

Better living through plasmonics

Mixing light with nanotechnology could help treat cancer and build faster computers

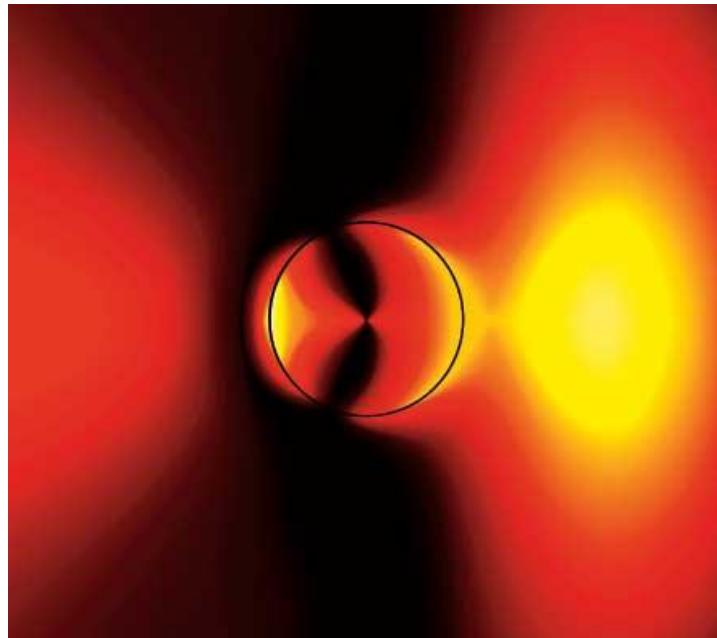
By Jenny Lauren Lee

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A well-polished mirror reflects the world faithfully back to the viewer's eyes. But break that mirror into billions of nanosized chunks and each tiny silver sliver would not reflect the world with such fidelity. Instead of bouncing back to the viewer, the light would be sucked into the surface of the nanochunk like a genie into a bottle. When it hits the surface of a scrap of metal, light can set off a wave in the free electrons hanging out on the metal's surface. This wave carries the light along like a surfer riding on an electron sea. The light-and-electron hybrid is called a surface plasmon wave, and the study of this bizarre phenomenon is called plasmonics.



New wave in nanotech Light that hits a gold sphere (circled) resonates with electrons to create a plasmonic effect. Emitted light intensity is depicted in the simulation above. CSEM

First named in 2001, the field of plasmonics has become popular among physicists and engineers only recently, as scientists have developed tools to create nanosized structures that can guide and shape these light-and-electron waves. Now the field of plasmonics is taking off, possibly leading to new kinds of miniature lasers, better cancer treatments and faster computers.

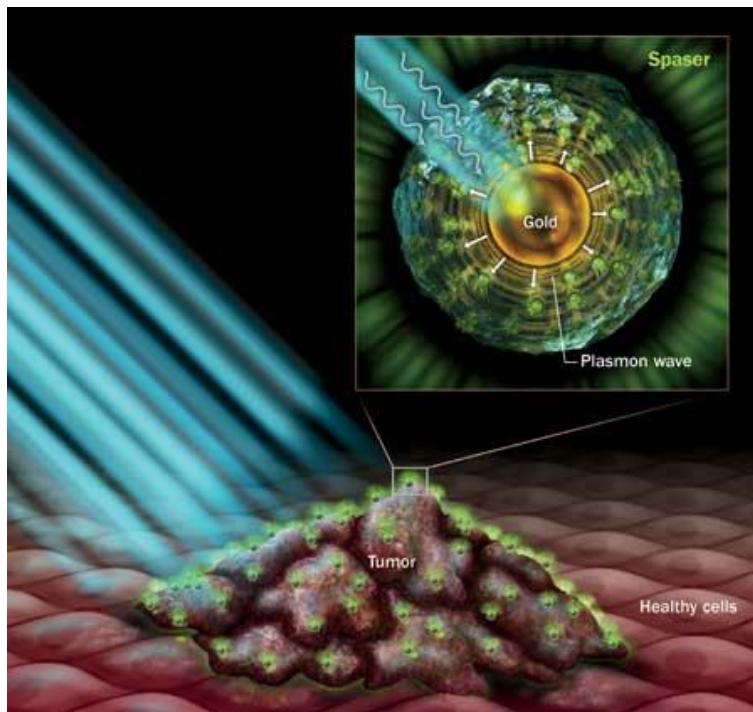
"This is a moment in time where it's all possible," says engineer Henri Lezec of the National Institute of Standards and Technology in Gaithersburg, Md. "I think it's really opened up because of developments in different fields — materials science, optics, nanofabrication."

The promise of plasmonic materials goes well beyond medicine and computing. In new kinds of solar cells, nanoparticles could trap light to convert more of it into electricity. Or the cells

could use light with a broader range of wavelengths. Even invisibility cloaks may be possible once physicists master the secrets of manipulating light on a nanoscale.

