rials and molecular responses, through engineering metamaterials to a bio or chemical hazard of interest, will provide an interesting approach beyond simple dielectric induced resonance shifts."

STEVEN TROHALAKI

Nonlinear Optical Mixing Enables Silicon-Chip-Based Ultrafast Oscilloscope with Sub-Picosecond Resolution

As high-speed optical communications and ultrafast science have pushed the envelope on the meaning of "fast," they have created a corresponding need for ultrafast measurement technologies. Techniques based on nonlinear optical mixing and repeated averaging can achieve very high time resolutions, but are not useful for measuring single, nonperiodic, or asynchronous optical events. Now A.L. Gaeta, M. Lipson, and colleagues at Cornell University have developed a device that may lead to a new class of ultrafast oscilloscopes based on nonlinear optical mixing in silicon. Their device has a resolution of 220 fs and a record length of 100 ps, and is fully compatible with complementary metal oxide semiconductor (CMOS) technology. They reported their results in the November 6, 2008 issue of *Nature* (DOI: 10.1038/nature07430; p. 81).

The research team's device uses the technique of time-to-frequency conversion, in which a quadratically varying phase shift is added to the optical signal to be measured. This phase shift causes the signal to evolve so that at a later period its amplitude in time is a scaled replica of its original frequency spectrum, and its frequency spectrum is a scaled replica of its original amplitude in time. The group accomplishes this phase shift addition by injecting the optical signal (centered at 1580 nm wavelength) into a 1.5-cm length nanoscale silicon-on-insulator waveguide (with a cross-sectional area of 300 nm by 750 nm) along with a suitably prepared pump signal wave. Four-wave mixing in the waveguide leads to a quadratic phase shift (or linear frequency shift) that is equivalent to 1 nm of wavelength shift for every 5.2 ps shift in time. After the waveguide and an appropriate signal propagation time, the signal spectrum is measured by an optical spectrometer, and the spectrum is scaled to obtain the original signal amplitude in time.

To characterize the device, the researchers first measured several 342-fs optical pulses with varying delays, determining that the device's record length is 100 ps and its inherent resolution is 220 fs. These limits are likely caused by high-order dispersion in the optical fibers carrying the signal and the performance of the spectrometer, and not by the four-wave mixing in the silicon waveguide. The researchers next measured several more complicated signals, and compared the results with measurements of the same signals using an average of many conventional cross-correlation measurements. The results clearly demonstrate the accuracy of the device and its ability to maintain a long (100 ps) record with high time resolution in a single shot.

According to the researchers, the use of dispersion-flattened fiber or dispersion-engineered waveguides may enable sub-100-fs resolution, and the technique can be used with other CMOS-compatible waveguiding materials such as SiN or SiON. Additionally, the individual components of the device are all the subject of extensive current research in photonics, suggesting that it may soon be possible to integrate the entire device on a chip. If that is correct, both telecommunications engineers and ultrafast scientists may one day think of bulky, super-picosecond oscilloscopes as a thing of the past.

COLIN MCCORMICK

Spin-Echo Technique in Nitrogen-Vacancy Diamond Impurities Enables Nanoscale Magnetic Sensing

The ability to detect extremely weak magnetic fields at short distances would enable important applications in a wide range of fields, from probing individual nuclear spins in complex biological molecules to storing and controlling quantum information encoded in electronic or nuclear spins. In pursuit of this ability, researchers M.D. Lukin and A. Yacoby of Harvard University, R.L. Walsworth of Harvard and the Harvard-Smithsonian Center for Astrophysics, J.S. Hodges of Harvard and the Massachusetts Institute of Technology, J.M. Taylor of the Massachusetts Institute of Technology, M.V.G. Dutt of the University of Pittsburgh, and their colleagues have demonstrated the use of coherent control of an individual electronic spin in nitrogen-vacancy diamond impurities to detect magnetic fields at the nano-Tesla level. In combination with diamond nanocrystals, this technique may lead to a new class of sensitive, extremely short-range magnetic sensors.

