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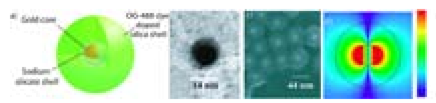
New nanolaser key to future optical computers and technologies

WEST LAFAYETTE, Ind. - Researchers have created the tiniest laser since its invention nearly 50 years ago, paving the way for a host of innovations, including superfast computers that use light instead of electrons to process information, advanced sensors and imaging.



"Spaser"
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Because the new device, called a "spaser," is the first of its kind to emit visible light, it represents a critical component for possible future technologies based on "nanophotonic" circuitry, said Vladimir Shalaev, the Robert and Anne Burnett Professor of Electrical and Computer Engineering at Purdue University.

Such circuits will require a laser-light source, but current lasers can't be made small enough to integrate them into electronic chips. Now researchers have overcome this obstacle, harnessing clouds of electrons called "surface plasmons," instead of the photons that make up light, to create the tiny spasers.

Findings are detailed in a paper appearing online in the journal *Nature* that reports on work conducted by researchers at Purdue, Norfolk State University and Cornell University.

Nanophotonics may usher in a host of radical advances, including powerful "hyperlenses" resulting in sensors and microscopes 10 times more powerful than today's and able to see objects as small as DNA; computers and consumer electronics that use light instead of electronic signals to process information; and more efficient solar collectors.

"Here, we have demonstrated the feasibility of the most critical component - the nanolaser - essential for nanophotonics to become a practical technology," Shalaev said.

The "spaser-based nanolasers" created in the research were spheres 44 nanometers, or billionths of a meter, in diameter - more than 1 million could fit inside a red blood cell. The spheres were fabricated at Cornell, with Norfolk State and Purdue performing the optical characterization needed to determine whether the devices behave as lasers.

The findings confirm work by physicists David Bergman at Tel Aviv University and Mark Stockman at Georgia State

University, who first proposed the spaser concept in 2003.

"This work represents an important milestone that may prove to be the start of a revolution in nanophotonics, with applications in imaging and sensing at a scale that is much smaller than the wavelength of visible light," said Timothy D. Sands, the Mary Jo and Robert L. Kirk Director of the Birck Nanotechnology Center in Purdue's Discovery Park.

The spasers contain a gold core surrounded by a glasslike shell filled with green dye. When a light was shined on the spheres, plasmons generated by the gold core were amplified by the dye. The plasmons were then converted to photons of visible light, which was emitted as a laser.

Spaser stands for surface plasmon amplification by stimulated emission of radiation. To act like lasers, they require a "feedback system" that causes the surface plasmons to oscillate back and forth so that they gain power and can be emitted as light. Conventional lasers are limited in how small they can be made because this feedback component for photons, called an optical resonator, must be at least half the size of the wavelength of laser light.

The researchers, however, have overcome this hurdle by using not photons but surface plasmons, which enabled them to create a resonator 44 nanometers in diameter, or less than one-tenth the size of the 530-nanometer wavelength emitted by the spaser.

"It's fitting that we have realized a breakthrough in laser technology as we are getting ready to celebrate the 50th anniversary of the invention of the laser," Shalaev said.

The first working laser was demonstrated in 1960.

The research was conducted by Norfolk State researchers Mikhail A. Noginov, Guohua Zhu and Akeisha M. Belgrave; Purdue researchers Reuben M. Bakker, Shalaev and Evgenii E. Narimanov; and Cornell researchers Samantha Stout, Erik Herz, Teeraporn Suteewong and Ulrich B. Wiesner.

Future work may involve creating a spaser-based nanolaser that uses an electrical source instead of a light source, which would make them more practical for computer and electronics applications.

The work was funded by the National Science Foundation and U.S. Army Research Office and is affiliated with the Birck Nanotechnology Center, the Center for Materials Research at Norfolk State, and Cornell's Materials Science and Engineering Department.

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Note to Journalists: Journalists may obtain a copy of the research paper by contacting *Nature* at press@nature.com or calling (212) 726-9231.

IMAGE CAPTION:
Researchers have created the tiniest laser since its invention nearly 50 years ago. Because the new device, called a "spaser," is the first of its kind to emit visible light, it represents a critical component for possible future technologies based on "nanophotonic" circuitry. The color

diagram (a) shows the nanolaser's design: a gold core surrounded by a glasslike shell filled with green dye. Scanning electron microscope images (b and c) show that the gold core and the thickness of the silica shell were about 14 nanometers and 15 nanometers, respectively. A simulation of the SPASER (d) shows the device emitting visible light with a wavelength of 525 nanometers. (Birck Nanotechnology Center, Purdue University)

A publication-quality image is available at http://news.uns.purdue.edu/images/+2009/shalaev-spasers.jpg

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ABSTRACT

Demonstration of SPASER-based Nanolaser

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One of the most rapidly growing areas of physics and nanotechnology focuses on plasmonic effects on the nanometre scale, with possible applications ranging from sensing and biomedicine to imaging and information technology. However, the full development of nanoplasmonics is hindered by the lack of devices that can generate coherent plasmonic fields. It has been proposed that in the same way as a laser generates stimulated emission of coherent photons, a "spaser" could generate stimulated emission of surface plasmons (oscillations of free electrons in metallic nanostructures) in resonating metallic nanostructures adjacent to a gain medium. But attempts to realize a spaser face the challenge of absorption loss in metal, which is particularly strong at optical frequencies. The suggestion to compensate loss by optical gain in localized and propagating surface plasmons has been implemented recently and even allowed the amplification of propagating surface plasmons in open paths. Still, these experiments and the reported enhancement of the stimulated emission of dye molecules in the presence of metallic nanoparticles lack the feedback mechanism present in a spaser. Here we show that 44-nm-diameter nanoparticles with a gold core and dye-doped silica shell allow us to completely overcome the loss of localized surface plasmons by gain and realize a spaser. And, in accord with the notion that only surface plasmon resonances are capable of squeezing optical frequency oscillations into a nanoscopic cavity to enable a true nanolaser, we show that outcoupling of surface plasmon oscillations to photonic modes at a wavelength of 531 nm makes our system the smallest nanolaser reported to date - and to our knowledge the first operating at visible wavelengths. We anticipate that now, when it has been realized experimentally, the spaser will advance our fundamental understanding of nanoplasmonics and the development of practical applications.

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