types of gas lasers, and both finally succeeded in obtaining lasing action, although at an extremely low power output.

These tests and a few others proved in principle the feasibility of nuclear-pumped lasers. At least one large power-engineering corporation has a prototype design under study.

How nuclear lasers work

Nuclear lasers convert the kinetic energy of the fission fragments, a direct product of nuclear fission, into light. These fission fragments—fission products, in familiar nuclear power plant terminology—contain 85 percent of the energy released in the fission reaction, and therefore any successful nuclear laser must be capable of absorbing this energy in some way. Gamma rays, neutrons, and other radiation make up the other 15 percent of fission energy, and are not very important for nuclear lasers.

A laser medium can either be a solid, liquid, or gas—but in all cases must be transparent to the laser radiation (i.e., light), and remain so during all operating conditions. Solid lasing mediums are generally very susceptible to nuclear radiation damage and thus far have been unsuccessful. Similar problems have occurred with liquid lasers, although some recent work at the University of Florida with inorganic liquids has shown some promise.

The greatest success to date has occurred with gaseous lasing media, which are the least susceptible to nuclear radiation damage. It is also much easier to mix a gaseous lasing medium with a gaseous nuclear fission fuel and maintain a transparent medium.

Concepts under investigation

The problem in making the nuclear laser work is to get the kinetic energy of the fission fragments uniformly dispersed and absorbed in the lasing medium, such that the laser will still lase. This is difficult to achieve for any significant laser power output.

Two basic approaches for developing a usable nuclear-pumped laser are under investigation. The first, direct nuclear pumping, has been studied for several years. A more recently developed concept is the "duo-media approach."

Using the second approach, a University of Florida research team led by John Cox and Richard Schneider has recently developed a scheme for achieving the kinetic energy transfer, and has proposed a laboratory test program to verify its feasibility. Instead of directly transfering the kinetic energy of the fission fragments to the laser medium by ionization, which is the usual approach, they propose to transfer it as light directly from the hot (3000°K) uranium carbide reactor fuel particles. This would keep the reactor fuel material and the lasing medium separated, eliminating some of the problems associated with mixing the two materials. This light then impinges on the laser medium, in this case an inorganic liquid, causing excitation and lasing.

During normal power operation, the fuel particles heat up due to the absorption of fission fragment energy. Like a piece of hot iron, the particles become almost "white hot" (but at a much higher temperature than iron). This heat energy is then radiated as light, instead of being conducted by some cooling material, as in most nuclear reactors. It is this light that excites and pumps the laser medium.

Since such a reactor will normally operate in a pulsed mode, the light will radiate as instantaneous flashes, in the manner of a camera flash bulb. Thus, the laser would also operate by pulsing the beam.

The reactor design concept chosen for this system, called a colloidal core reactor, was developed in the early 1970s for the NASA nuclear rocket program, and work on it was dropped when that program was cut. It operates with a mixture of helium gas and small suspended solid particles of uranium carbide fuel swirling around inside a vessel in the form of a vortex.

The other concept, the direct pumping system, has received more attention. It uses a UF_6 fueled gaseous nuclear reactor fuel mixed with either a CO_2 or Ar-Xe based lasing gas medium. The two materials are intimately mixed in this concept. Test experience to date has shown that although it does produce lasing, the lasing is rapidly quenched (stopped) by one of the many complicated transitional states of the UF_6 molecules.

