A Powerful Way to Make an X-Ray Laser

It takes a strong laser to make coherent X-rays

By DIETRICK E. THOMSEN

An X-ray laser has been a longstanding goal of the people who push laser development. Lasers began at long wavelengths; in fact, the concept of amplification by stimulated emission was first applied in the maser, a microwave radio amplifier, developed in the 1950s. The first lasers were infrared, and are still probably the easiest to make. The trick gets harder and harder as one tries for shorter and shorter wavelengths. The first lasing in what could be called the X-ray range was reported about a year and a half ago (SN: 11/3/84, p. 278).

The Lawrence Livermore (Calif.) National Laboratory, one of the first two laboratories to claim X-ray lasing, uses the 120-kilojoule optical laser, Nova, to provide beams of light that zap little metal foils to turn them into plasmas (ionized gases) that produce coherent X-rays. Lasers are frequently used to power other lasers, but when the power source is the world's most powerful optical laser, and the one piggybacking on it is pushing laser technology to some of the shortest wavelengths yet recorded, the combination is unique. Nova's full 120 kilojoules come from 10 parallel laser arms working together. So far the X-ray laser has used only two of the 10 arms, but according to Dennis Matthews of Livermore, who described the X-ray laser to SCIENCE NEWS, it may someday use all 10. (Nova does a number of other things, too; see box.)

Part of Nova was used as a set for scenes in the movie "Tron," and the whole thing does have a kind of science fiction look: a huge hall filled with giant racks carrying arrays of whitish pipes, white-coated people moving around on catwalks, etc. The whitish pipes are optical conduits, in which the amplification of the light takes place. They form 10 parallel arms, each of which gets wider and wider the farther it is from the start.

The process starts on a tabletop. A small laser provides a wavelength to be amplified. Oval disks of purple neodymium-doped glass powered by xenon flashlamps amplify this little incoming beam of 1-micrometer-wavelength light. The amplifiers get bigger as the power increases. The largest of them are 46 centimeters across. At this size designers had to worry about lasing in the direction perpendicular to the beam as well as along it. The transverse lasing could provide a kind of backfire that could damage the xenon lamps, so these last amplifiers are split in the transverse direction to prevent it.

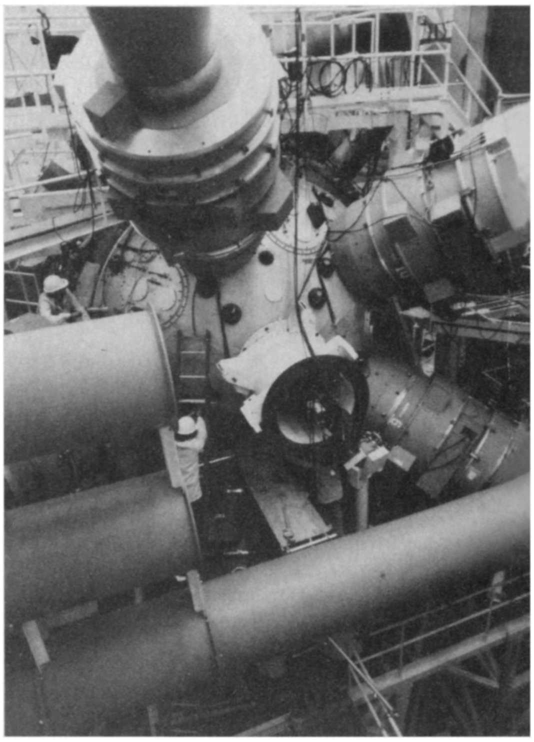
Two of the 46-cm pipes enter the side room where the X-ray laser work takes place and do zigzag turns to get on either side of the small chamber where the X-ray lasing occurs. In that chamber, on a small post, sits a bit of metal foil. (Selenium, yttrium and molybdenum have been used; silver is next on the list.) The X-ray wavelength produced depends on the atomic number of the metal: The higher the atomic number, the shorter the X-ray wavelength.

