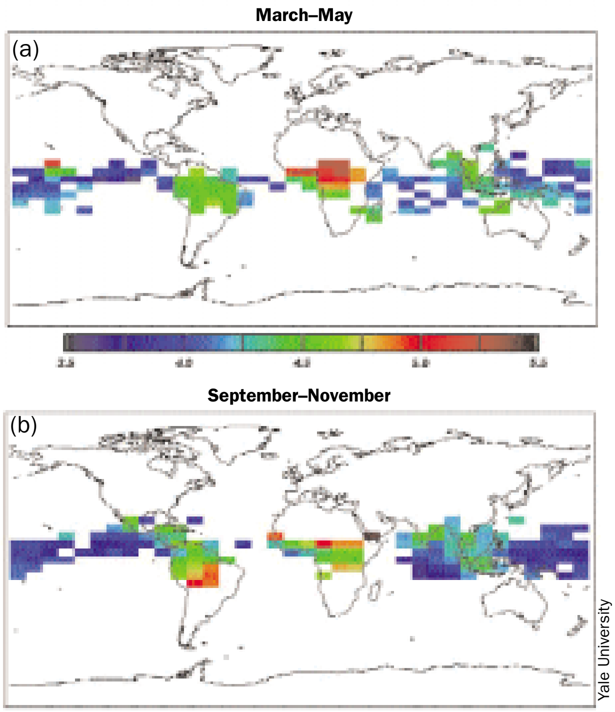
by Eric J. Lerner

Tropical fires feed global warming

Tropical deforestation has reduced biological diversity, fed carbon dioxide into the atmosphere, and disrupted water cycles regionally and, perhaps, globally. Now Yale University geophysicist Steven Sherwood has discovered another major impact. Smoke from the burning of vegetation in deforestation and agricultural clearing is driving up humidity in the stratosphere, and this increase in stratospheric water is exacerbating global warming and the depletion of the ozone layer.



Ice-crystal size in the tropics, averaged in spring over the northern (a) and southern (b) hemispheres, shows smaller crystals (red) over burn regions in Africa and South America.

Humidity in the stratosphere has doubled during the past 50 years, with half the increase due to the oxidation of increased amounts of methane. But the cause of the other half of the increase has been more mysterious. Sherwood thought that the increased humidity could result from a slight shrinkage in the size of ice crystals that circulate from the lower atmosphere up to the stratosphere and back. Because smaller crystals evaporate more rapidly in the stratosphere and fall back to lower altitudes more slowly than large ones, Sherwood calculated that even a slight shrinkage in average ice-crystal diameter could increase humidity by 25%.

Satellite observations now confirm the link between crystal size and stratospheric humidity (*Science* 2002, *295*, 1272). Space-based radiometers determine ice-crystal size by detecting the reflectivity of clouds and humidity and measuring the absorption in certain wavelength bands. Globally, Sherwood found that monthly fluctuations in ice-crystal size correlate with variations in stratospheric humidity.

But why the slow shrinkage in ice-crystal size? "There is strong evidence that the reason is smoke from biomass burning," says Sherwood. Burning vegetation creates huge numbers of fine smoke particles that act as nuclei on which ice crystals form. The more smoke produced, the more ice crystals and, given a constant supply of moisture in the lower atmosphere, the smaller each ice particle is. Again, satellite data show a strong correlation month-by-month and regionally between increases in smoke from biomass burning and decreases in ice-crystal size. As biomass burning has increased, ice-crystal size has apparently shrunk, leading to the increase in stratospheric humidity.

The rise in humidity contributes directly to global warming because water vapor, which is a greenhouse gas, warms the atmosphere beneath the stratospheric layer. Conversely, increased stratospheric humidity blocks heat rising from below and cools the stratosphere itself. "With increased humidity and colder temperature, more stratospheric ice clouds are produced," Sherwood points out. "It is in these ice clouds that the chemical reactions take place that destroy ozone."

