LASERS AND LASER APPLICATIONS

NARROWBAND FLUORESCER USED TO DRIVE AN IODINE PHOTODISSOCIATION LASER

The high energy and average power eventually required for a laser-fusion power reactor preclude the use of solid-state or liquid lasers as now conceived. A program is under way at LLL to develop short-wavelength, high-efficiency, gas-laser media that have the appropriate physical characteristics for reactor applications. Photolytic lasers pumped by narrowband excimer fluorescence are one possibility. We recently demonstrated an iodine photodissociation laser using fluorescence from the XeBr* excimer as a pump source. We are pursuing this scheme as a candidate source for future laser-research facilities.

The development of efficient, high-power new lasers is one of the most important problems bearing on the ultimate use of laser-driven fusion reactions as an energy source. The lasers required to drive the fusion core of an eventual 1-GW pilot plant will have to meet some truly severe specifications: high peak power per pulse (>100 TW), high average power (pulse rates of ~100 Hz), and high overall efficiency (>10% for pure fusion reactors, >3% for fusion-fission hybrids).

Although the elements of a program designed to get us into this parameter space are not yet fully defined, these specifications appear to limit the types of laser media one should study to the following:

- Metastable species where energy is channeled to the excited upper laser level and is stored there until extracted.
- Gases, which can be exchanged between shots (unlike solid-state media) and which minimize flow effects on the optical field (unlike liquid media).
- Simple spectroscopic structure to simplify energy channeling and extraction; this implies atoms or simple molecules.

In addition, account must be taken of wavelength effects in the absorption of laser light at the target. A long-wavelength laser transition may require the construction of expensive targets to facilitate useful absorption of the laser light. Thus attention has centered on short-wavelength transitions involving electronic levels of atoms or molecules. We have a

LLL LASER PROGRAM

This Laboratory is conducting a program to assess the scientific feasibility of laser-driven implosion and thermonuclear burn of microscopic targets containing deuterium and tritium. Experiments are being run on a single-shot basis, the emphasis being on fast diagnostics of neutron, x-ray, e-particle, and scattered laser-light fluxes from the target. Our laser source for this work is the Nd:glass laser operating in a master oscillator-power amplifier configuration, where a well-characterized, mode-locked pulse is shaped and amplified by successive stages to peak powers of a few terawatts in a 20-cm-diam beam.

A series of Nd:glass laser systems is planned, scaling from the 0.4-TW Janus system operational today to a 100- to 200-TW system proposed in the early 1980's. A key stage in these scaleup experiments is targeted for FY 1978, when 20 TW of peak laser power will be delivered to a target from 20 separate output stages by SHIVA, the Laboratory's $25 million target-irradiation facility. Experiments with SHIVA are expected to demonstrate significant thermonuclear burn by laser-driven implosion of the target.

Beyond these basic questions of scientific feasibility lie the difficult issues of the technical feasibility and cost-effectiveness of lasers for commercial applications. As explained in the accompanying article, the lasers for future power reactors will clearly be gas lasers.

One of the most convenient ways to excite large volumes of gas is by injecting relativistic electron beams. The resulting secondary electron gas produces the desired excited species through collisional processes. Two approaches have been followed in applying this concept: direct bombardment of the laser gas by electrons, and bombardment of a fluorescer gas that in turn excites the laser gas in an adjacent container with light (a photolytic or optically pumped system). Both techniques are being explored experimentally at LLL.
program in progress at LLL to develop photolytically driven laser systems appropriate for reactors.

Photolytic Lasers. The photodissociation iodine laser is one of the leading candidates for laser-fusion applications. It uses the photodissociation of alkyl iodides, usually \( \text{CF}_3\text{I} \) or \( \text{C}_3\text{F}_7\text{I} \), to generate excited iodine atoms. The long radiative lifetime of \( \text{I}^* \) (130 ms) gives this laser an attractive potential for high power output. The energy storage characteristics and kinetic processes of iodine lasers have been studied extensively,\(^2\) and substantial system scaling on a single-shot basis is being attempted at the Max-Planck-Institut für Plasmaphysik in Germany. However, the efficiency of these lasers has been limited by poor coupling between the emission spectrum of the xenon flashlamps used and the absorption spectra of the alkyl iodides. Recent experiments with arc sources driven at current densities of about 80 kA/cm\(^2\) have yielded at most a 3 to 4% transfer of input energy into radiation suitable for exciting the alkyl iodides.\(^3\) Moreover, the use of xenon flashlamps for scaling to high average powers (multiple pulses) is highly questionable.

For more efficient optical pumping (excitation) of the iodides, and for potential scaling to high average powers, an intense light in the ultraviolet region is needed. A recently discovered new class of narrowband fluorescers – rare-gas halides – provides just such an intense series of near-ultraviolet photolysis sources.\(^4\) The fluorescence is produced by the decay of excimer states of these halides.\(^5\) As shown in Fig. 6, the band emitted by the \( \text{XeBr}^* \) molecule shows significant coupling to the absorption spectrum of \( \text{C}_3\text{F}_7\text{I} \).

