search & discovery

Phonon wind drives electron-hole droplets

If a semiconductor at low temperature receives a pulse of photons whose energy is larger than the band gap, the electrons and holes produced by the pulse are sometimes bound in neutral pairs, or "excitons." A few years ago several groups of investigators found that in some materials at sufficiently low temperatures, excitons, which normally behave like atoms in a gas, condense to form drops of liquid (see PHYSICS TODAY, December 1973, page 17). Recent work has clarified the nature of these drops and has illuminated the interaction between the drops, phonons and other features of the crystal lattice. Much of this work was discussed at the Edinburgh Semiconductor Conference in September.

Perhaps the most interesting development is the observation and measurement by several groups of a "phonon wind" that drives the electron–hole drops through the crystal. This wind is clearly demonstrated in experiments by John Hensel and Robert Dynes[1] at Bell Labs (Murray Hill), by Jim Wolfe and Michael Greenstein[2] at the University of Illinois (Urbana), and Joachim Doehler and John Worlock[3] at Bell Labs (Holmdel).

Droplets. After an electron and hole are created by a photon, they lose their kinetic energies very rapidly (nanoseconds) and bind together in relatively stable neutral pairs (lifetimes on the order of microseconds), which appear to behave as a gas of weakly interacting particles within the crystal. In some semiconductors, mostly indirect-gap materials, this gas condenses into a liquid phase consisting of small droplets, like a cloud of fog, that remains in the vicinity of the exciting pulse of light. The liquid phase appears to be metallic, that is, the carriers (electron and hole) are dissociated, not bound, as in an exciton. The drops can be seen by the light emitted when the electron–hole pairs recombine.

Most of the experiments have been done with germanium, because the drops

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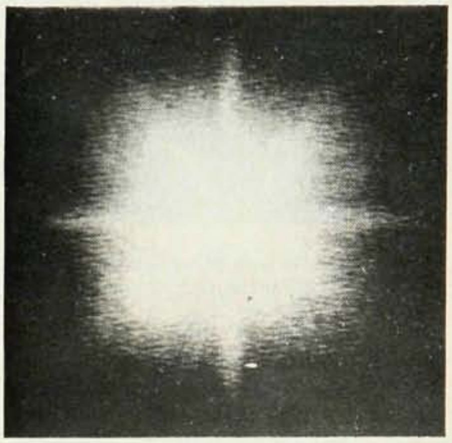


Cloud of electron-hole droplets in germanium as detected by their recombination luminescence. Droplets are excited by a laser beam focussed on the rear face of the crystal, at the center of the pattern. The view is into the (001) direction; the sharp spikes appear along the (100) axes and the broad lobes along the (111) directions. The photo shows an area of the crystal about 5 mm across. (From reference 2.)

Rochester operates user facility for laser fusion

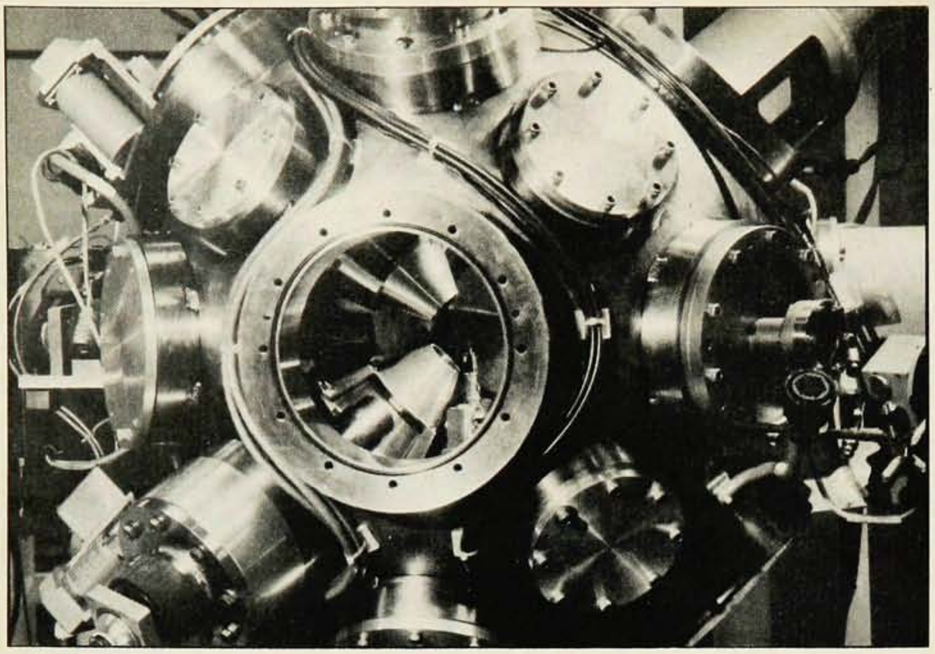
The University of Rochester is now operating a National Users Laser Facility. Last October the first stage of the 30-terawatt Omega system, which uses neodymium glass, began experiments. This stage, known as Zeta, has six beams and delivers 3–4 TW peak power. In December the second stage, with 24 beams and 12–16 TW peak power, is expected to operate. Construction has been supported by DOE. The last stage, still not funded, is planned to reach 30–40 TW peak power (energy of 10 kJ) by the addition of 24 active-mirror booster systems. The pulse shape can be tailored, with the total pulse length between 0.05 and 1 nanosec.

