Getting the Drop on Lasers

Tiny drops of liquid can become lasers with important uses for science and technology

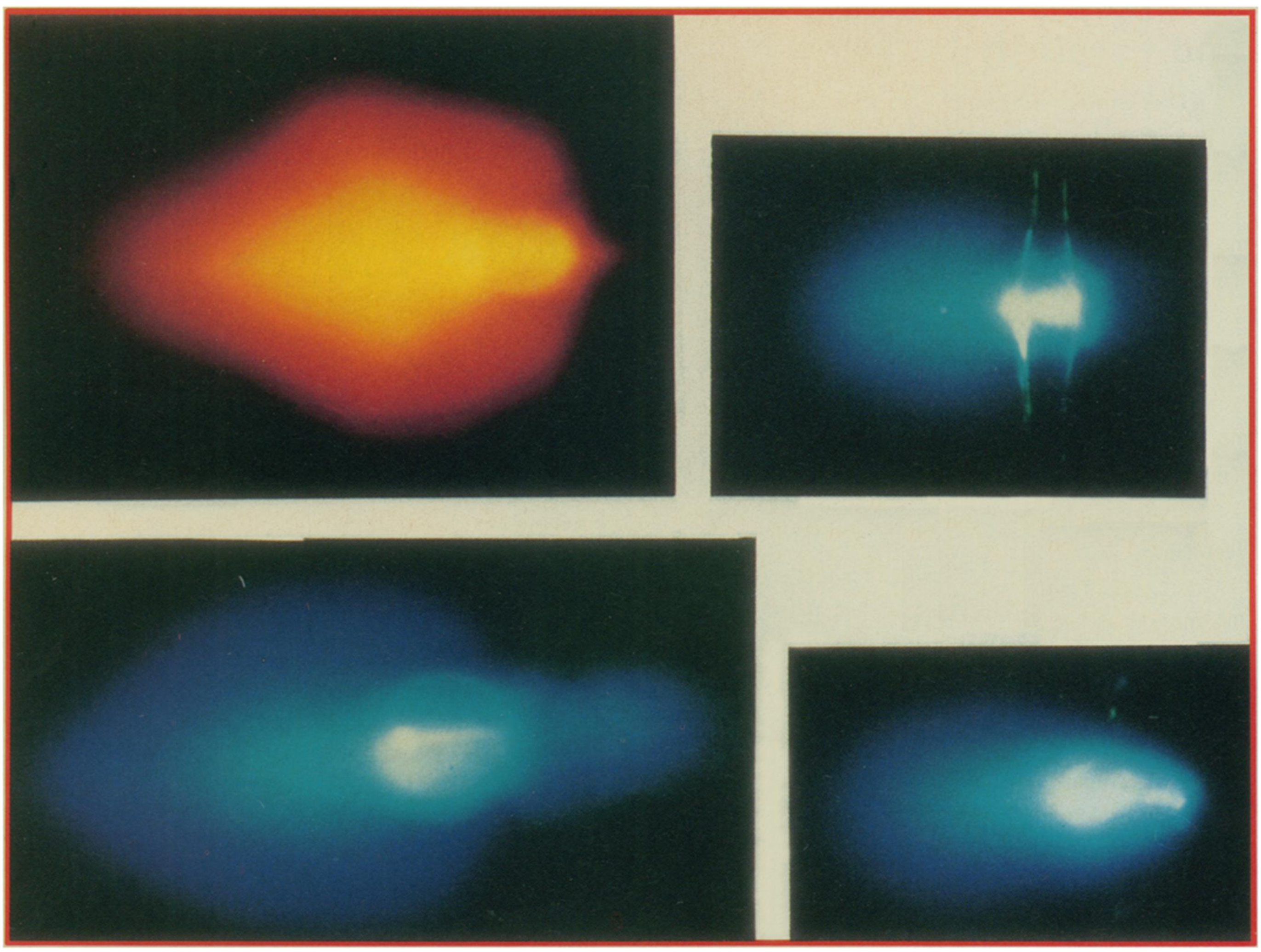
By DIETRICK E. THOMSEN

Liquid drops appear in many facets of nature, art and technology: mist, rain and fog; fuel in engines; chemical reaction processes; biological culturing techniques. They also show up in physical experiments on the mechanics, evaporation and ionization of liquids. Shining laser light on tiny liquid droplets can produce a number of what scientists call nonlinear optical effects, in which the wavelength of the incoming light is altered, or its intensity amplified, or both. These effects can yield important information on the physics, chemistry and biology of the droplets.

In such experiments a group of scientists, led by Richard K. Chang of Yale University's Center for Laser Diagnostics, has produced such nonlinear phenomena as fluorescence, stimulated Raman scattering and lasing. Most recently they have produced explosive disruption of the drops, as Johannes Eickmans, Wen-Feng Hsieh and Chang will report in the January OPTICS LETTERS. Others involved in various stages of the work include Shi-Xiong Qian of Fudan University in Shanghai, Judith B. Snow of the Naval Underwater Systems Center in New London, Conn., and Huey-Ming Tzeng of the IBM Research Laboratory in San Jose, Calif.

