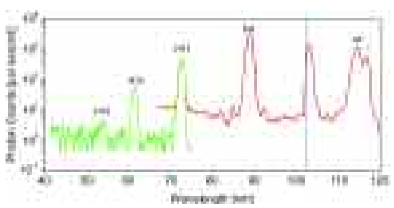
EXTREME SPECTROSCOPY |

Laser Pulses Deep into the UV Could Lead to New Levels of Spectroscopy

Two groups working with ultrafast lasers have shown they can generate a regularly spaced range of frequencies in the extreme UV (EUV), creating the potential for applying spectroscopy on an extremely tiny scale.

Working separately, groups at JILA (Boulder, CO) and the Max Planck Institute for Quantum Optics (Garching, Germany) produced frequency combs in the EUV. In a frequency comb, discrete wavelengths of light are spaced at regular intervals. Jun Ye led the group at JILA, a research institute run jointly by the National Institute of Standards and Technology and the University of Colorado, while Theodor Haensch directed the group at Max Planck.

The setup was similar in both experiments. They started with a Ti:sapphire laser producing femtosecond pulses and fired those into a resonator. The resonator consists of mirrors that store the pulses while more laser energy is fired in. The pulses interfere constructively and increase their pulse energy. The higher energy photons then travel through a thin cloud of xenon gas, which generates harmonics of the fundamental laser frequency, producing output at shorter wavelengths.

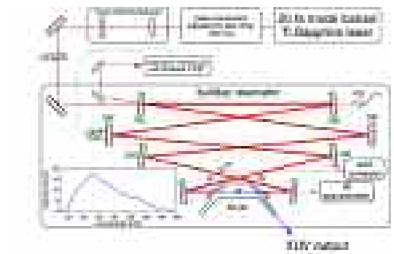


MAX PLANCK INSTITUTE FOR QUANTUM OPTICS

A spectrum attained using an ultrafast laser and a resonator cavity shows clear peaks down to the 13th-order harmonic of the fundamental wavelength.

"Usually from [continuous-wavelength] lasers with a crystal you can achieve second-order harmonic generation or third-order harmonic generation," says Christoph Gohle, a PhD student in Haensch's group. In this case, he says, researchers reached 13th-order harmonics. "The idea is pretty straightforward, but there [are] a few technical difficulties to get around," Gohle says.

For one, they needed special mirrors for the resonator cavity. The mirrors had to have very high reflectivity over a broad spectral range of about 20 or 30 nm. They also had to deal with dispersion that could cause pulses to change shape and interfere with one another. The third challenge was getting the radiation out of the resonator, which they achieved by using sapphire windows with a small refractive index.



Here, the EUV laser setup: ICp, coupling mirror with 1% transmission; CM, chirped mirrors; PD, photodiode; W, Brewster-angled sapphire window of 1-mm thickness; PZT, piezoelectric transducer. Inset: The reflectance of sapphire for p-polarized EUV light at an incidence angle of 60.48 (Brewster angle for 800-nm radiation).

Ye says the two experiments were nearly identical. "Really, the only difference comes down to a couple technical details in terms of the pulse width we used."

"This is really great work," says Erich Ippen, a physics professor at the Massachusetts Institute of Technology (Cambridge, MA). "Jun Ye and Ted Haensch are the two leading scientists in the world in the area of frequency combs and high-precision spectroscopy. Their success at pushing comb technology into the [EUV] will certainly open up a wide range of new opportunities for important spectroscopy in both atomic and molecular physics."

Both groups will have to increase the power of their output by about 1000 times to actually perform spectroscopy. Ye says his group is considering using a fiber laser for input to increase the initial energy of the pulses. They are also looking at different designs for the resonator cavity.

If the groups are successful, they will have a photon source for spectroscopy with enough resolution to observe atomic transitions in helium, allowing them to actually see basic properties of physics that have been predicted by theory but have been experimentally out of reach. Ye says the frequency combs might be used for illumination in EUV microscopy. Gohle says it might also be possible to use the technology to create ultradense holographic storage because the size of the wavelengths is so small.