Lighting the way

Both light and electrons can carry information (think fiber optics and electronic circuits), but both technologies are reaching limits of speed and size. Scientists hope that plasmonics can harness light's and electrons' advantages together to perform some tasks better than either could do alone.



Detecting tiny tumors Researchers are designing plasmonic devices that could eventually detect small cancers. One idea (illustrated here) uses spacers, gold balls coated with dye and silica, to attach themselves to cancer cells and glow under laser light. Nicolle Rager Fuller

Electronic devices exploit signals of flowing electrons that can be compressed into nanosized wires, allowing complicated circuits to process a lot of information in a small space. Light signals, on the other hand, can travel immense distances without losing much of their oomph and can be switched on and off rapidly, making them ideal for fast computing.

But lenses and fiber optic cables can't squeeze light the way electronic circuits can funnel electrons: Light can be compressed by only about half of its wavelength in today's photonic devices. For visible light, this means a space of a few hundred nanometers.

That may sound minute, but it's still a hundred times larger than the nanowires that carry information in electronics. At the moment, a computer based on light instead of electrons, though incredibly fast, would be the size of a room.

Plasmonics offers a way to bridge this scale gap by squeezing light into a piece of metal just a few nanometers across.

"If you want to make [light] really small, you have to do a trick," says

Vladimir Shalaev of Purdue University in West Lafayette, Ind. "And the trick is to convert light to surface plasmon waves."

For the past few years, scientists have been creating the pieces necessary for a computer that combines electronics and plasmonics. Now, new research demonstrating plasmonics-based lasers indicates that such a computer is closer than ever. Some experts think the field is on the cusp of a computing revolution similar to the electronics revolution of the mid-20th century.

The ability to manipulate light on a nanometer scale could also lead to better detectors of small biological molecules, microscopes with higher resolution and more effective cancer treatments. Just last year, the Food and Drug Administration approved Nanospectra Biosciences Inc. in Houston to begin clinical trials of a therapy that uses the plasmonic properties of tiny gold-coated silica balls called nanoshells to cook tumors while leaving healthy tissue intact.

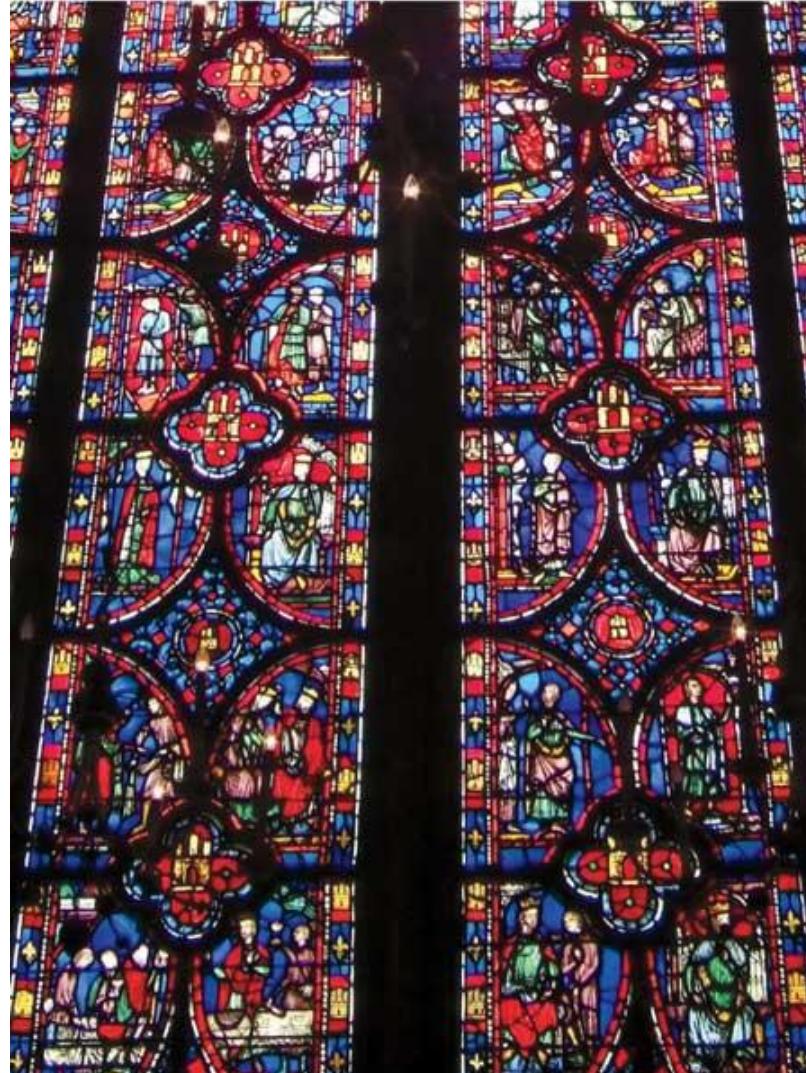
The genie in the bottle

Surface plasmons are effectively ripples in a pond of freely floating electrons on the surface of a metal that has a lot of unbound electrons to spare. Gold and silver work particularly well: Shine a beam of light onto a nanosized plate of gold, for example, and free electrons will carry that light along. Though the wave moves across the plate, the electrons themselves do not travel far, similar to the way baseball fans can do "The Wave" without moving from their seats.