Meanwhile, the Rochester Laboratory for Laser Energetics, directed by Moshe Lubin, is encouraging potential users to submit proposals for beam time. Roughly one-third of the time can be made available to outside users. He notes that the lab is more user-oriented than other laser-fusion facilities and is particularly suitable for academic and industrial scientists. The possible experiments fall into four categories: inertial-confinement fusion, fundamental studies of the coupling of optical radiation with matter and energy, laboratory astrophysics (equation-of-state studies) and very short, intense x-ray generation.

In the US a number of other laboratories have high-power laser-fusion devices. Livermore is now operating a neodymium-glass laser facility, Shiva, which has 20 beams. It has already yielded 26 TW peak power and is expected to go as high as 30 TW. A larger facility, Nova, with 40 beams and 400 TW peak power, is planned for 1985–86. Los Alamos is currently operating a 10-kJ (17 TW) carbon-dioxide system, called Helios, and is constructing Antares, a 100-kJ system scheduled to run in 1983. KMS Fusion in Ann Arbor, Michigan is in the midst of upgrading its neodymium-glass laser facility to produce 2 TW in a short pulse and 1000 J in a longer pulse. This year KMS plans to further upgrade the facility to double the power and deliver 2000 J in a nanosec. The Naval Research Laboratory is planning to finish the upgrade of its Pharos II laser this spring, boosting the output to 4 TW peak power and 1 kJ in a 3-nanosec pulse.

Jack Wilson, deputy director of the Rochester lab, notes that such intense laser pulses as are available at Rochester and elsewhere generate equivalent pressures of greater than 10 Mbar in a target. And the temperature can be higher than 6 keV, he noted. Under these conditions, neutrons and intense x rays are generated from an essentially point source. So one can study, for example, the equation of state of matter under starlike conditions.

Even after dispersion, the x rays produced from the target are intense enough to expose film in very short time intervals. So one can make x-ray photographs, spectra and diffraction patterns in picoseconds, Lubin said, orders of magnitude smaller than possible with other techniques. For time-resolution applications, he went on, the high brightness of



Interim target chamber at the University of Rochester Laboratory for Laser Energetics uses the six beams of the Zeta neodymium-glass system. In December, 24 beams are expected to operate.

the laser plasma x-ray source makes it a unique tool. One could, for example make x-ray diffraction patterns of a biological specimen to study the temporal development of stimulated structural changes with better than nanosecond resolution. Lubin notes that photoreceptor membranes have picosecond response times.

In all three of its stages, Omega can operate with a repetition rate of about 30 minutes (and could run 18 hours a day), unlike the Livermore facility, for example, which has a repetition rate of several hours. The 30-minute rep rates are possible also with the Los Alamos, KMS and NRL lasers. Lubin emphasizes that the short duty cycle allows significantly greater data-gathering capability. He feels that the reproducibility of inertial-confinement data is important—that one needs 20 or 30 data points to draw reliable conclusions, particularly in trying to optimize target design.