Ye says it should take less than a year to discover if they can reach the higher power levels. "We are confident we can get there, but it's not going to be easy," he says. —*Neil Savage*

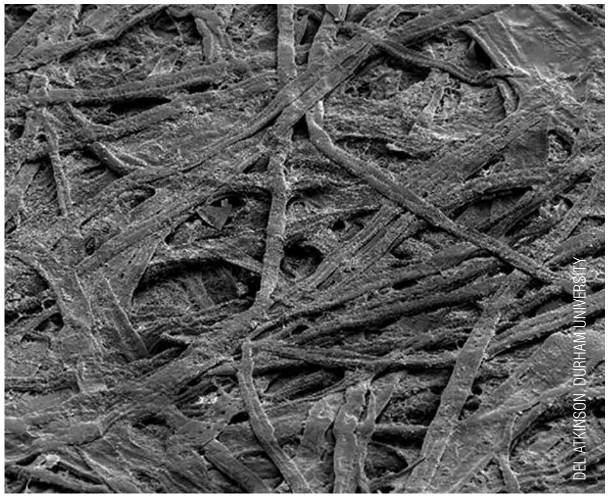
SECURITY |

Microscopic Surface Imperfections Provide Fingerprint for Combating Fraud

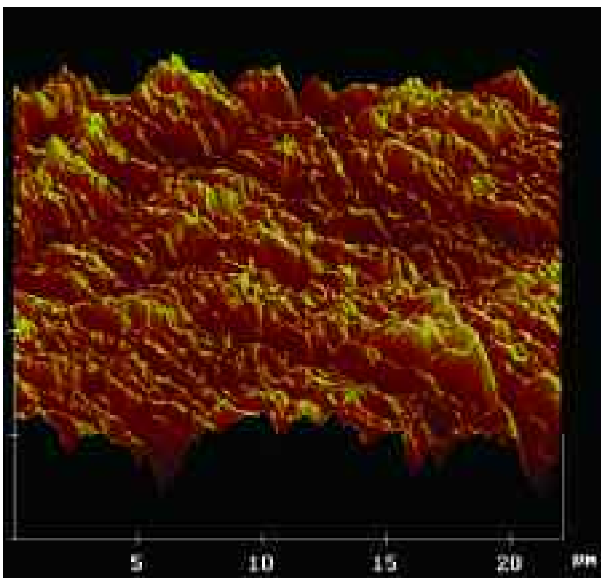
New research by several UK institutions, including Imperial College London in collaboration with Durham University and the University of Sheffield, may offer a ubiquitous, inexpensive way to secure documents based on microscopic surface imperfections.

Naturally occurring randomness in the physical properties of materials provides a means of ascribing a unique "fingerprint" to that material, which can be probed easily using the optical phenomenon of laser speckle. James Buchanan from Imperial College London and his research team examined the fine structure of different surfaces using the diffuse scattering of a focused laser. Speckle, which can hinder other optical techniques used in homeland security applications, is commonly used for determining surface roughness, identifying small deformations on metal, and visualizing blood flow in the medical industry.

By focusing a laser beam across a sheet of standard white paper and continuously recording the reflected intensity from four different angles using photodetectors, the team was able to differentiate the random fluctuations from different types of paper. Similar results were also obtained between other types of material, including plastic credit cards and identity cards. They found that even after the object had been handled roughly, recognition was good. For paper this included screwing it into a tight ball, submerging it in water, scorching the surface, scribbling over the scanned area with ink, and scrubbing it with an abrasive cleaning pad. Comparing the amplitude of the cross correlation peak, it was possible to determine the probability of two objects sharing indistinguishable fingerprints. For the two different types of paper, the correlation was 10^{-72}.



