Free-Electron Laser for the Far Infrared

Using a scanning electron microscope scrounged from colleagues, a team of researchers at Dartmouth College in Hanover, New Hampshire, has built a compact, low-power free-electron laser that generates tunable coherent beams in the far infrared (FIR) spectral region, which ranges from about 10 μm to 1 mm. Researchers have long desired a convenient source of radiation in the FIR region of the spectrum because it is a window for measuring the vibrational spectra of gases, liquids, and solids, and the rotational spectra of atoms and molecules. Applications include studying plasmas, semiconductor nanostructures, the behavior of long-chain molecules, and the constituents of the atmosphere.

Led by physics professor John E. Walsh, the team made inexpensive modifications to a surplus scanning electron microscope so that it could send a beam of electrons across a metal diffraction grating. As the electrons pass over the grooves of the grating at nearly the speed of light, electromagnetic coupling forms oscillating dipole arrays that emit wavelets of energy in the form of infrared light—a phenomenon known as the Smith–Purcell effect. The beam can be tuned by changing the grating period, the angle of the grating to the beam, or the electron beam voltage.

The scanning electron microscope produces electron beams with energies from 20 to 40 kV and a current of less than 1 mA. At the grating, the beam must be focused down to a size less than the wavelength of the emitted radiation, which is not a problem for an electron microscope. In the Dartmouth free-electron laser, the electron beam is focused to a cross section of about 20 μm. Gratings of about 100 to 300 μm, which are relatively easy to fabricate, generate FIR wavelengths from 300 to 900 μm.

The prototype device generates FIR output in the microwatt range, which is adequate for use with highly sensitive detectors. The Dartmouth team is working to boost the power output into the milliwatt range, which should be sufficient for most ordinary spectroscopic measurements.

The Dartmouth device easily fits on a tabletop, but Walsh suggests that in time the device will "fit in the palm of your hand like a deck of cards." When he started developing a compact free-electron device about 10 years ago, free-electron lasers were huge, some the size of a five-story building. Walsh has applied for a patent for a "grating-coupled free-electron laser apparatus and method." Vermont Photonics, Inc., (Brattleboro, VT) is developing a commercial version of the laser.

Small devices would make it possible to use FIR in factories, in the field, and in space. "The potential uses of a portable device are enormous," says Hayden Brownell, a senior research associate on the team. "A unit could be used to increase the sensitivity of far infrared telescopes by many orders of magnitude, and could do the same for satellite-borne sensors that detect changes in the atmosphere."

Walsh notes, "Reaching this kind of research goal is always a team effort." Members of the research team included graduate student John Urata, who first observed that the device had succeeded in producing a coherent beam, and doctoral candidate Michael Goldstein, who first observed spontaneous emission from the device (both now at Intel); senior research associate John Swartz; and Maurice Kimmitt, emeritus professor of physics at the University of Essex in England and adjunct professor at Dartmouth College.

Motion in Microdevices

Photographing movement in microelectromechanical systems is difficult because of the tiny dimensions of the components and the relatively high velocity of their movements. Recently, researchers at the University of Ulm in Germany, using a new ultrahigh-speed digital camera, have developed a prototype imaging system for capturing the nanosecond dynamics of moving parts in microdevices. The prototype will be exhibited in April at the Hanover Industrial Fair in Germany.

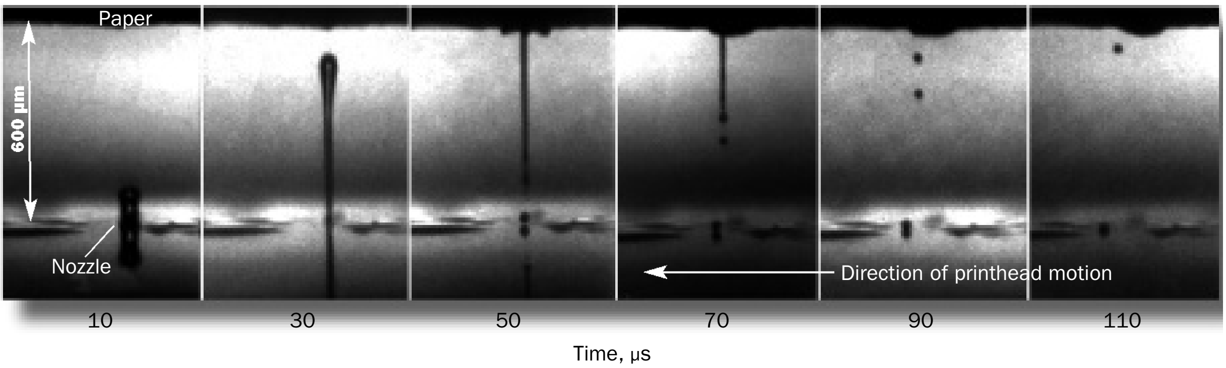


Figure 1. The droplet ejection from a moving printhead was imaged with the help of an intense pulsed light source, an ultrahigh-speed camera, and a standard optical microscope.

The Imacon 468 camera, developed by DRS Hadland (Tring, U.K.), a subsidiary of DRS Technologies (Parsippany, NJ), uses a novel beam splitter to divide the incoming beam into eight images that are conveyed via optical fibers to eight charged-coupled devices (CCDs) arranged in a circle around the beam splitter (see also *The Industrial Physicist*, 12/97, pp. 28-31). The camera system simultaneously captures both frame and streak images through the single optical axis. Software running under Microsoft Windows controls the camera and image display, and calculates velocity, distance, angle, and area.

