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HIGH-SPEED LASER CAMERA

By incorporating a laser in a high-speed camera, Caltech engineers have now made it possible to observe extremely rapid phenomena under high magnification. The high-speed laser camera not only greatly improves the quality of observations; it opens up an entirely new avenue of dynamic observation.

The laser (an acronym for *l*ight *a*mplification by *s*timulated *e*mission of *r*adiation) is an exciting new development being pursued by scientists in a variety of fields, from communications to medical instrumentation, welding, and weapons.

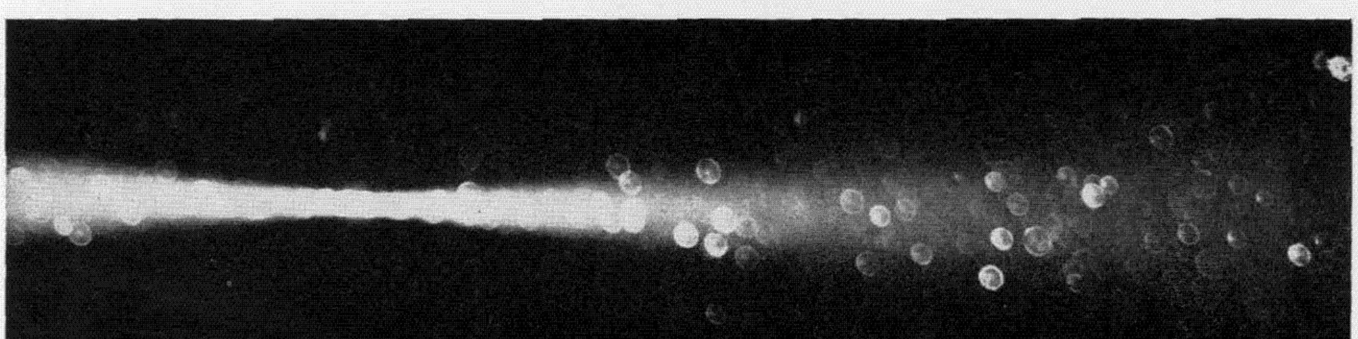
Basically, the laser is a device that converts ordinary light, which is of many wavelengths, into coherent light of one narrow wavelength moving in one direction. By means of optical pumping, the atoms in a synthetic ruby doped with chromium ions are caused to emit photons of light of one particular wavelength. Due to the crystalline structure of the ruby and the nature of stimulated radiation, the light which is emitted is coherent, monochromatic (one wavelength, or color), and linearly polarized. The intensity of this light is thousands of times greater than any previously obtainable light source.

The light in a ruby laser is ordinarily emitted in random, short-duration pulses of uneven intensity. Now, however, Dr. Albert T. Ellis, associate professor of applied mechanics at Caltech, and Michael E. Fourney, a graduate student, have converted the laser's random pulses into a series of pulses of uniform intensity up to repetition rates of over 500,000 pulses a second. The power in this laser beam is equivalent to more than 20,000 hundred-watt bulbs.

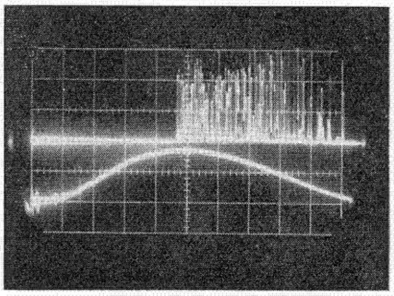
This provides enough light for the extremely short exposures necessary in taking motion pictures of very fast events. The instrument also enables researchers to use the laser pulses, in effect, as a camera shutter for filming at the rate of 500,000 frames a second. Exposure times as short as one billionth of a second are possible.

The primary objectives in the development of the laser camera are to study cavitation damage, to study dynamic phenomena in solids by means of photoelasticity, and to study fluid flow by means of scattered light from very small tracer particles as well as by standard Schlieren techniques.