A scanning electron micrograph of the surface of normal office paper shows a complex pattern of fibers, even when the paper is handled roughly. The fibers form the fingerprint for paper documents.



GANG XIONG, DURHAM UNIVERSITY

An atomic force micrograph of the surface of a plastic ID card is shown here. The slight undulations to the surface form the fingerprint for plastic items.

With the 200–500 bytes of storage space that each fingerprint provides and the ability to use a low-cost portable laser scanner, researchers hope that this technique will provide a new approach to authentication and tracking, offering a complementary method for existing fraud protection techniques. Indeed, the group has already spun out a company, Ingenia Technology Ltd. (London), to commercialize their findings. Regarding the method's ability to differentiate between different types of paper, Russell Cowburn, group leader and co-author, explains, "We obtain a unique signature for every note; the paper type is largely irrelevant. We can uniquely differentiate every single dollar bill from every other dollar bill. It works equally well on dollars, euros, and pounds."

The range of applications for this technique is considered to be vast, including preventing grey-market trafficking of tobacco and pharmaceuticals. More directly, the technique can be used as an adjunct to other security technologies for securing passports, visas, and birth certificates. Because it works well with bank notes, the technique could facilitate the removal of counterfeit notes from circulation and enable shops to check the authenticity of notes at the point of sale. As for ease of use, Cowburn says, "We've done extensive tests on both the sensitivity of positioning of the item and also the usability of the system by unskilled personnel."

Dennis Treece from the Massachusetts Port Authority said he anticipates greater use of the technology in the identification of forged passports and very high-end historic documents, which could be registered and stored in a database and used by agencies such as police investigators, museums, and auction houses. The cost, installation, maintenance, and training for the readers, however, was highlighted as an important part that needs to be quantified before developing a market for this technology. "The technology can be an effective tool for high-stakes forgery detection and ought to be encouraged if it works as advertised," Treece says. —*Ruth Woodward*

Here, a schematic shows how the technology would be used. A focused laser is scanned over the surface of the item to be identified. The sensor records an imprint in the reflected laser light of the underlying naturally-occurring irregularities on the surface (paper fibers in this case, shown in the inset) and converts this into a serial code.

MICROCHIP LASERS

Microchip Laser Nears 2-MW Output

Researchers at the Institute of Molecular Science (Okazaki, Japan) have developed a microchip laser using a saturable Q-swtich capable of producing 1.7 MW.

Diode-pumped, solid-state lasers (DPSSL), including microchip lasers, have much to recommend them. Not only are they compact and highly efficient, but they also offer a long life compared to flash-lamp pumped, gas and dye lasers. But for the purposes of Takunori Taira's research, DPSSLs high beam quality and accumulation of energy are perhaps the most significant source characteristics. "Our objective with the project was to increase the pulse brightness in a microchip configuration," Taira says.

The team picked a passive Q-switched laser because it needs neither high voltage nor high-frequency power supplies, Taira says, making the system safer to handle. In addition, its advantages include compact size, low cost, and portability.

Taira's team used a diode end-pumped high-brightness Nd^{3+}:YAG microchip laser that was passively switched by a Cr^{4+}:YAG saturable absorber (SA). Taira's research revealed that SAs do not reach complete saturation; instead, there is a residual loss, which Taira accounts for by assigning T_o to the initial transmission before saturation and T_f to the final transmission when the laser oscillation is completed in the SA.

"In order to investigate the key parameters that determine the characteristics of the laser," Taira says, "we calculated the rate equations of the passively Q-switched laser. As a result, we found that the pulse energy increases when the reflectivity of the output coupler decreases, when the initial transmission of SA decreases, and when the effective area of the resonator mode at the laser medium increases."

