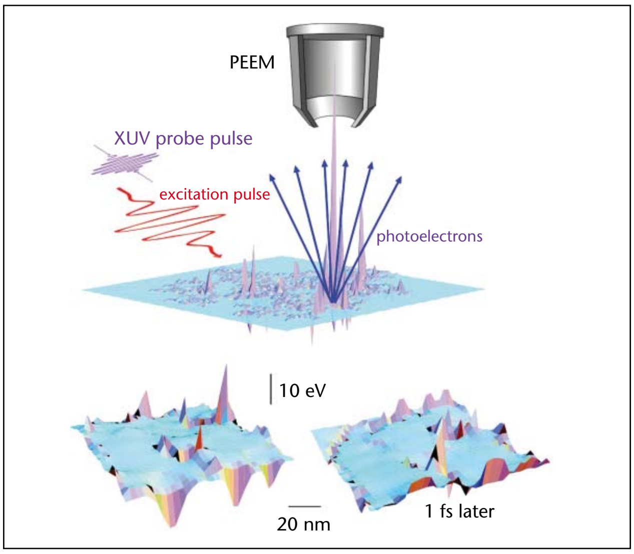
A Nano-Microscope for Ultrafast Processes

Measurement of Processes on Attosecond Timescales with High Spatial and Temporal Resolution

Metallic nanostructures, consisting of a few thousand atoms, exhibit optical and electronic properties which are not present in extended solid state systems. The interaction of electromagnetic radiation (light) with nanoparticles leads to collective, coherent oscillations of electrons (so called surface plasmons). A team of scientists from the Georgia State University (Atlanta, Georgia, USA), the Max Planck Institute of Quantum Optics in Garching (MPQ), and the Ludwig Maximilians University at Munich (LMU) have now proposed a new microscope that allows for the first time to resolve the ultrafast dynamics of plasmonic fields with high spatial and temporal resolution. In particular, applications in optical and optoelectronical information processing, transfer, and storage would benefit from a better understanding of these collective excitations. Furthermore, this ultramicroscope would have applications in the spectroscopy of single (bio)-molecules, where nanoparticles act as antennas for light interaction.

Without deeper insight, the makers of colored glass vases in ancient Rome or church windows in the middle ages have already used the properties of metallic nanoparticles to their advantage. The shiny red color was achieved by adding gold dust to the glass melt. The origin of this effect is understood by specialists today: nanoparticles, i.e. particles with extensions in the range from a few to 100 nanometers – less than the wavelength of visible light (ca. 400–800 nanometers) – consist of as little as a few thousand atoms. If such a particle is exposed to visible light, the freely moving conduction electrons are displaced by the light's electric field. Since the structure is small, they are not moving very far, but alternate being bunched on one side or the other. This way, the electrons are moving collectively in synchronized coherent oscillations. Such oscillations have particle character and are called surface plasmons. The red color of ancient Roman vases and old church windows is based on the absorption of part of the visible light by the gold nanoparticles, which is converted into plasmons. Then the residual light shines in the complementary colors. "Plasmons create very high electromagnetic fields at the nanoparticle and its direct environment. But how these fields are created and how they decay is not understood in detail. The fastest dynamics of the collective motions takes place in only a few hundred attoseconds (1 attosecond is a billionth of a billionth of a second) and belongs therefore to the fastest processes in nature," explains Dr. Matthias Kling, Junior Research Group leader at MPQ.



Principle of the nano-microscope for ultrafast processes (MPQ).

A new method to resolve the dynamics of plasmonic fields with the highest temporal and spatial precision has been suggested by the theoretical physicist Prof. Mark Stockman (Georgia State University at Atlanta, Georgia, USA) together with experimental physicists from LMU and MPQ in Germany. In their model (see figure), the scientists simulated a geometric assembly of silver nanoparticles on a surface, which are then excited by an (extremely short) few femtosecond pulse (a femtosecond is a millionth of a billionth of a second). The interaction with the light-pulse consisting of only a few oscillation periods – leads to the formation of plasmonic fields, whose amplitudes and frequencies (between the near infrared and near ultraviolet) depend on the size, shape, and environment of the nanoparticles. The plasmon dynamics is probed by a 170 attosecond, extreme ultraviolet laser pulse incident on the nanosystem that is synchronized with the excitation pulse and releases electrons. The plasmonic fields are monitored by the energy and spatial distribution of these so called photoelectrons as they were – prior to their detection – accelerated by these fields.

"In our suggested approach we combine two techniques, which are by themselves already state-of-the-art: the photoemission electron microscope, also called PEEM, and the attosecond streak camera," explains Prof. Ulf Kleineberg from LMU. "This way we obtain a spatial resolution, which is on the order of the dimension of the nanoparticles between a few ten to hundred nanometers, and achieve simultaneously – due to the use of attosecond light flashes – the extremely high time resolution in the attosecond domain. The measurement principle lays the foundation to measure the formation and temporal evolution of these fields and to control them by specifically shaped laser pulses in the future."