Sherwood's findings have important implications for public policy. If smoke from biomass burning turns out to have a significant impact on climate and ozone depletion, eliminating export-oriented policies that encourage forest clearing may become critical to slowing global climatic change. Ω

Raman lasing from spheres

Raman lasers are desirable for many applications because they can extend the useful wavelength range of other lasers. They do this through a nonlinear interaction between the laser light and phonons—vibrations in the lasing material. The interaction pumps energy from the light to the phonons, shifting the light to longer wavelengths. Raman amplification is also becoming important in fiber-optic communications as more and more different wavelengths are piped through a single fiber.

But a disadvantage of Raman lasers is that the nonlinear interaction requires a high intensity of light and thus high pumping power. This makes Raman lasers too large to fit on a microchip or to incorporate into a variety of inexpensive and portable devices. Now K. J. Vahala and graduate students Sean Spillane and Tobias Kippenberg at Caltech have shown that Raman lasing can take place at very low pumping powers, simply by using tiny spheres of silica glass (*Nature* **2002**, *415*, 621).

Although a typical laser uses two mirrors at the opposite ends of a lasing cavity, a microsphere sends laser light around in a circle, reflecting the light repeatedly off the inside curve of the sphere. This is termed a "whispering-gallery mode" after the curved-ceiling rooms that similarly reflect sound waves and allow a person to hear a whispered conversation from many yards away. The smaller the microsphere, the smaller the pumping power needed to achieve the nonlinear Raman effect.

"The difficult part is to get the light in and out of the microspheres," explains Vahala. Early experiments pumping liquid-droplet microspheres with laser beams carried through the air had very low efficiency. The Caltech group's calculations showed that coupling in and out of the 70-μm spheres could be improved by using fine fibers only 1.5 μm in diameter. Ordinary optical fiber would not do because the light waves are trapped deep within the fiber. In addition, calculations showed that the fiber diameter was critical because it affected the speed of light through the fiber.

"The speed of light in the fiber must nearly match the speed of light in the spheres for high-efficiency coupling, which occurs with a 1.5-μm fiber," says Vahala. The team formed the ultrafine fiber by heating and stretching an ordinary optical fiber, and made the microspheres by melting the tip of a fiber with a laser.

The positioning of the fiber and the sphere also proved critical. A fiber too close

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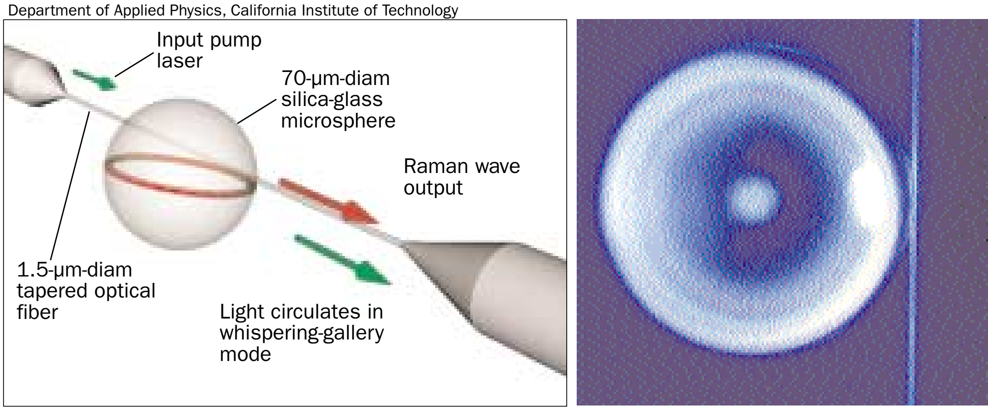


When an input pump laser (green) in a 1.5-µm-diam optical fiber brushes by a 70-µm-diam silica-glass microsphere, it creates a whispering-gallery circle of light and an amplified Raman wave output (red).

to the sphere interfered with the circulation of the light in the sphere, but if the fiber was too far away, the coupling was weak.