The Rochester lab also has a variety of diagnostics available: on-target and target-reflected energy, prepulse characterization to less than 1 microjoule within 1 nanosec of the laser pulse, incident and reflected pulse time history, and on-target irradiation profile. The target tank has x-ray streak and pinhole cameras, detectors and spectrometers, nuclear-reaction product detectors and light and plasma calorimeters.

Those interested in using the facility should contact Wilson at the lab, who will advise potential users how to seek support. Research in these fields has been traditionally supported by universities and by government agencies, such as DOE, the Department of Defense and NSF. The Foundation, for example, has indicated that it will consider proposals from potential users in the normal competition occurring in each appropriate program. Such an approach has been used in the past for high-energy physics, in which NSF supports users at DOE laboratories. —GBL

Progress on deep-sea neutrino detection

For several summers, a group of physicists, astrophysicists and oceanographers interested in using the oceans to detect ultrahigh-energy cosmic-ray neutrinos have been meeting to exchange ideas. Their interest arises because clean seawater could provide the massive detector needed to observe low fluxes of weakly interacting, deeply penetrating neutrinos (PHYSICS TODAY, April 1976, page 18). The detector volume, about one cubic kilometer, located 5 km or so underwater, would avoid gross interference from ordinary cosmic rays. Organized as DUMAND (Deep Underseas Muon and Neutrino Detector), the group has been formulating the questions that would need to be answered in any feasibility study of the project. The most recent workshop[1] took place 24 July–1 September at the Scripps Institution of Oceanography, La Jolla, with about 90 participants from the US, the Federal Republic of Germany, Japan and the Soviet Union.

Although the project has no specific funding as of yet, some parameters have been determined, explained Frederick Reines (University of California, Irvine), chairman of the DUMAND executive committee. For example, to detect neutrinos by means of the Cerenkov light produced by the secondary muons and hadronic cascade, the transparency of the water is critical. Water with optimal properties has been found near the Hawaiian Islands.

One working group concentrated on practical construction and deployment techniques and came up with several new schemes. The least expensive and most reliable of these, according to Reines, would use a drill ship to emplant and connect preassembled packages. The workshop participants came up with a standard DUMAND array: a hexagonal arrangement of detectors that is being used in all studies of design problems. The array contains about 25 000 optical detectors in a set of string-like patterns. And, for the first time last summer, data processing was discussed at length.

The total cost of this DUMAND array is estimated at \$50–100 million. Grants from the US Department of Energy, NASA, NSF and the Office of Naval Research partially supported the workshops, and proposals are in to support a full feasibility study. In addition to Reines, the DUMAND executive committee includes Howard Blood (Naval Ocean Systems Center, San Diego), Hugh Bradner (Scripps), John Learned (University of California, Irvine, and University of Wisconsin, Madison), Arthur Roberts (Fermilab) and George Wilkins (Naval Ocean Systems Center, Kaneohe, Hawaii).

Acoustics. A development closely related to DUMAND is the recent determination that acoustic detectors could be feasible for high-energy neutrinos. This idea was first suggested by Theodore Bowen (University of Arizona, Tucson) and, independently, by Boris Dolgoshein (Moscow Physical Engineering Institute), and discussed at an earlier DUMAND summer session. Stimulated by these discussions, a group of physicists from six universities have now done some experiments at Brookhaven National Laboratory and at Harvard University, with protons from three different accelerators—the 200-MeV linac at Brookhaven, the 158-MeV cyclotron at Harvard and the 28-GeV proton fast-extracted beam at Brookhaven. The proton beams simulate the particle showers produced by neutrino interactions. These experiments were reported in November at the joint meeting of the Acoustical Society of America and the Acoustical Society of Japan in Honolulu.[2]

The group found that the energetic charged-particle beams produced a signal that could be detected with hydrophones, and that the acoustic wave observed agreed with the predictions of a thermal expansion model. This agreement is important because significant contributions from such phenomena as microbubble formation could complicate data analysis. As Lawrence Sulak (Harvard) of the acoustics-studies group explained to us, knowledge of the responsible mechanisms is needed to design an