Science & Technology

The 'xraser' comes to the laboratory

by Charles B. Stevens

The most important message from the meeting on "Lasers and Particle Beams for Fusion and Strategic Defense," held at the University of Rochester April 17-19, is that "xrasers" (x-ray lasers) have come to the laboratory, to stay. While this topic was not the focus of the conference, important new insights on how xrasers can be developed and improved, emerged during informal poster sessions held as part of a tour of the University of Rochester Laboratory for Laser Energetics (LLE).

Last fall, fusion scientists from Lawrence Livermore National Laboratory in California and Princeton Plasma Physics Laboratory in New Jersey announced that they had demonstrated the physical conditions needed to construct x-ray lasers in the laboratory for the first time. They had achieved a five-fold increase in the electromagnetic frequency of lasers. In terms of the application to science and industry, the potential impact of this is to be measured in orders of magnitude. More general considerations show that bringing x-ray lasers into the lab will profoundly affect every aspect of science and technology.

For example, to date, living processes on a microscopic scale have been opaque to human observation. X-ray laser microholography will make it possible for the first time to see the dynamics of living processes on an atomic scale—in terms of both spatial and temporal scales. Similarly, the atom itself is opaque; atomic processes must be inferred from observations of the effects of atomic transformations on other materials. The x-ray laser will permit the coherent probing of the atom for the first time. Since all forms of human physical economy are currently based on, or mediated by, living processes and/or atomic/chemical transformations, the x-ray laser will provide a unique tool to revolutionize the full range of current scientific and technological practice.

The Livermore selium x-ray laser

At the fall meeting of the American Physical Society Plasma Physics Division, scientists from Lawrence Livermore National Laboratory reported the first unambiguous measurement of amplified spontanous emission of x-rays obtained in a scientific laboratory. The configuration utilized consisted of irradiating a thin, metal foil with a concentrated beam of ultraviolet laser light. The ultraviolet laser pulse transformed the thin foil into an expanding plasma. Collisions between free, plasma electrons and ions produced inner orbital excited states that support xrasing. When the expanding plasma—and this was the trick—reached a specified density and temperature, which determine the ion-electron plasma collision rate, x-ray lasing was generated.

One of the major experimental difficulties involved was that this density-temperature condition had to be generated uniformly throughout a length-wise region of the expanding foil plasma and maintained over a sufficient period of time to permit the emergence of the x-ray laser beam.

Lasing was achieved with foils made from two elements, selium and yttrium.

The Princeton x-ray laser

While the Livermore xraser is based on plasma electron pumping, that of Princeton Plasma Physics Lab is based on plasma recombination pumping. In this case, a thin rod of carbon is irradiated by a powerful pulse from a CO_2 10-micron wavelength laser. The resulting plasma is confined by a powerful magnetic field (on the order of 100,000 Gauss) and consists at first of completely stripped carbon ions and free plasma electrons. The incident laser light is sufficiently powerful to remove all 12 of the carbon atom's electrons. But on a very short time-scale, many of the free electrons will recombine with the completely stripped carbon ions to form lower charged ions. These recombination ions, when formed, constitute excited-state ions capable of x-ray lasing.

Princeton scientists produce carbon plasma columns two to five centimeters in length and held to a one to two millimeter diameter by the 100,000 Gauss magnetic field. A 100-fold increase in the .0182 micron x-ray wavelength is observed.

Overview

Contrary to the Cassandras who doubted the 1981 reports of Livermore's bomb-pumped xraser, documented laboratory experiments have now demonstrated that xrasers are feasible and, within the coming year, will be made fully operational for laboratory experiments and applications. This is underlined by an xraser applications workshop held by Livermore in February, to which were invited the world's leading experts in a number of scientific fields that will be affected.

The remaining question is, to what extent and at what rate can xraser capabilities be proliferated throughout industry and academia? An important determinant of this is how quickly xrasers can achieve higher outputs and shorter wavelengths.