Generally the nanoplasmonic ultramicroscope would allow for the first direct observation of ultrafast processes in nanosystems, such as the conversion of sunlight into electrical energy. The authors see future applications of the technique particularly in the development of novel devices, in which localized nanoplasmonic fields replace electrons in conventional electronics, i.e. are used for information transfer, processing, and storage. "The advantage would be that plasmons in these nanosystems allow for information processing and transfer at much higher frequencies (ca. 100,000 times) as compared to electrons in solid state systems. This way, extremely fast optoelectronic and optical devices for computations and information processing may be realized."

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ITER Organization Formally Established

First International Research Project on Nuclear Fusion with Net Output Started

Cadarache (at) – As of October 24, 2007 the new International Organization ITER was formally established. Already in November 2006 the representatives of the People's Republic of China, the European Union, the Republic of India, Japan, the Republic of Korea, the Russian Federation and the United States of America had signed the ITER Joint Implementation Agreement which since has been ratified by all seven Member Parties and will now officially enter into force.

The overall aim of the ITER Organization, implemented in Cadarache, France, is to build and operate ITER which is to demonstrate the technical and scientific feasibility of fusion power. ITER will be the first fusion facility to produce net power on a large scale. As for the experimental nature of ITER it will also test most of the key technologies that will be needed to use fusion as a future energy source and validate industrial production techniques of the large and high-quality components needed for future fusion power plants.

"Today is a notable milestone in the history of our organization", Kaname Ikeda, ITER Director General Nominee, said on the occasion. "With ITER, a new international organization has been created. By creating ITER the nations of the world have understood the need for new sources of energy and demonstrated their commitment. Furthermore, by creating the ITER Organization our Member Parties have established a completely new model for international collaboration and it is our challenge to show that outstanding talent coming from many different nationalities can also fuse to create a dynamic workforce."

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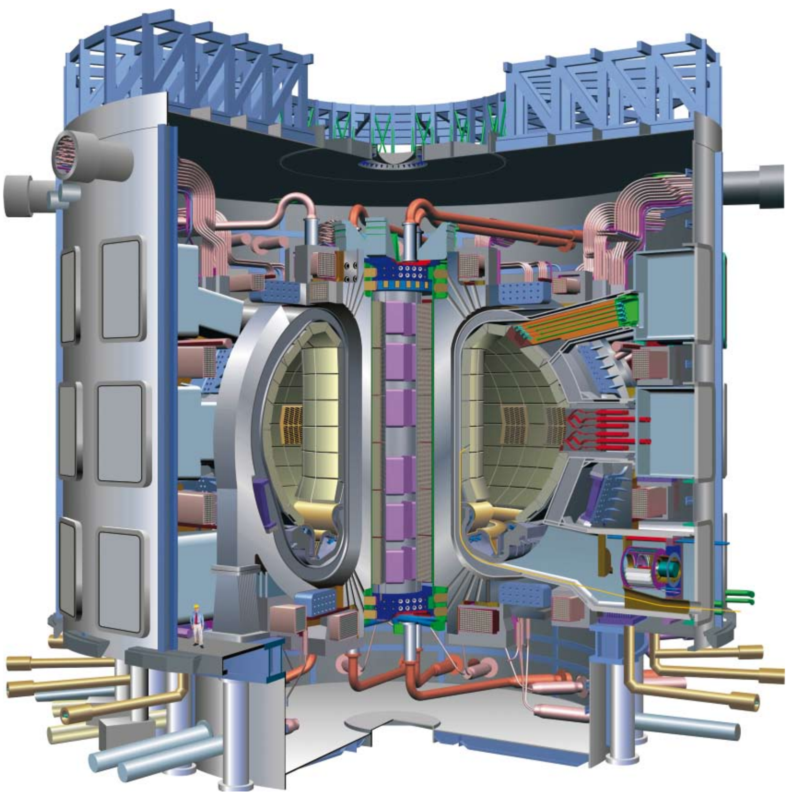
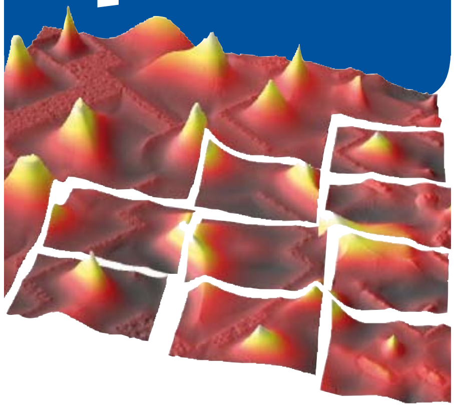


Draft of ITER construction (Grafic: ITER)



MIT Works Toward 'Smart' Optical Microchips

Light-powered Micro-machines Could Advance Telecommunications

A new theory developed at MIT could lead to "smart" optical microchips that adapt to different wavelengths of light, potentially advancing telecommunications, spectroscopy and remote sensing.