Cavitation bubbles, generated by propeller blades, might typically grow to about 1/10 inch in diameter and live about a thousandth of a second. The impact of millions of these bubbles, collapsing with the pressure of 10,000 to perhaps

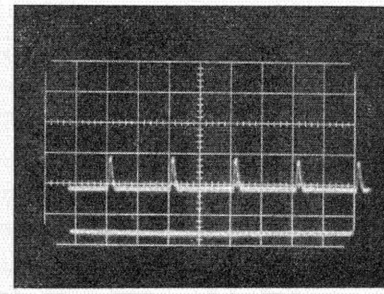


Vapor bubbles in water, generated by a focused laser beam. Magnified approximately 20 times.



Left: Traces from a dual-beam oscilloscope show (lower trace) the intensity of the light entering a ruby laser and (upper trace) the random pulse intensities and timing of the light emitted by the ruby.

Right: Photocell record of the light emitted by the ruby when pulsing is controlled by a Kerr cell at 500,000 per second.



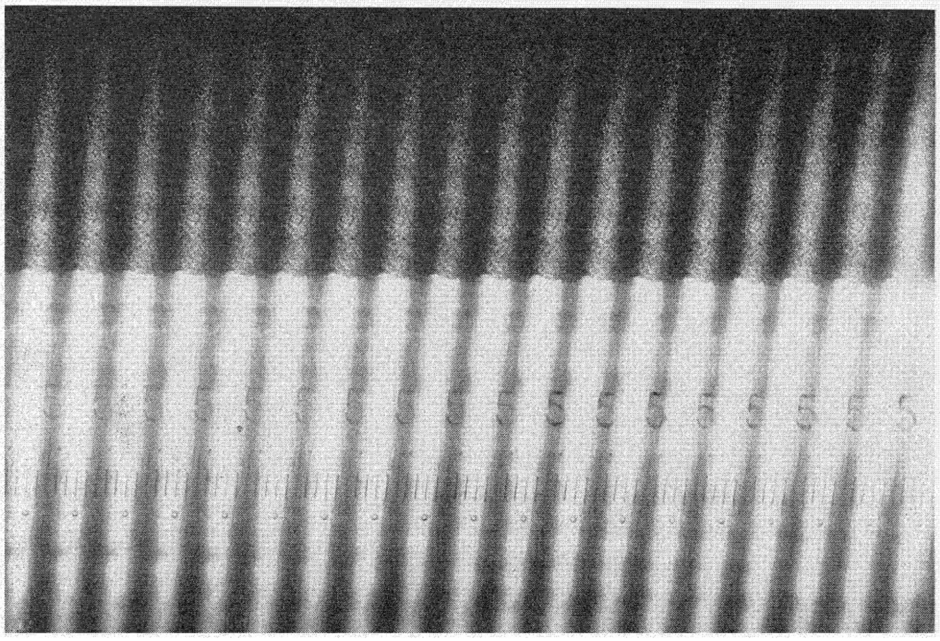
1,000,000 pounds per square inch, quickly eats away metal surfaces. Their damage to ship propellers and pumps has been a major problem for 100 years.

Dr. Ellis has been interested for some time in high-speed photography as a tool to study cavitation damage. With a multi-million-frame-per-second camera which he designed and built a decade ago, he has studied the history of a collapsing cavitation bubble. The newly developed laser camera makes a more detailed study of this possible. Also, now, the action of cavitation on a solid boundary may be observed by means of photoelastic techniques, a field in which Mr. Fourney has worked for the past few years.

The laser used in this camera consists of a ruby rod 3 inches long and ¼ inch in diameter enclosed in a cylindrical cavity of elliptical cross-section with highly polished surfaces. The ruby rod is located at one focus of the ellipse and a pumping light at the other; consequently, all of the pumping light is focused into the ruby rod. In the normal ruby laser, both ends of the cylindrical ruby rod are reflective so that light traveling along the axis of the rod will be reflected back into the rod. One end has a partially transmitting mirror so that a small portion of the light is allowed to escape on each pass. This light represents the output of the laser. As the light makes several passes through the ruby, the intensity is amplified by a cascading process as each photon of light, striking an atom in an excited state, causes it to fall to its ground state. This results in two photons of light of the same wavelength and phase relationship, traveling in the same direction as the incoming photon.