As noted above, the team started with a diode end-pumped passively Q-switched Nd^{3+}:YAG laser. The cavity was formed between the end face of the laser medium—which was a 5-mm-long Nd^{3+}:YAG crystal (1.4 at %)—and the output coupler—a flat mirror with 56% reflectivity. The SA was constituted by CR^{4+}:YAG crystals with initial transmission T_o of 30%, 65%, and 80%, with a 30-µm

Microchip *continued on page 8*

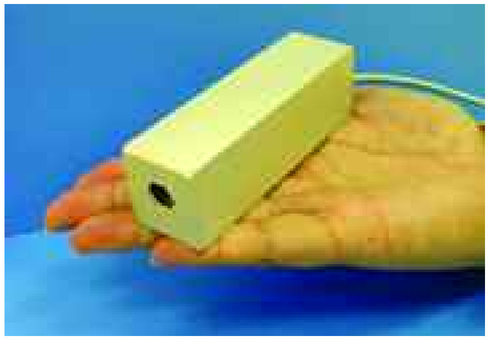
Microchip *continued from page 7*
cavity length. The pump source was a fiber-coupled diode laser with a core diameter of 400 µm, numerical aperture of 0.22, and a center wavelength of 806 nm. The diode laser was pulsed at 100 Hz to control the repetition frequency of the passively Q-switched laser.

"During our experiments, we found that the pulse energy increased and the pulse width decreased as the initial transmission of SA was reduced," Taira explains. "We then conducted a theoretical analysis to find an explanation for this phenomenon, and arrived at the equation $T_f = \exp.(0.043 \times \ln T_o - 0.098)$. We found that the experimental values were well in agreement with those calculated, as well."

With this improvement, Taira's team achieved a laser pulse energy of 0.95 mJ, a pulse width of 480 ps (1.7 MW peak power), a beam quality of $M^2 = 1.05$ for a pump peak power of 30 W (450-ms pulse width), initial transmission of SA $T_o = 25\%$, and a cavity length of 20 µm at the repetition rate of 100 Hz. "Our results were excellent for this kind of small laser," Taira says. "We were able to package the optical head of the passively Q-switched Nd:YAG laser in a box only 3 × 3 × 10 cm."

Kodo Kawase of the Nagoya University (Nagoya, Japan) Department of Quantum Engineering says, "One important feature of Taira's Q-switched laser is its single-frequency oscillation. We found it ideal for generating sharp-spectrum, single-frequency terahertz waves in our own experiments."

"Tightly focused spots with high energy density are a must for laser microfabrication," says Yoshihiko Matsuoka of the National Institute of Advanced Industrial Science and Technology (Tsukuba, Japan). "Taira and his team have achieved a high-quality, high-brightness, compact, stable laser source. Hereafter, we think a microchip laser such as Taira's may be used as a power application for microfabrication." —*Charles Whipple*



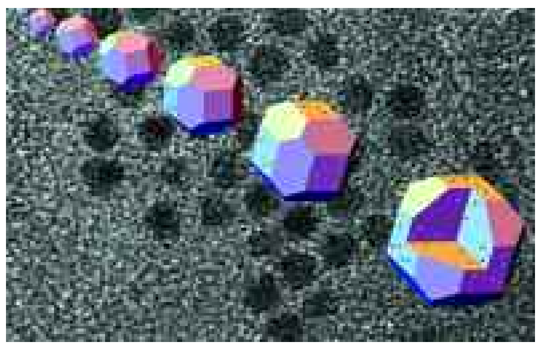
Taira and his research team succeeded in creating a very compact high-power Nd:YAG laser.

NANOTECHNOLOGY |

Doping Mechanism in Nanocrystals Is Now Understood

Semiconductor nanocrystals are of great interest due to their small size and unique electronic, optical, and magnetic properties, which can be utilized in a variety of technologies; however, it has proven more difficult to dope impurities into nanocrystals rather than into their bulk crystalline counterparts. This problem led to the widely accepted belief that nanocrystals were intrinsically difficult to dope due to a self-purification process that expels impurities from their interior.

