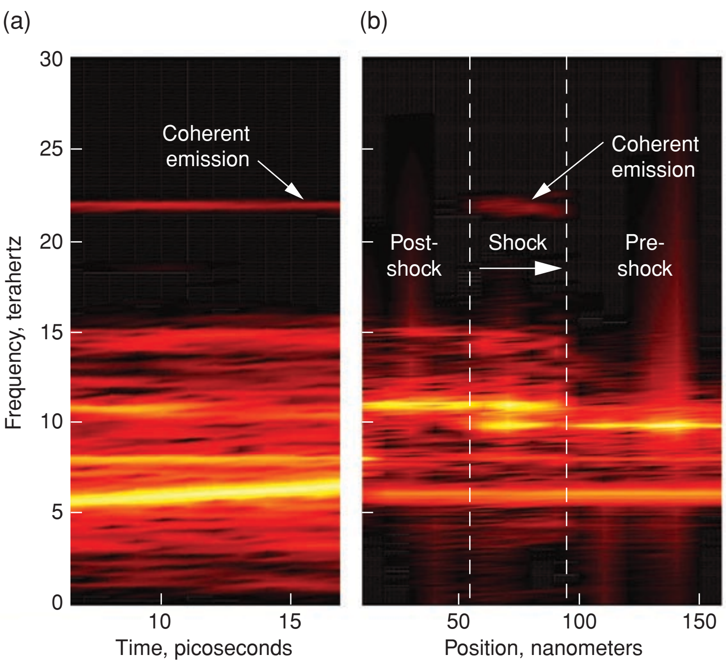
# A Shocking New Form of Laserlike Light

A Livermore scientist has predicted a new method for producing coherent light, one of the few since the invention of lasers nearly half a century ago. This novel, laserlike light is made by whacking certain kinds of crystals with a sharp mechanical shock.

"In the past, we expected to generate mostly random photons and possibly some 'sparks' when shocking a crystal," says Livermore's Evan Reed, who came up with the mechanical-shock concept for generating coherent light. "We found one can also produce coherent light in the terahertz region—a frequency band below infrared but above that used by cell phones." Narrow bandwidth radiation in the terahertz range, like that generated in these shocked crystals, is an area of interest and active research at the Laboratory. Coherent radiation could potentially be used in a host of applications, such as a diagnostic for shock waves and for explosives detection. Other applications may also arise. When lasers were invented in 1958, they were considered novelties with limited practical use, yet laser light is now a part of everyday life.




In a molecular dynamics simulation of shocked sodium chloride, coherent light is emitted at 22 terahertz. (a) The emission of the light is shown as a function of time while the shock is propagating. (b) The generated radiation is shown as a function of location within the shocked crystal, indicating the 22-terahertz coherent signal is generated at the shock front (between the dotted lines).

## Coherently Speaking of Light

Anyone who has observed the red light from a laser pointer or a grocery store checkout scanner has seen coherent light in the visible part of the spectrum. The photons emitted in coherent light all have the same wavelength and frequency. (In incoherent light, such as that emitted from a light bulb, the wavelengths vary randomly.) Not only are the photons at the same wavelength in coherent light, the waves are synchronized, rising and falling in concert. This characteristic is what gives laser light its special properties and its high brightness.

In lasers, a pulse of light is focused on a lasing material, and the light's energy is absorbed by the electrons in the material. The electrons "hop up" to a specific, higher energy level, then fall back down to their normal energy state when stimulated by a photon, releasing a photon of the same frequency. Thus, a single photon stimulates others to be released simultaneously. This phenomenon is what gives lasers their name: light amplification by stimulated emission of radiation. The mechanism by which a shocked crystal releases coherent light is quite different.

## The Crystallization of an Idea

Reed's research on coherent light stems from work he performed on shock waves propagating through photonic crystals while he was a graduate student at the Massachusetts Institute of Technology (MIT). Two years ago, Reed came to Livermore under a Lawrence Fellowship. (For more information about Lawrence Fellowships, see *S&TR*, November 2002, pp. 12–18.)

In the lattice of photonic crystal structures are "energy gaps" where certain bands of energy are not allowed, and thus no photons of corresponding frequencies are allowed to propagate through. "I thought it might be possible to get these crystals to emit light of specific frequencies, and the frequencies would be in the terahertz range because of the small lattice constants of ionic crystals," says Reed. "I began testing this theory to see if those possibilities might have some physical basis."