Cylindrical lenses focus the round beams of Nova into lines; the experimenters want to produce a long, thin, pencil-shaped plasma. In this lensing the split in the last Nova amplifier turns into a cut that sections off a piece of the target foil. The experimenters can dial the length of plasma they want, from a tenth of a millimeter to 62 mm. The longer the plasma, the greater the amplification. X-rays that start from one end and proceed along the axis to the other can be amplified several times.

So far all the amplification comes in one pass. Lasers generally have mirrors to reflect the light back and forth through the lasing material for increased amplification. Mirrors for X-rays are made by stacking up very thin layers of different materials. The optical properties of these materials cooperate in a way that reflects a part of the incident radiation. Matthews and his co-workers have been trying such mirrors on the X-ray laser but without much success at first.

Last year they put one of these mirrors at one end of their plasma column for a double pass by the X-rays. They expected about 15 times the amplification they had without the mirror, but got about 3 times. The first reaction, Matthews says, was "Oh, damn! What did we do wrong?"

As they strive to test and prove the technology, they are beginning to learn what went wrong. First, the X-ray laser is a hostile environment for mirrors, and the mirrors suffer much damage from that hostility. Second, the mirrors turn out not to be as reflective as they were touted to be. Unlike mirrors for visible light, which can reflect as much as 99 percent of the incident radiation, the best X-ray mirrors are rated theoretically at 50 percent. However, Matthew's group decided to send a team to a synchrotron in Berlin that happens to have a calibrated source of X-rays to test the mirrors with known X-ray intensities. Their reflectivity turned out to be more like 25 percent. That difference, the experimenters figure, accounts for a good part of the amplification they didn't get; the rest they



Photos: Lawrence Livermore Nat'l. Lab.

Nova's target chamber.

attribute to damage to the mirrors.

During the first week in June they intend to begin experiments to see if the mirrors can survive the environment of the X-ray laser in good shape, something about which the previous work was inconclusive. If the mirrors survive, experiments will go on to double pass and then multiple pass.

In spite of the difficulties, the experimenters are still excited about the possibilities of using mirrors. If the mirrors work, much higher X-ray powers will be possible. The experiments will also have an alternate way of reaching shorter wavelengths: Instead of using heavier and heavier elements, they can use certain lighter elements that produce shorter-wave X-rays because of the way the energy states of their inner electrons happen to be configured. As it happens, these elements emit at much lower power levels and so require more amplification to reach a useful level. If the mirrors don't work, the alternative, Matthews says, is to "hit it with a bigger hammer," that is, all 10 of Nova's arms.

Reaching shorter wavelengths is a large part of the effort, driven by both the desire for the scientific achievement and the possibility of applications. The laser's wavelength is now around 10 nanometers. The experimenters would like to get down to 3 or 4 nanometers. At 10 nanometers scientists could do surface studies of nonliving materials, as well as holograms of living cell surfaces, but they are limited mainly to surfaces. Between 3 and 4 nanometers imagery can go inside the cell. Water will transmit the X-rays — "Most of these things are swimming in water," Matthews reminds us — and images of both carbonaceous and calciferous structures in cells could be made. "With enough resolution you could even see the chains of carbon in the DNA," he says.

Although his group is already cooperating with several physical and biological scientists on applications of these sorts, Matthews's first concern is developing the physics and technology of the X-ray laser. "When we first came on, everybody said, 'Oh, yeah, somebody finally did it,' " he recalls. Now the job is to make it better and more useful, and that means higher output and shorter wavelength and making it fire more often than once or twice a day.