When the system was optimized, the required pumping power was cut to 60 μW, almost 1,000 times less than that achieved with the liquid microspheres and free-space lasers. The pumping efficiency was high as well—about 35% of the input energy was converted to output laser light.

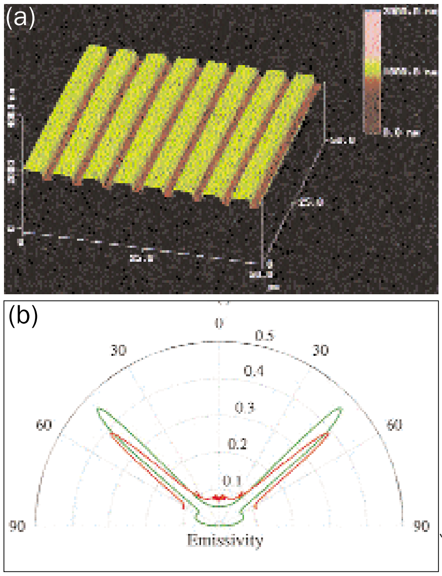
However, the microspheres cannot fit into the planar geometry of microchips. For a practical device, tiny disks will be needed and pump power must be reduced to nanowatts. The Caltech team is currently working on these problems.

Cosmology to technology

Astrophysics seems the field of physics most isolated from practical applications. But on occasion, the study of the cosmos has led to important uses, such as the development of reliable navigation based on predictions of the moon's orbit and the discovery of thermonuclear fusion as the source of the sun's energy. In a less dramatic example, a phenomenon that first gained prominence as a way to explain the redshifts of quasar spectrums may now give rise to efficient heating and cooling and the generation of coherent radiation without lasers.

Although most astronomers believe that the large shifts of quasar spectrums to longer wavelengths (redshifts) are caused by the expansion of the universe, a few researchers have pointed to discrepancies in which quasars and galaxies, which seem physically connected, have widely different redshifts. This implies that part of the redshift might be generated inherently within the quasars. In 1987, Emil Wolf at the University of Rochester showed that redshifts could theoretically arise in a motionless medium if it had certain regularities. A year later, in a widely noted article in *Nature*, he hypothesized that the effect could explain the redshifts. But the effect was never observed in the laboratory for thermal, random radiation, which is what quasars produce.

Now a French team has generated the Wolf effect from a thermal source in the process of producing coherent radiation (*Nature* 2000, *416*, 61). The team, led by Jean-Jacques Greffet of École Centrale Paris and the French National Center for Scientific Research (now on sabbatical leave at the University of Rochester), started not from cosmology but from observations and calculations concerning ionic crystals. When the surfaces of these crystals vibrate, coherent electromagnetic waves called surface-phonon polaritons are set up. Ordinarily, polaritons are confined to the surface and do not radiate. But the French team determined that by scribing a grating into silicon carbide, the coherent surface waves could be coupled to the thermal infrared radiation coming off the surface.



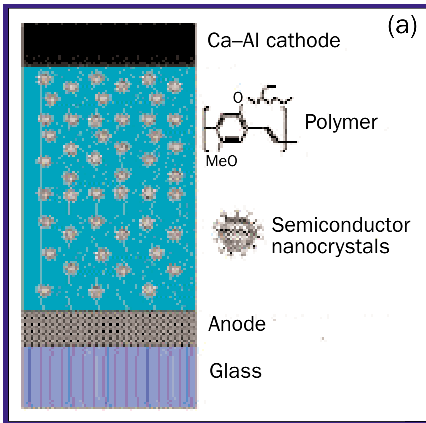
When heated to 800 K, a silicon carbide grating (a) with period of 6.25 μm and a height of 0.284 μm emits infrared light in two narrow lobes, as shown in (b) with experimental data (red) and theoretical calculations (green).

"It was well known that a shallow grating could produce narrow angles of almost complete absorption of radiation," explains Greffet. "So, by Kirchhoff's law that equates absorptivity and emissivity, we reasoned that such a system would also emit radiation in narrow coherent beams. The key question was then to understand the microscopic mechanism that was converting random thermal motion into a coherent current. This is where surface modes play an essential role."