In his calculations, Reed used molecular dynamics and Maxwell-equation computer simulations, the LAMMPS code, and several other Livermore-developed codes to approach the problem. To ensure accurate simulation results, Reed needed to model tens of millions of atoms for tens of picoseconds (1 picosecond is a millionth of a millionth second). A simulation of this size required the capabilities of Livermore's 23-trillion-floating-point-operations-per-second Thunder supercomputer. Using Thunder, Reed and his colleagues, Richard Gee from Livermore's Chemistry, Materials, and Life Sciences Directorate and Marin Sojacic and J. D. Joannopoulos from MIT, modeled what would happen if dielectric crystal arrays were subjected to a sharp mechanical shock. For their simulations, Reed and his colleagues used crystals of sodium chloride (regular table salt) and then launched a virtual shock wave of the sort produced by laser light, a gas gun, or a projectile at the highly ordered arrays of atoms.

"We hit the crystal lattice arrays with a high-amplitude planar shock wave—a wave with a 'flat' front—and watched how the lattice responded," says Reed. The wave front excites the atoms in the first plane, causing them to move in a synchronized manner. The periodic motion of the atoms is then replicated in the next plane as the planar shock moves forward through the array. "Because the salt atoms carry a charge, the movement of these charged particles creates a temporally periodic electric current in the crystal," says Reed. "The charged particles move together, with the same amplitude and frequency, producing coherent radiation, or laserlike light."

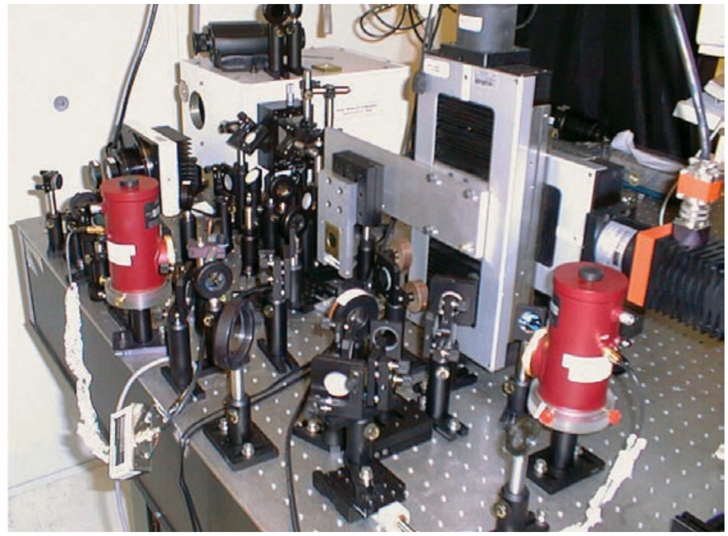
This effect, Reed noted, occurs at the front of the shock wave. The frequency of the emitted light is determined by the shock wave speed and the crystal lattice structure. "Most of the Laboratory's research on effects of shock waves focuses on what happens long after the front has passed," he says. "A great deal of work is being done on turbulence, chemical reactions in explosives, and other effects of shock waves on a material. Calculating and experimentally measuring what happens at the front of the shock wave is an entirely different area of research."

Results of the simulations showed that, indeed, coherent light was produced in the 1- to 100-terahertz range. This part of the spectrum has not been examined in shock experiments, because most shock wave probes are either at much higher or lower frequencies. "Detectors in this range are currently much less sensitive than those for other frequencies," says Reed.

### Stepping Up to Experimentation

"I didn't know in the beginning if anything would come of the theory," says Reed. "The Laboratory invested in this basic science question, and now it's come to fruition." Reed and his colleagues from the Laboratory and MIT are moving on to the experimental phase of the research. Reed recently received funding from Livermore's Laboratory Directed Research and Development Program to conduct shock-induced light experiments.

"We have gained confidence through our simulations that radiation will be present given certain experimental parameters," says Reed. "We're using well-established tools such as molecular dynamics simulations. We have just stretched their use to a different regime, calculating electromagnetic signatures of nonequilibrium phenomenon that have not been examined before." Reed, postdoctoral researcher Michael Armstrong, and researchers from Los Alamos National Laboratory are collaborating on experiments at the Los Alamos Center for Integrated Nanotechnologies to search for this signal in the terahertz range.



Researchers at Livermore and the Massachusetts Institute of Technology will use this experimental apparatus to attempt to produce coherent light from mechanically shocked crystals.

A number of possible applications beckon. Laserlike light in the terahertz range could be used as a diagnostic for understanding shock waves, including shock speed, and the crystallinity of a substance. Laserlike light in this frequency range could also propagate through walls and containers, enabling a unique imaging capability for security applications or aiding the remote sensing of explosives. In addition, signals could be used in spectroscopy to provide a window on a relatively unknown part of the spectrum.

Smash a crystal with a shock wave and probably the last thing one would expect to emerge is laserlike light. Yet, the physical world is full of surprises—and it's those surprising twists and turns that take scientists into unknown territory and often yield the most interesting results. Sometimes, it's a matter of keeping one's eyes open for the unexpected light.

*—Ann Parker*

**Key Words:** coherent light, crystal lattice arrays, ionic crystals, laser, molecular dynamics simulations, shock wave, terahertz frequency, Thunder supercomputer.

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