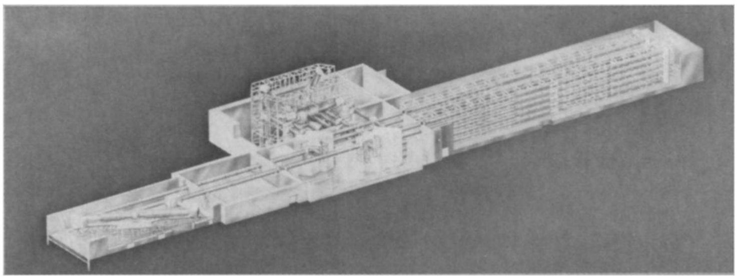
It also means making it possible for people who do not have Nova as a power source. Matthews says they often joke that one of their foil targets costs $1,000 but the power source cost $200 million. "We've got to reduce that power supply cost," he says. One possibility is to use excimer lasers that repeat once a second. They could provide enough power — if the mirror technology works. "I keep coming back to that," Matthews says. "It's really crucial." ☐

Nova's work load

Nova at the Lawrence Livermore (Calif.) National Laboratory was planned to be the world's most powerful laser, with 20 amplifying arms delivering a total of 200 kilojoules of power. Commissioned a year ago, it is the world's most powerful laser, with 10 arms and 120 kilojoules of power. What hit it in the meantime was an ax known as the federal budget. The change in maximum power seems to coincide in part with a shift in research interest that coincides also with a shift in the scientific interest of the federal government.

Dennis Matthews of Livermore. "With 200 kilojoules we thought we could do break-even; with 30, no way. What we need is a bigger one of these, but nobody in Washington wants to hear it."

Nevertheless, the first experiment done with Nova was an inertial confinement fusion experiment. Steve Lane and co-workers shot a pellet of deuterium and tritium with all 10 of Nova's beams and got out 10^{13} neutrons, more than any other experiment ever got out of such a pellet. In this reaction, where deuterium nuclei fuse with tritium nuclei, neutrons carry the energy out. More neutrons coming out mean more fusions have taken place, but this number is still far from break-even.



The Nova system.

Originally, Nova was presented as a step forward for the inertial confinement fusion program. Its laser power, concentrated on a tiny pellet of deuterium mixed with tritium, would implode the pellet, compressing and heating it to the point where nuclear fusions would take place. With the 200-kilojoule Nova, enough fusions should eventually have occurred in such a target to reach scientific break-even, the point where the energy generated by fusions would equal the energy expended to crush the pellets.

With the actual Nova, no one would look for break-even, even if all the energy hit the target, and now all the energy doesn't. Nova produces an infrared wavelength of around 1 micrometer. This is the optimum wavelength for making such a powerful laser. However, many recent experiments combine to show that it is not a good wavelength for inertial confinement fusion. It now seems that green or blue light will be better. Certain arrangements of crystals will double the frequency (halve the wavelength) of Nova's light. One application of this arrangement turns it green, two applications turn it blue, but the change has to be done after the amplification. Such high powers at such short wavelengths going through the Nova system would damage the mirrors that control the paths of the light beams. Changing the color costs severely in energy. Conversion of 100-kilojoule infrared to blue reduces the energy to 30 kilojoules, says

Under present circumstances, about 50 percent of Nova's work will be on inertial confinement fusion, about a quarter on X-ray lasers and about a quarter on other applications, including weapons simulation of the type that had been planned from the beginning, as well as something close to the heart of the Reagan administration, the Strategic Defense Initiative (SDI).

Weapons simulation is one of the main incentives for building these high-powered lasers, and it was part of Nova's *raison d'être* from the very first plans. The lasers are used with these tiny fuel pellets to make what amount to mini-explosions and to produce the radiations encountered in nuclear detonations. This permits testing the effects of those radiations on various materials without actually setting off bombs. In fact, it was experience with this kind of testing that originally led physicists to the idea that inertial confinement fusion might work as a source of energy.

SDI, of course, is a much more recent concept. Lasers are one class of device under consideration for SDI weaponry. While it would be highly impractical if not impossible to put something like Nova into orbit, Nova can test the effects of high-power laser beams on the sort of materials and objects SDI planners would like to shoot down. Matthews says Nova has done at least one such experiment. *— D. E. Thomsen*