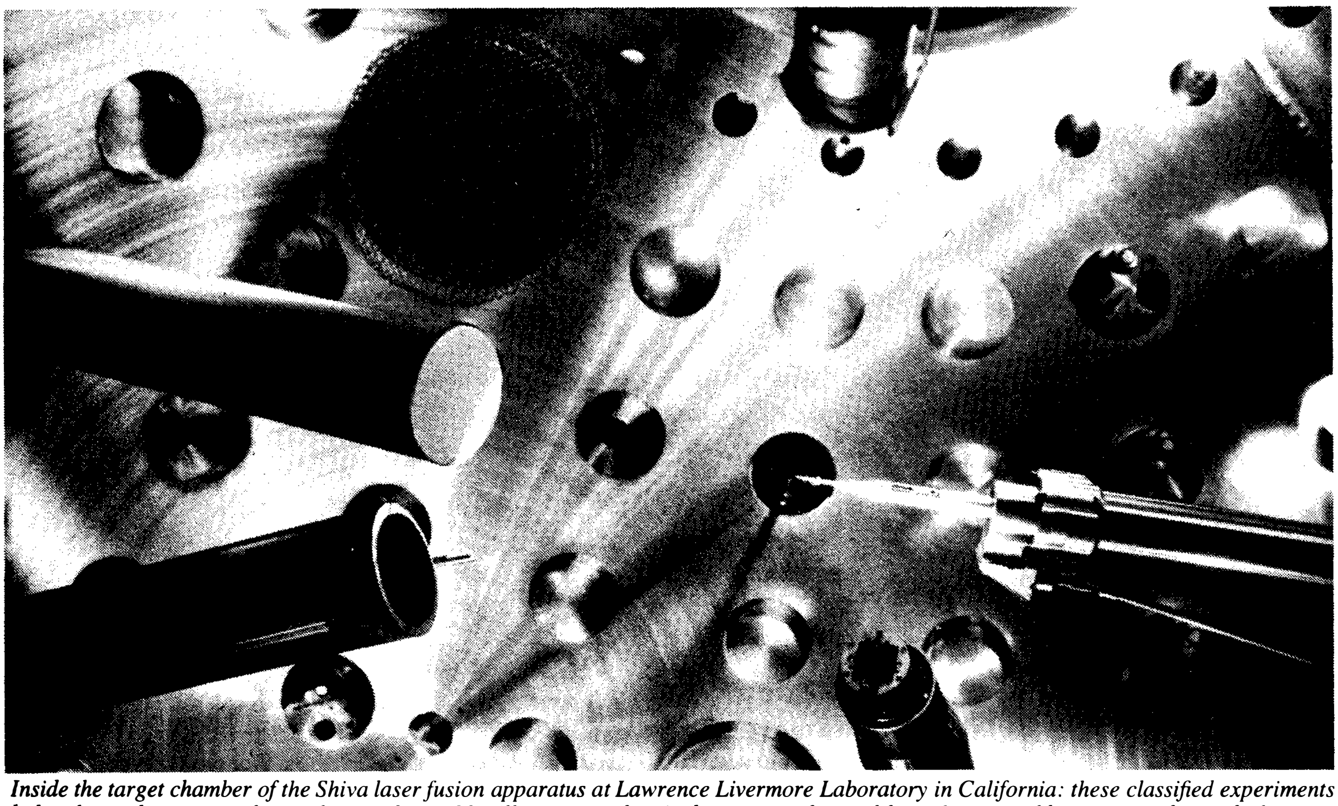
Application as a beam weapon

The colloidal core nuclear reactor and the proposed liquid laser system would make an excellent space-based laser weapon. The estimated 5 percent conversion efficiency could produce a laser beam power output of 10 MWs—twice the minimum necessary to knock out ICBMs—and do this with a total reactor power output of about 200 MWs.

This reactor, designed to operate in a pulsed mode, would be turned on only when called upon to fire the laser. It will therefore never generate any significant amount of fission products, and thus an accidental re-entry and breakup in the earth's atmosphere is not a significant hazard.

The unique design of this compact, Greyhound bus-sized integrated nuclear reactor/laser system incorporates rotating cylindrical moderator/reflector control elements which provide rapid power pulsing, and therefore laser firing many times a second if necessary. One-megajoule pulses of 1-millisecond duration are envisioned from this machine-gun-like output.

It was the military application of the nuclear power reactor on the nuclear submarine that proved feasibility, and provided the impetus for the commercial nuclear power industry. And it will be the military implication of these more advanced and complicated fission reactors and laser systems that will prove their operational feasibility. As before, the commercial applications of these systems will be a direct spinoff, especially for the fusion energy program.



Courtesy of the U.S. Department of Energy

Inside the target chamber of the Shiva laser fusion apparatus at Lawrence Livermore Laboratory in California: these classified experiments led to the nuclear-pumped x-ray laser. Above, 30 trillion watts of optical power are focused from the top and bottom onto fusion fuel targets at the tip of the positioner at right.