The result of coupling the surface waves and infrared radiation is the production of a thermal source that emits coherently. The spectral coherence length in the plane of the source was estimated to be 0.6 mm instead of 6 μm for blackbody radiation. Instead of radiating in all directions and over a broad spectrum, the infrared radiation emerges as coherent beams similar to those emitted from an antenna or a laser. As Wolf predicted, the wavelength of the radiation depends on its emission angle, with "redshift" increasing as the angle gets closer to the plane of the surface.

Whether similar waves in the plasma of a quasar produce anomalous redshifts remains to be seen. But the phenomenon demonstrated by Greffet and his colleagues has near-term practical applications. For one thing, economical tunable infrared sources could be created for sensing devices. And the coherent mechanism radiates far more efficiently than ordinary incoherent radiation in the near-field, close to the radiating surface. Emissivity increased 20-fold in the French experiment. This finding could lead to more radiative cooling of many surfaces and widespread use, given the ubiquity of excess heat.

Finally, the radiation in the near-field is nearly monochromatic and could be fed to photovoltaic cells, potentially greatly increasing their efficiency.



The huge market in optical-telecommunications (b) may be able to use polymers that incorporate tiny nanocrystals of ceramic semiconductors (a) to create near-IR optical amplifiers and light-emitting devices.

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Polymer LEDs

In recent years, polymers that emit light have stirred excitement with the prospect of inexpensive, flexible displays. But the huge optical-telecommunications market seemed closed to these new light-emitting polymers because the plastics could not emit efficiently in the 1.5-μm near-infrared (near-IR) band where the optical fibers that carry communications are most transparent. Now, Nir Tesslar of the Technion-Israel Institute of Technology (Haifa), Uri Banin of the Hebrew University (Jerusalem), and their colleagues have found a way to get polymers to emit near-IR radiation by incorporating nanocrystals into them (*Science* **2002**, *295*, 1508). Potentially, such nanocrystal polymers, once commercialized, could cut the cost of the hundreds of millions of telecommunications terminals that will be needed to bring fiber-optic communications to individual homes.

Polymer light-emitting diodes (LEDs) are much less costly to make than conventional solid-state LEDs and lasers, which are produced by lithographic processes in a vacuum. Because polymers can be disolved in a fluid, polymer layers can be sprayed onto materials with ink-jet printers to form devices as the fluid evaporates, which is simpler and less expensive than lithography. Visible-light-emitting polymers are already in commercial use.

However, optical telecommunications require near-IR radiation. "Researchers thought that polymers could not efficiently produce near-IR radiation," explains Tesslar. "The problem is that when electrical currents produced the radiation, they also generated vibrations in the polymers. These vibrations bled off most of the energy of the radiation." The result is that polymers produce near-IR radiation at low efficiency—around 0.01%, which is far below that needed for economical operation.

To get around the problem, Tesslar and Banin incorporate nanocrystals of solid semiconductor into the polymer. "The polymer just conducts the electricity to the nanocrystals, where the near-IR radiation is emitted," says Tesslar. The nanocrystals have a shell of zinc selenium, which isolates a core of indium arsenide from the vibrations of the polymer and acts as a sort of nanoscale shock absorber. In this way, when the nanocrystals emit near-IR radiation, the energy is not linked to the polymer vibrations and hundreds of times more radiation is produced. The Israeli team has demonstrated an efficiency of 2 to 3% at a wavelength of 1.3 μm, within the range of interest in fiber-optic telecommunications. Because the nanocrystals are dissolved within the polymer, the polymer–nanocrystal solution can be ink-jet printed just like other polymers.

The Technion-Hebrew University collaboration is now in the process of developing different polymer–nanocrystal combinations to increase efficiency to 20 to 30%. "We also expect to increase the wavelength to 1.5 mm, the best wavelength for telecommunications," says Tesslar. Ω