Advanced collisional pumping designs

A number of suggested improvements to the Livermore expanding plasma foil, collisionally pumped xraser, intended to make it more efficient, emerged from discussions at Rochester. Inefficiency arises from several factors. First, only a small portion of the expanding plasma lases. Second, most of the incident laser light simply passes through the expanding plasma. Reversing the plasma motion from an outward expansion to an inward implosion could substantially reduce both of these built-in inefficiencies.

Bringing x-ray lasers into the laboratory will profoundly affect every aspect of scientific and technological research.

For example, instead of irradiation of a plane foil, a foil made into a cylinder could be utilized. If the cylindrical foil could be made to implode in such a way that it achieved the required temperature and density when it attained its maximum compression, most of the plasma could lase. Furthermore, this implosion geometry is far better for achieving more efficient optical laser light absorption, since the plasma density increases as it is imploded.

Another improvement suggested at Rochester would consist of utilizing a combination of incoherent soft x-rays and hard line x-ray radiation. In this case, the xraser foil would be surrounded by a number of other foils. These outer foils would absorb the incident optical laser light and generate various spectrums of x-rays—a sort of x-ray flash lamp. It would be these optical laser-generated, incoherent x-rays that would heat and implode the inner, xraser foil.

While this general configuration has application to various xraser pumping methods, its potential can readily be seen in the case of the Livermore collisional xraser.

First of all, as demonstrated by the Japanese Cannonball laser fusion hohlraum target, configurations already exist for both effectively trapping and converting optical laser light into x-rays.

Second, the steep density gradients produced by efficient, soft x-ray implosion could provide the most efficient assembly of the desired xrasing plasma. In this case, the plasma implosion would be designed to create a sort of square wave density profile—steep on the edges and flat across the plasma width. As a result, most of the plasma would xrase. And concomitantly, most of the energy absorbed by this plasma would be going into generating x-ray lasing. Most significantly, it would appear that soft x-rays are the best means of producing this most desirable plasma-density configuration.

Third, a variety of specific hard x-ray line radiations could be generated simultaneously with that of the soft x-ray spectrum. Foil layers acting as filters could further limit and thereby tune the actual hard lines which irradiate the xraser foil. These hard lines would provide the means of penetrating and heating the interior of the dense, imploded plasma. As a result, the ability to "tune" the plasma temperature within a specific density configuration would be greatly improved.

Fourth, the great symmetry of blackbody x-rays provides the means of producing great uniformity throughout the full dimensions of the imploded plasma column. Along these lines, the x-ray flashlamp provides a ready means of temporally and spatially shaping the energy flux incident upon the imploding xraser foil. This last capability will become increasingly important as the lengths—and consequently, the gains and total outputs—of xrasers are increased.

As can be seen from the above, the achievement of plasma conditions required for collisionally pumped xrasers are primarily determined by carefully arranging the hydrodynamic evolution of an imploded plasma. X-ray flashlamps and blackbody radiation are currently the most effective and versatile means of hydrodynamically imploding matter. And at the same time, the methods and means of predicting the atomic physics side of xrasering are demonstrably at a very primitive stage of development. Therefore, it is essential that this hydrodynamic capability be most extensively explored in order to provide the experimental base for realizing collisionally pumped xrasers.

Future prospects

Given the investment of sufficient funds, a wide range of existing facilities will produce operational laboratory xrasers over the coming year: Lawrence Livermore National Lab's Nova Laser, Japan's Osaka Grekko XII laser, the University of Rochester's Omega laser. Once mastered, the capability could be rapidly expanded to scores of other existing high power laser facilities that exist throughout the world, but operate at about one-tenth the power level of the mainline systems.

Another possibility is to use pulsed power devices, like those used for electron and light ion beam generation. These machines can be readily reconfigured to implode cylindrical foils. Successful xraser demonstration on this type of machines could increase proliferation by orders of magnitude, since hundreds of them already exist.