Chang told SCIENCE NEWS that his interest in the field he calls laser-induced spectroscopy was aroused by studies of the interaction of laser light with particles of coal. He decided, however, to study what happens to transparent droplets, mainly ethanol and water. It is at the higher intensities of incoming laser light that all these interesting nonlinear optical effects begin. The droplets, characteristically 35 microns across, are produced by a device that shakes them off the bottom of a column of liquid so that they drop through the region where the laser light shines on them.

As Chang described the interaction to the recent Second International Laser



Images: Chang

In breakdown, spherical and nonspherical droplets develop both forward and backward plumes. Bright spots in backward plume (see especially upper right image) indicate air breakdown. Views are through red or blue filters.

Science Conference held in Seattle, the laser light that strikes the droplet gets refracted and tends to focus into a hotspot on the shadow side of the droplet. There the light interacts with the electrons of the substance of the droplet. It may produce fluorescence, in which particular energy transitions of the electrons are excited to produce certain resonant wavelengths of reemitted light. Or it may produce Raman scattering, in which the light reacts collectively with a bunch of electrons so as to alter its wavelength. Characteristically green light comes in and red or orange comes out.

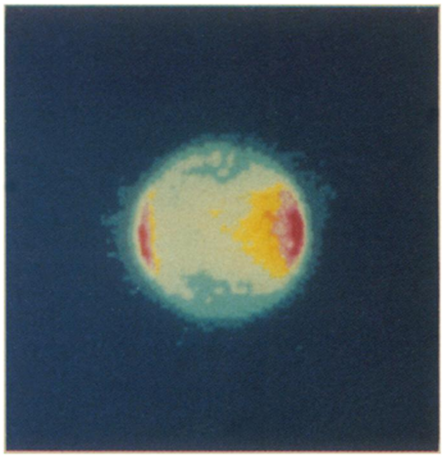
The altered light then travels around the inside of the droplet along a polygonal path, being reflected back into the droplet many times as it strikes the liquid-air surface. If the traveling wave returns to the hotspot in phase with the vibrations of the electrons going on there, gain, or energy buildup, can occur if the light has not lost too much energy to absorption and leakage on the way around.

Lasing can come from gain. Chang told the conference that the experiments had produced all the characteristics of a laser except directionality: Light from the lasing droplets comes out in all directions.

Typically, a laser's light comes out in a narrow, well-directed beam. This directionality is one of the traditional and expected advantages of a laser. However, if anyone needs a laser that shines in all directions, Chang says, here it is. Put a little rhodamine in the ethanol and it becomes a nice little dye laser, he says.

The Raman effect is repetitive. As light that has been Raman-shifted once travels farther into the material, it will be shifted again and again. Light traveling around the insides of these droplets has undergone as many as 14 successive Raman shifts. In this 35-micron droplet, Chang says, the same number of Raman shifts occurs as one would expect in light traveling through 15 meters of a transparent fiber. This spectrum of Raman-shifted wavelengths — and the fluorescence spectra as well — can identify the substances present in the drops. Minute impurities — of sodium or rhodamine, for example — can be detected and followed.

The outcoming light lets scientists study the morphology of the droplets, on which the resonances also depend. The spectra can give information on evaporation rates; if the drop is a mixture, the spectrum will change as the different substances evaporate at different rates at different temperatures, and so the changes in composition can be charted. Chang says biologists are interested in the method because the spectra give them a means to discriminate between droplets containing live cells and those containing dead ones. Thus they can sort out their cultures and samples. Researchers interested in combustion, in the detailed behavior of fuel droplets, can also use these studies.



False color indicates intensity of fluorescence from droplet, with highest intensity from hotspot at right.

Among the scientists most interested are those who want to propagate laser beams long distances through the atmosphere. One of their main desires is to know what happens when the laser power gets high enough to induce explosive breakdown of the material. In pure air, breakdown does not occur, Chang says, but whenever water and dust are present, it will happen.

The specialists have been arguing whether the breakdown starts in the water droplets or in the nearby air. As breakdown proceeds, plumes of ionized material appear on two sides of the droplet: in the forward direction where the original laser beam comes out of the droplet and in the backward direction where the laser beam first strikes the droplet. The question particularly was whether the ionized material first forms inside the droplet and is expelled as plumes, or whether ionization starts in the nearby air and is then driven into the droplet.

The results of the latest series of experiments show a three-step process. At relatively low intensity of the incident laser beam, only stimulated Raman scattering occurs in the droplet. At higher intensity a plasma, an ionized gas, begins to form in the region of the hotspot on the shadow side of the droplet. This pushes out as a plume in the forward direction. Still higher intensity of the incident light triggers a backfire, a plasma wave going against the incident light, which comes out as the backward plume.

Only in this backward plume does evidence of the breakdown of air appear. Thus it seems that the breakdown begins within the water droplet. Quite an impressive plasma appears there, according to Chang. It has a temperature of about 6,000°K and a density of detached electrons of 10^{18} per cubic centimeter. Chang says he is just starting to learn the plasma physics involved. □