The grating-actuated transient optical recorder (GATOR) is designed to acquire sequential images of x rays or optical light in a trillionth of a second or faster during experiments on the National Ignition Facility.

High-Speed Imager for Fast, Transient Events at NIF

FUSION ignition experiments at the National Ignition Facility (NIF), the only laboratory in the world capable of re-creating the extreme temperatures and pressures found in stars and in thermonuclear weapons, will last only a few billionths of a second. An actual fusion "event," when a capsule filled with tritium and deuterium—isotopes of hydrogen—undergoes ignition and thermonuclear burn, occurs in just trillionths of a second, much too quickly for traditional diagnostic and imaging equipment to record.

For the National Ignition Campaign to reach its goals of advancing understanding of plasma physics and helping to certify the reliability and safety of the nation's aging nuclear stockpile, a new generation of ultrafast, high-resolution diagnostic equipment must record events in picoseconds (trillionths of a second). To meet that need, Livermore physicists developed the grating-actuated transient optical recorder (GATOR), which won an R&D 100 Award. This optical instrument is designed to capture and record fleeting, sequential images of x rays and other radiation emitted from the miniature "stars" created in the NIF target chamber.

A New Concept to Record Ignition

An entirely new concept for high-speed imaging, GATOR encodes two-dimensional x-ray or optical images onto coherent light. Its design is derived from a 2009 Laboratory Directed Research and Development project on probing extreme high-energy-density states of matter with x rays. The instrument can provide the necessary time resolution in picoseconds to record x-ray or optical images of NIF's ignition events, enabling scientists to better understand the physical processes occurring in these experiments. Because the radiation conversion process is done optically, GATOR does not use charged particles and thus does not suffer from the fundamental space-charge limitations of commercial electro-optical systems, which can restrict a system's speed, spatial resolution, and dynamic range.

In addition, because GATOR can convert x rays and other types of radiation to coherent optical radiation, which can be transported and recorded remotely, the instrument can operate in an environment

in which copious amounts of neutrons, x rays, and gamma rays are released during ignition experiments. These radiation levels would almost certainly disable or destroy conventional detectors installed near an igniting capsule.

Creating Ignition at NIF

The extreme temperatures and pressures occurring during NIF ignition and burn—predicted by simulations to last for only 50-trillionths of a second—create enormous challenges for diagnostic instruments. During that time, conditions change rapidly, with the capsule emitting x rays, gamma rays, and neutrons. Two-dimensional images with a spatial resolution of about five-thousandths of a millimeter and a time resolution of about five-trillionths of a second are needed to measure the detailed physical processes. The instrument must achieve this performance without being affected by hard-to-shield neutrons and gamma rays or the electromagnetic pulse they generate. The GATOR diagnostic can record a sequence of images with picosecond time resolution, enabling researchers to measure these fast transient phenomena.

The GATOR diagnostic system has four elements: a grating, a specially prepared semiconductor, a probe laser, and a recording system. Radiation from an external source (in this case, the ignition event) strikes a grating or mask containing a series of thin bars that block some of the light. This pattern of light is then focused on a specially treated semiconductor, where it is absorbed. The absorbed light modifies the optical properties of the semiconductor in proportion to the intensity of the illumination. A probe laser beam striking the rear surface and reflecting off the front surface of the semiconductor passes through the optically modified semiconductor twice, diffracting a portion of the beam away from its original path. The focused pattern of the diffracted beam is a series of spots, one for each diffraction angle, arrayed symmetrically around the undiffracted part of the probe beam. The diffracted portion of the beam is relayed by a lens system and focused to form high-resolution images of the incident radiation on a charge-coupled-device detector located at a distance and heavily shielded from the experiment's high-energy background radiation.

Because the duration of the recording is determined by the duration of the applied laser beam, GATOR can acquire sequential images, capturing temporal changes in the target in a small "movie" of the fleeting event. The instrument converts the source radiation to optical images before slower-moving neutrons, charged particles, or debris can reach the semiconductor. Because GATOR is an all-optical device, no electronics or cables need to be located near the x-ray source, helping make the system much less vulnerable to the potentially destructive effects of radiation and electromagnetic-pulse fields. Livermore calculations show that the instrument can produce useful images in environments with neutron yields greater than 20 megajoules.

A flexible system, GATOR can be adopted for any application in which very fast, high-power energy sources are used or created, including high-power lasers, free-electron x-ray lasers, and high-energy-density objects. GATOR will allow detailed measurements to be taken of the ignition conditions involved in studying the high-energy-density physics of thermonuclear burn, advancing scientific understanding of stars and furthering stockpile stewardship.

—Arnie Heller

The GATOR development team: (from left) Steve Vernon, Rick Stewart, Warren Hsing, Mark Lowry, and Paul Steele. (Not shown: Susan Haynes.)

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