Surface plasmons may sound exotic, but they are present in a number of familiar places. Many medieval stained glass windows get their brilliant red and blue hues from nanoparticles of gold and silver suspended in the glass. Light passing through the glass sets off an oscillating plasmon wave that rings the metal bits like bells and scatters the light. Different scattering patterns appear depending on the angle of the sunlight — a single piece of glass can change from red to green as the sun sets.

Plasmonics are also at work in modern pregnancy tests. Balls of gold just tens of nanometers in diameter turn a barely detectable reaction between a pregnancy hormone and protein antibodies into bright lines.

Computer chips that use plasmonics for faster processing are not here yet. But “people are continuously coming up with more and more clever designs” for devices that could be used in a plasmonic computer, says Stanford University’s Mark Brongersma, whose 2007 book *Surface Plasmon Nanophotonics* collects several authors’ writings on this growing field.



Medieval plasmonics Plasmonic effects create some of the brilliant colors in stained glass, such as those at La Sainte Chapelle in Paris. Bryan Busovicki/Shutterstock

Laser lasing, spaser spasing

Even more exciting news for the field of plasmonics comes from a spate of papers on nanolasers in the past few months.

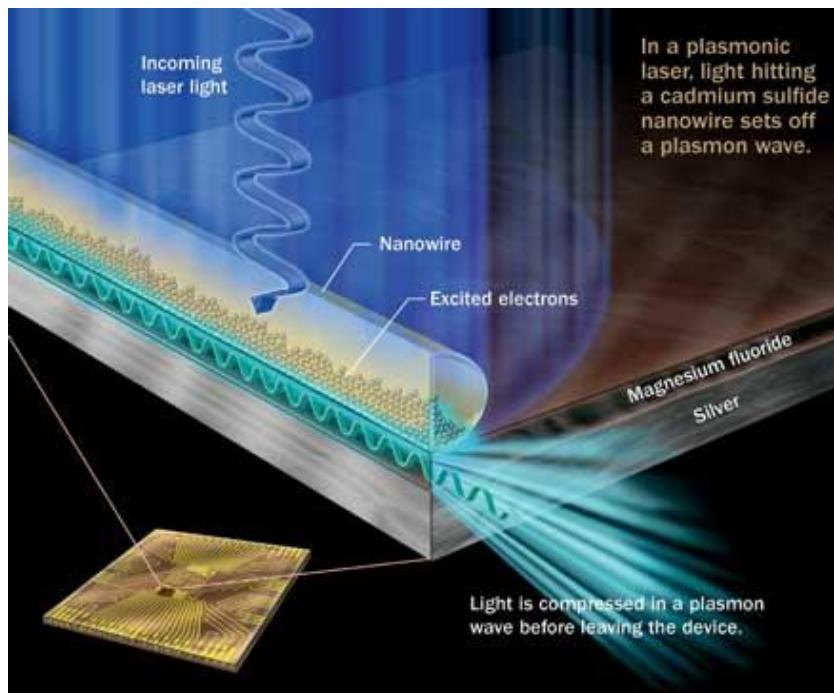
In the Aug. 27 *Nature*, scientists from Purdue, Norfolk State University in Virginia and Cornell University reported what may be the smallest laser in the world. Called a spaser, short for “surface plasmon amplification by stimulated emission of radiation,” it consists of a dye-and-silica-coated gold ball that acts as a minilaser just 44 nanometers in diameter (*SN*:

9/26/09, p. 4). Shining light on this ball starts off a plasmon wave in the gold layer that excites electrons in the dye coating. When the electrons settle back down, the dye glows. Turn the light off, and the glow stops.

Proof that spasers are possible has put scientists on a path to creating transistors for a computer that uses light instead of electronics, says Mark Stockman of Georgia State University in Atlanta, whose 2003 paper with David Bergman of Tel Aviv University introduced the concept of the spaser.

Stockman hopes the tiny new lasers will make it possible to do for optics and electronics integration what the transistor did for electronics. He suggests that the all-or-none nature of spasers could be adapted to amplify a small signal in a computer circuit; a tiny signal, above a certain threshold, would turn into an enormous and detectable signal.