Electron-Beam-Driven Photolysis. In a recent experiment, we produced laser action at 1.3 \( \mu \text{m} \) by using fluorescence from the \( \text{XeBr}^* \) excimer to pump \( \text{C}_3\text{F}_7\text{I} \).\(^6\) Our apparatus is shown schematically in Fig. 7. We used a 130-kV Marx capacitor bank to drive a 1-m-long cold-blade cathode that emitted an electron beam with an energy of 230 keV and a current density of 3 A/cm\(^2\). The beam entered a gas cell through an electron transmission window of 13-\( \mu \text{m} \) Kapton over 25-\( \mu \text{m} \) titanium; the cell contained a mixture of 0.1-kPa \( \text{Br}_2 \), 4-kPa \( \text{Xe} \), and 200-kPa \( \text{Ar} \).

A quartz laser tube (9-mm i.d.) was installed 3 cm from the electron transmission window and filled with 130-kPa \( \text{C}_3\text{F}_7\text{I} \). The optical cavity for the laser consisted of a 5-m-radius, dielectric, coated mirror with maximum reflectivity at 1.3 \( \mu \text{m} \) and a 10-m-radius output coupler of 99% reflectivity. The resulting laser emission was detected on a calorimeter and a suitably attenuated photomultiplier tube. The laser output was 0.1 mJ in a 500-ns pulse. Because this was a proof-of-principle experiment, we did not try to couple the \( \text{XeBr}^* \) emission optimally into the laser tube.

By viewing a well-defined emitting volume at the midplane of the gas cell with the laser tube removed, we determined the efficiency for converting electron beam energy into \( \text{XeBr}^* \) fluorescence to be about 11%. We used SANDYL,\(^7\) a three-dimensional Monte Carlo electron transport code developed at Sandia, to calculate the electron-beam energy deposition in the cell. The excellent agreement observed between SANDYL predictions and calorimetry data lends strong credence to this efficiency figure.

Because the laser tube in this experiment was small, the \( \text{C}_3\text{F}_7\text{I} \) was optically thin and absorbed only about 25% of the \( \text{XeBr}^* \) power spectrum. Larger tubes should significantly increase this absorption, although there are tradeoffs in attempting to optimize the system geometry because uniform gain is also desirable. If the laser tube is enlarged so that the medium is optically thick, absorption occurs primarily near the

![Fig. 6. Coupling of \( \text{XeBr}^* \) emission to the absorption spectrum of \( \text{C}_3\text{F}_7\text{I} \); \( \sigma \) is the absorption cross section.](image-url)
Fig. 7. Experimental apparatus for electron-beam-pumped iodine laser. The gas cell contained a mixture of 0.1 kPa Br₂, 4 kPa Xe, and 200 kPa Ar. The laser tube, filled with 130 kPa C₃F₇I, is 3 cm from the electron transmission window.

Tube’s boundaries and the central region remains unexcited; this produces a nonuniform gain where the energy output itself resembles a hollow tube. It seems plausible, however, that at least 75% of the XeBr* emission could be effectively used for laser pumping, which would then result in converting about 8% of the electron beam energy into photolysis.

Having established a lower bound for fluorescence efficiency, we believe that the kinetic processes governing the production of XeBr* warrant a concerted study. Optimization of these processes, along with aggressive development of electron-beam technology, may produce a high-energy-storage laser with an overall efficiency greater than 1%. The concept of an electron-beam-driven photolytic laser suggests the plausibility of scaling in the transverse dimension.

We are presently studying relativistic electron beams to find ways of providing more efficient and uniform energy deposition for pumping gas-laser media. One geometry that may be of interest, which we are pursuing, is shown in Fig. 8. The electron beam is directed through a cylindrical anode foil in the radial direction. The fluorescer gas is located between this foil and the laser tube, which is coaxial with the anode. Increased efficiency is obtained if the anode also serves as the tube’s boundaries and the central region remains unexcited; this produces a nonuniform gain where the energy output itself resembles a hollow tube. It seems plausible, however, that at least 75% of the XeBr* emission could be effectively used for laser pumping, which would then result in converting about 8% of the electron beam energy into photolysis.

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as a reflector. Although small-scale (i.e., table-top) cylindrical electron beams have been demonstrated, larger versions will require significant development effort.

Another approach to producing these fluorescence bands is by electric-discharge pumping of rare-gas halide mixtures. It may be possible to enhance the efficiency of fluorescence production by this means, provided that an electron beam is present to stabilize the discharge in the highly electronegative mixtures containing halogens.

Future Applications. The high energy and average power eventually required for controlled thermonuclear power generation so far exceed today's technology that construction of intermediate laser systems is mandatory. A logical and necessary step toward developing the ultimate reactor laser is to identify, develop, and construct a high-energy-storage, short-wavelength laser capable of producing single-shot, 100-TW pulses. This facility would be used to explore the physics of thermonuclear pellets under conditions approximating those of a pure-fusion reactor, but it would not entail the expense and technological complexity needed to build and operate a rep-rated (high-average-power) laser system. An upgraded SHIVA laser (from 20 to 100-200 TW) may serve this function. Farther downstream, on-site construction of a Laser Fusion Engineering Research Facility (LAFERF) has been proposed for the mid-1980's. Its design specifications also stipulate a 100-TW power output but with a 50-Hz repetition rate. The iodine photodissociation laser is a possible source for this facility. Other photolytic lasers of this type are also being considered.

Key Words: excimers; iodine — dissociation; iodine — fluorescence; iodine lasers; LAFERF; laser beams; laser beam — propagation; laser induced fusion; lasers; lasers — design; lasers — Lawrence Livermore Laboratory; lasers — optical pumping; narrowband excimer fluorescence.