The microtechnology research group at the University of Ulm, headed by Eberhard P. Hofer, mounted an Imacon 468, a xenon lamp, and a standard optical microscope on a test rig. The image to be recorded, which can be magnified up to 500 times by the optical microscope, passes directly into the Imacon camera. The CCDs have gated image intensifiers that can operate at up to 100 million frames per second, which permits exposures as brief as 10 ns. The exposure time can be changed in 10-ns steps up to a maximum of 1 ms.

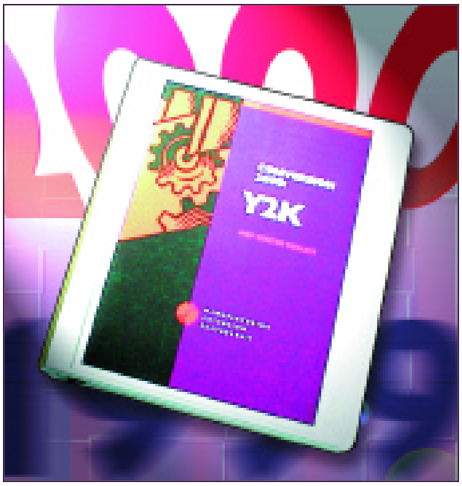
With this prototype system, Hofer's group has analyzed the motion of several microdevices, including a 350-µm microturbine rotating at 200,000 rpm; the oscillation of a microrelay with a switching time of 400 µs; the operation of a thermal micropump with a heating cycle of 2 µs; and droplet ejection in a thermal ink-jet printhead (Figure 1).

The Imacon digital imaging system is used mainly in military applications, such as measuring crack propagation and stress failure in aerospace materials, impact resistance of composites for body armor, and detonation phenomena. Industrial applications include photographing the early stages of combustion in automobile engines, analysis of high-voltage discharge, and studies of plasmas.

For standard high-speed imaging, the Imacon 468 camera can be fitted with 50- to 600-mm Nikon lenses. Options include infrared, ultraviolet, and high-speed schlieren imaging. According to Hadland, capturing multiple discrete image frames from the single optical input in the Imacon avoids the image displacement that occurs when several high-speed cameras are mounted side by side.

— Update —

The National Institute of Standards and Technology (NIST) and the University of Colorado at Boulder have jointly developed a key time-testing tool for the year 2000 glitch in computers (see *The Industrial Physicist*, 12/98, pp. 9-10). A supporting grant from the National Science Foundation helped fund the creation of the new software for the Y2K problem.



NIST's time and frequency division has set up a special time-checking service available over the Internet or by direct modem dial-up that one can use to test how a computer handles dates after the year 2000. The service transmits the exact time and a date that is exactly two years in the future. For example, if the service is accessed on March 1, 1999, it will return the exact time and the date March 1, 2001. The service supports all common digital time formats. The time of the date is directly traceable to the NIST atomic clock that is used to set the official time in the United States.

Software that enables Windows 3.x/97/98 to use the NIST Y2K test time-server is available free from the NIST Y2K Web site (www.nist.gov/y2k). Computers that have time-setting software can access the service directly (y2ktest.timefreq.bldrdoc.gov, or IP address 132.163.135.136). Users of NIST's automated computer time service can get the Y2K time test by setting their modems to dial 303-554-7760.

Two new Y2K glitches have been reported. Microsoft, which previously said that Windows 98 was year 2000 compliant, has admitted to a bug in its new software and has issued a free patch to fix it. During start-up, Windows 98 accesses the real-time clock on the microprocessor, which keeps track of time when the computer is turned off. If the start up occurs during the fraction of a second when the time is changing in the clock, Windows 98 may display the wrong time or date. A Microsoft spokesman claims that the error was caused when a programmer through habit mistakenly entered a two-digit code for the year, instead of four digits.

The second Y2K glitch, dubbed the Crouch–Echlin effect, also is thought to result from a misreading of the real-time clock during start-up. It was discovered accidentally when Jace Crouch, a history professor at Oakland University in Michigan, left the date in his AT (Intel 286 microprocessor) personal computer set at the year 2000 after it successfully rolled over from 1999 to 2000. In the next few weeks, he found that the date jumped ahead sporadically after the PC had been turned on and off; and other anomalies cropped up.

A computer programmer with Atomic Energy of Canada Limited, Michael Echlin, became intrigued with the problem and began testing a variety of PCs. He determined that the jump in dates occurs randomly forward and backward in old microprocessors that do not have buffered real-time clocks. When a PC is turned on, the BIOS (basic input–output system) obtains the current time from the real-time clock. If the clock happens to be turning over to the next second, the BIOS is programmed to wait briefly. In a buffered system, the BIOS obtains the time from memory rather than directly from the clock.

Echlin believes he has traced the problem to the interaction between the BIOS and an unbuffered real-time clock when the date is set beyond the year 2000. A few of the older BIOS, he says, take a longer time to calculate dates beyond the year 2000, and the extra time required can cause a misreading of the time registers and result in a faulty date. However, a number of computer experts do not agree with Echlin's findings, and some deny that the Crouch–Echlin effect exists at all. Even if it does, they say, it is not important because it is found only in outdated PCs.

Both the Windows 98 Y2K bug and the Crouch–Echlin delayed effect appear to be related to trying to read the real-time clock when it is turning over to the next second. In fact, this is an old problem that BIOS software developers have coped with for more than a decade. Now owners of old PCs may have to learn how to cope with it when our calendar enters its next millennium.