In collaboration with scientists at the University of Minnesota (Minneapolis, MN), researchers at the Naval Research Laboratory (NRL; Washington DC) discovered the true doping mechanism in semiconductor nanocrystals and showed that in order to be incorporated, impurities must be able to bind to the nanocrystal surface for a period of time long enough to be incorporated into the nanocrystal. This



STEVE ERWIN

Nanocrystals of zinc selenide can be controllably doped with atoms of manganese, which selectively adsorb on certain crystal facets before being incorporated. The background image shown is a transmission electron micrograph of zinc selenide nanocrystals.

concept enabled the team to predict conditions favorable for doping in a wide variety of nanocrystal systems.

"This simple idea explains both the general difficulties with doping nanocrystals due to the small relative fraction of 'sticky' surfaces and the specific difficulties with hexagonal structured nanocrystals due to the underlying hexagonal crystal structure, which naturally leads to less sticky surfaces, compared to the more commonly occurring cubic crystal structure," explains NRL materials researcher Steve Erwin.

The group studied zinc selenide (ZnSe) nanocrystals with 25–50 Å diameters. "We focused on manganese (Mn) as a dopant, because its photoluminescence properties enable detailed optical characterization of Mn-doped nanocrystals and because electron paramagnetic resonance can be used to distinguish Mn that is inside the nanocrystal from Mn that is stuck to the surface" Erwin says. However the team's conclusions are not limited to either ZnSe nanocrystals or Mn dopants, as the general principle of surface binding applies to many other systems.

This novel concept may pave the way for the development of a variety of new technologies ranging from high-efficiency solar cells and lasers to futuristic "spintronic" and ultra-sensitive biodetection devices. —*Phillip Espinasse*

SEMICONDUCTORS |

Nanotube-based Electronics Enable Smaller Circuits

Nanotube-based electronics use multiple carbon nanotubes fixed to substrates that are subjected to complex deformations during manufacturing. Conventional manufacturing methods use chemical vapor deposition for growing nanotubes in a pattern on a silicon chip, however, this process does not control the direction of nanotube growth, makes it difficult to separate metallic from semiconducting nanotubes, and produces nanotubes with larger diameters than required for electronic switches.

Physicists at the University of Pennsylvania (Philadelphia, PA) circumvented these issues by growing large quantities of 200- to 300-nm-long single-walled carbon nanotubes (SWNTs) with average diameters near 1 nm. The physicists used a high-pressure carbon monoxide (HiPCO) method.

The group's approach to making useful electronic devices from SWNTs is to start with bulk material and process it so that individual SWNTs are suspended in a solution of water and surfactant. Positions on the substrate where SWNTs are supposed to go are then covered with a self-assembled molecular monolayer that acts as "glue" for the surfactant-coated SWNTs. When the substrate is dipped into a SWNT suspension, SWNTs stick in the desired locations. The surfactant is then removed, and metal electrodes are fabricated using ordinary lithographic techniques to complete the electrical circuit.

"The properties of carbon nanotubes are so remarkable, it seems as if nature has created them for application in electronic devices," says A. T. Charlie Johnson, Jr., of the research group. The team purified the HiPCO material to remove the amorphous carbon and other impurities,

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The figure shows an artist's rendition of tubes in solution, then deposited on a substrate, and, finally, the completed circuit.

recovering approximately 95% of the original SWNT content. "The circuits made from purified material had resistances 200–2000 times lower [better] than similar circuits made from unpurified SWNTs [5 Mohm to 500 Kohm]," Johnson says.

The current target application focuses on SWNT molecular sensor arrays. In the long term, it may be possible to design microprocessors to have integrated SWNT interconnects and/or transistor channels. —*Phillip Espinasse*

Erratum:

In "The Misunderstood M^2" on p. 30 of the August 2005 issue, the equation for M^2 should have read: $M^2 = \pi D_{min}{}^2/(2\lambda | Z_{min} - Z_{max} |)$.

View a corrected version of the article online at oemagazine.com/fromTheMagazine/aug05/testtalk.html. We regret any confusion this error may have caused.