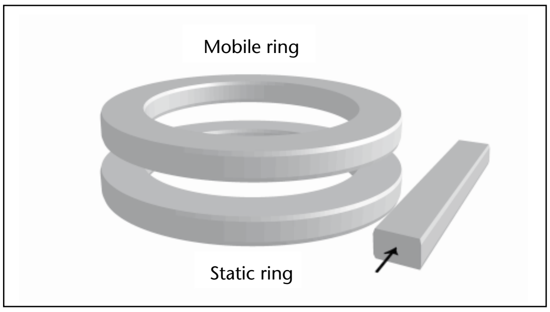
Drawn by the promise of superior system performance, researchers have been exploring the concept of microchips that manipulate light instead of electricity. In their new theory, the MIT team has shown how such chips could feature tiny machines with moving parts powered and controlled by the very light they manipulate, giving rise to fundamentally new functionality.

"There are thousands of complex functions we could make happen by tinkering with this idea," said Peter Rakich, an MIT postdoctoral associate who invented the theoretical concept along with postdoc Milos Popovic. The work was described in the cover story of the November issue of Nature Photonics.

For example, such chips could one day be used to remotely adjust the amount of bandwidth available in an optical network, or to automatically process signals flowing through fiber-optic networks, without using any electrical power, Rakich said.

Coauthors on the paper were Marin Soljacic, assistant professor of physics; and Erich Ippen, the Elihu Thomson Professor of Electrical Engineering and professor of physics.

"The idea that opto-nanomechanical devices can be designed to self-adapt to all-optical control – i. e., by self-aligning their resonances to optical control frequencies and by permitting all-optical tuning and dimension control – is new and exciting," said Ippen.



Rings, one millionth of a meter in size, are the moving parts of a 'smart' micromachine that could be powered and controlled by light on an optical chip. The rings move around and adapt to the color of light that is traveling through the bar, right (Image courtesy/Peter Rakich).

Earlier this year an MIT team composed of many of the same researchers showed that photonic circuitry could be integrated on a silicon chip by polarizing all of the light to the same orientation. The current work shows how tiny mobile machines can be built on such chips, taking advantage of the substantial pressures exerted by photons as they strike the walls of a cavity.

In the macroscopic world, light waves do not exert significant forces, but in the unique world of the microscopic, coupled with ultrapure laser light, photons bouncing off the walls of a cavity can build up a measurable force called radiation pressure. This is similar to the pressure exerted by gas molecules trapped in an aerosol can.

To take advantage of this radiation pressure, the researchers propose machines built from ring-shaped cavities only millionths of a meter in size located on the chip surface. When pressure on the cavity walls is high enough, the cavity is forced to move. This movement forms a critical part of an optical micromachine, which adjusts its configuration to respond to light in a predesigned way.

A unique application of this concept involves processing data that travels in fiber-optic networks. Today resonators employed in fiber-optic networks have to be synchronized with the incident light to ring at its frequency, in the same way an opera singer has to tune the pitch of her voice to make a wine glass ring.

Remarkably, a "smart" resonator based on the MIT concept could chase the frequency (color) of the laser light incident upon it. As the frequency of the laser beam changes, the frequency of the resonator will always follow it, no matter where it goes.

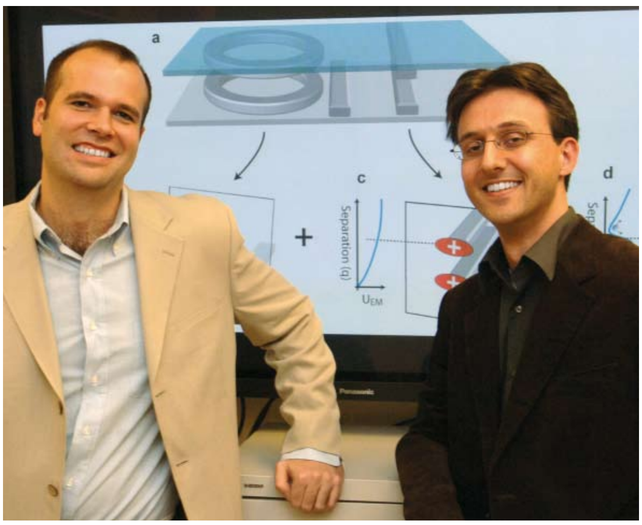
In other words, this new, unique resonator is like a wine glass that self-adjusts to the pitch of the singer's voice and follows it along throughout a song, Rakich said. He noted that physical systems that adapt to driving light and behave like these nanomachines do not exist elsewhere in nature.

By coupling the resonating cavities with nano-scale cantilevers, optical devices analogous to microelectromechanical systems (MEMS) devices can be created.

Although the researchers focused on ring-shaped cavities, their model could be applied to other structures as well.

"Our objective now is to develop a variety of light-powered micro- and nanomachines with unique capabilities enabled by this technology," explained Popovic. "But the first step will be to demonstrate the concept in practice."

The research was funded in part by the Army Research Office through MIT's Institute for Soldier Nanotechnologies.



Postdocs Peter Rakich, left, and Milos Popovic of MIT's Research Laboratory of Electronics stand in front of a monitor that shows a demonstration of the way they propose to control microchips with light (Photo: Donna Coveney).

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