"Now the work will start," Stockman says.



Plasmonic computing A plasmonic laser (illustrated here) could be one component of an extremely fast plasmonic computer, giving light perhaps its tightest squeeze yet - about as small as the circuitry that moves electrons in standard electronics. Nicolle Rager Fuller

In a second paper, published online in *Nature* on August 30, scientists led by Xiang Zhang of the University of California, Berkeley demonstrate what they call a plasmonic laser. In this approach, light induces plasmon ripples that move across the surface between a silver plate and a cadmium wire, squeezing light into a gap only 5 nanometers wide. This would put light-based circuits in the ballpark of nanocircuitry.

Better biology

Spasers and plasmonic lasers may be good for more than just potential circuits for faster computers.

One of the most promising uses for the spaser is detecting small molecules, says Shalaev, a coauthor of the spaser study. Spasers could, in theory, be designed to attach themselves to certain types of bacteria or cancer cells and then call attention to the cells by glowing like beacons.

A similar type of plasmonic device has potential for both detecting and shrinking tumors. Called a nanoshell, the patented gold-coated silica nanobead was developed by Naomi Halas and Jennifer West of Rice University in Houston.

A tumor might grow to at least a few millimeters before it can be detected with today's technology, says plasmonics physicist Surbhi Lal, who works in Halas' lab.

"And even if you get it at that point, it's great," Lal says. "But what if you could catch it when it was just 1 to 2 millimeters in size?" Detecting very small cancer growths would allow doctors to take a shot at eradicating the cancer before it gets a hold on the body or requires invasive surgery.

Nanoshells enhance a light signal that would otherwise be buried and create brighter spots where cancer cells scatter light, Lal says.

By changing the thickness of the gold shell and silica core of the beads, Halas' group has also developed what could eventually be an effective cancer treatment. Instead of scattering light, these nanoshells convert laser light to heat that effectively fries the cancer.

"That one, I'm really impressed with," Lezec says. "It's a nifty application and might make its way to actual use in the near future."

In the procedure, patients are injected with nanoshells. Most of the gold balls are flushed out of the body, but many accumulate in tumor tissue when abnormal blood vessels there leak their contents, including the nanoshells, into the tumor. Doctors then shine laser light that is designed to pass straight through human flesh and activate the nanoshell like an antenna. As the plasmon wave is activated, heat radiates out into the surrounding cancer. Even a few extra degrees can kill the tumor. And since the laser itself is tuned to a frequency that is harmless to the human body, it can travel through healthy tissue without causing problems.

Nanospectra Biosciences Inc. found high remission rates in mice, according to a December 2008 review in *Accounts of Chemical Research*. The procedure got FDA approval last year for tests on humans and so far has shown good results, Lal says.

"Everything I've seen from it is very promising," she says. The biggest advantage, she adds, is the absence of the toxicity of chemotherapy and radiation. "Half the time people are sicker because of the side effects of chemotherapy than from the cancer itself."

Computer challenges

Despite its promise, plasmonics is still a young field with a long way to go before plasmonic computers are on desktops. One of the main challenges for creating plasmonic circuits is figuring out how to get light into the plasmon wave and then get it out again on the other side.

To adapt a computer's binary system of 1s and 0s for light, scientists also have to figure out the best ways to, in essence, flicker light on and off while it is carried along in a plasmon wave.

A group at Caltech recently invented a device — dubbed a plasMOStor, or a plasmonic modulator — that could help in this quest. The research team, led by physicist Harry Atwater, published its results in *Nano Letters* in January. PlasMOStors give scientists a way to modulate light by applying voltage that puts light waves and plasmonic waves either in or out of sync with each other — which allows the signal to be turned on and off.

Even getting a plasmon wave started can be hard in some cases. "You can't just send light into a metal and expect it to couple [with electrons]," says Jennifer Dionne of UC Berkeley. "It's difficult to do unless someone gives you a really big push."

Another problem is that a plasmon wave does not travel very far before dying out. For shorter wavelengths of light such as green and blue, the wave cannot travel much farther than a few micrometers. To send plasmon waves across a computer chip, scientists will have to find ways to either push more light into the wave or to shorten the distance the wave has to travel.

"Work in this area is still in its infancy," says Dionne, who worked with Atwater's group at Caltech on the plasMOStor. "But I think people realize the potential for this field."

With better control of light at the nanoscale, that potential could include applications even more fantastic than plasmonic computers, such as the ability to scatter light in highly controlled ways — perhaps the secret to a Harry Potter-style invisibility cloak.

And there may be many more uses that people have not yet imagined. "First there is something new, then people immediately start thinking about great applications," Shalaev says. "There are a number of very exciting problems here for plasmonics, and that's why it's so much fun to work with."

Jenny Lauren Lee is a freelance science writer in Los Angeles.