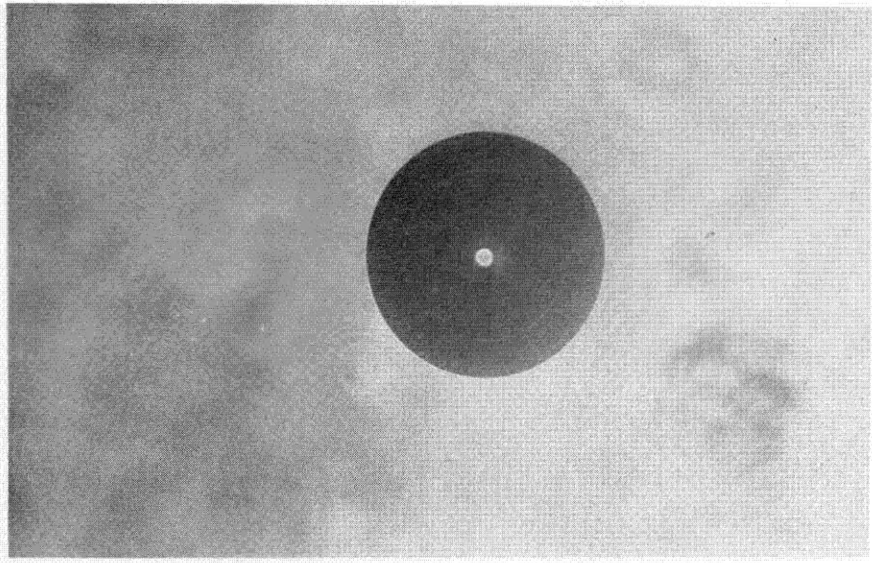
By introducing a Kerr cell in the light path between the active ruby material and the partially reflective mirror a shuttering effect is achieved. A Kerr cell is a small glass cell containing liquid nitrobenzene and two nickel electrodes. When no voltage is applied to the cell, the polarized light passes through without alteration. However, when a voltage is applied the nitrobenzene molecules are aligned in such a manner that the direction of polarization is rotated. Upon application of the proper voltage (10,000 volts for the cell used in the present experiment) the "lasing" action may be stopped. Thus, the lasing action may be controlled by regulating the voltage applied to the cell. The effect is similar to that of raising a dam so that more water (in this case, photons) is contained in the reservoir (crystal rod). When the dam (the Kerr cell shutter) is suddenly removed, a flood of photons is released through the partially reflecting mirror.

The Kerr cell as a shuttering device for a laser



In high-speed photography, light intensity requirements are much more severe at greater magnification. This test photograph of a ground-glass microscope scale, magnified 25 times, shows the sharpness that can be achieved with the laser camera operating at 200,000 frames a second. Division marks on the scale are 100 microns apart.

An air bubble, 0.13 centimeters in diameter, photographed in silhouette with light from a ruby laser. The bubble is held stationary by a sound field.



was first used by Robert W. Hellwarth and F. J. McClung at the Hughes Research Laboratories in Malibu, California. Dr. Hellwarth, a lecturer in physics at Caltech, and Dr. McClung produced a single pulse in which the amplitude was observed to be a thousand times greater than that of a normally operating laser. Dr. Ellis and Mr. Fourney have been able to produce multiple pulses in which the amplitude is also greatly increased. These light pulses are then used as a stroboscopic light source for the laser camera.

Dr. Ellis plans to use this newly developed laser camera in conjunction with a "blow-down" water tunnel for studying the collapse of cavitation bubbles in flowing water, the environment in which they are normally generated. Previously, in studying cavitation bubbles in still water, Dr. Ellis and his former student, Dr. Charl Naudé, had developed a theory that the damage is caused by a jet of water that pierces the bubble opposite to where it is in contact with a solid surface. With the assistance of another graduate student, Michael E. Slater, Dr. Ellis has developed the blow-down water tunnel, with velocities of up to 100 feet a second, in hopes of extending this theory to collapsing bubbles in flowing water. Assisting also on this project is Dr. J. S. Barnard, research fellow in hydrodynamics. This research, as well as the development of the laser camera, is supported by the Office of Naval Research.

Test photograph by scattered light of a concentrated solution of polystyrene spheres, .258 microns in diameter —smaller than the wavelength of the light used in taking the picture.