Electronic spin in nitrogen-vacancy (NV) impurities in diamond has been extensively studied as a candidate quantum bit because of its relative isolation from environmental effects that would cause quantum decoherence. Since ^{12}C has no nuclear magnetic moment, the primary source of local magnetic field for NV impurities comes from the nuclear spin of the small number (roughly 1% isotopic abundance) of ^{13}C atoms in the diamond lattice. As reported in October 2, 2008 issue of *Nature* (DOI: 10.1038/nature07279; p. 644), the researchers used a standard spin-echo technique to manipulate the electronic spin of a single NV impurity in a bulk, ultra-pure diamond sample. By matching the length of the spin-echo sequence to the period of the Larmor precession of the ^{13}C nuclei caused by an external dc magnetic field, the researchers were able to decouple the NV electronic spin from the nuclear magnetic field, and obtain strong spin-echo signals at times exceeding 0.5 ms. They then imposed a weak (~100 nT) ac magnetic field on the sample, and observed a sinusoidal variation of the decoupled spin-echo signal as a function of the ac field strength, caused by the accumulation of additional magnetic-precession phase from the time-varying Zeeman shift of the NV electronic spin during the spin-echo sequence. The system achieved a resolution of a few nano-Teslas for a 3.2-kHz ac magnetic field after 100 s of averaging, limited by the photon shot noise in the optical readout of the spin-echo signal.

The researchers also conducted a similar experiment using NV impurities in 30-nm-diameter diamond nanocrystals. These samples contained more spin impurities, leading to a shorter spin-coherence time (4–10 μs), and the technique displayed a sensitivity of 0.5 $\mu T\ Hz^{-1/2}$ for a field at 380 kHz. A higher sample purity and higher efficiency optical detection would likely improve this sensitivity significantly. In related work, a group at Stuttgart and Texas A&M Universities led by F. Jelezko, P. Hemmer, and J. Wrachtrup has used diamond nanocrystals to create a scanning magnetic-field sensor. In combination, these results may soon enable an extremely short-range (~10 nm), high-sensitivity (~1 nT) magnetic field sensor, with important applications in fields ranging from molecular biology to quantum information.

COLIN MCCORMICK

Silicon Nitride Membrane Dynamic Masking Allows Improved Shapes of Near-Field Optical Apertures Fabricated by FIB

Plasmonic devices structured on the scale of tens of nanometers for applications in optical interconnects, data storage, near-field lithography, and bio-sensors are often produced by directly milling the metal surface with a focused ion beam (FIB) (direct metal milling, DMM). However, obtaining high-quality structures by using this technique is difficult, as the ion beam's

https://doi.org/10.1557/mrs2009.5 Published online by Cambridge University Press

Gaussian profile produces rounded edges on apertures with small sizes and the structure becomes contaminated with gallium ions. To overcome these problems, J.B. Leen, P. Hansen, Y.-T. Cheng, and L. Hesselink from Stanford University have proposed a method of fabricating apertures by milling the metal through a silicon nitride membrane that allows long milling times that polish the metal sidewalls, and reduces the gallium contamination to negligible lateral depths, protecting in this way the metal layer from damaging gallium ions and beam tails. As reported in the December 1, 2008 issue of *Optics Letters* (DOI: 10.1364/OL.33.002827; p. 2827), the researchers compared C-apertures of various sizes fabricated with their new method of through-the-membrane milling (TMM) with apertures fabricated with conventional DMM, and simulated them by using realistic finite difference time domain (FDTD) modeling that includes rounding, gallium contamination, and metal surface roughness.

The researchers milled C-apertures in a 75-nm thick silicon nitride membrane onto which a 100-nm thick layer of gold and a 6-nm chrome sticking layer were sputtered. Apertures were produced by milling for ~3 s from the metal side (DMM) or for ~30 s from the nitride side (TMM), using a FIB operating at 30 keV and 1 pA beam current. The researchers observed that the tongue of the DMM aperture was heavily eroded by the tails of the FIB, and gallium contamination could be easily seen in and around the aperture, making it nearly useless for applications in optical data storage. On the other hand, TMM apertures were well formed, with the metal surface untouched by damaging gallium ions.

Simulation showed that the TMM aperture's near-field spot was 2.2 times smaller and 63 times more intense than the DMM aperture and that the primary effects of extending the aperture channel into the silicon nitride are to shift the resonant aperture size to larger values and to increase transmission by about 100%, both due to the lower refractive index at the aperture entrance.

The researchers verified the simulation by measuring far-field optical transmission and observed a strong resonance of the TMM apertures, 8.8 times more intense than that of the DMM aperture transmission peak, which implied a good agreement with simulations.

The researchers have simulated, fabricated, and tested a new method of creating high-quality near-IR regime near-field apertures in thin metal films and they said that the preservation of fine features at the metal surface and the protection from gallium contamination that the TMM technique provides is useful in the fabrication of several optical near-field structures including bow-tie and fractal apertures, periodic arrays, and gratings.

JOAN J. CARVAJAL

Nanoporous Carbon Membranes Characterized for Biological Use

Nanoporous membranes may serve as interfaces between implantable biosensors, immunoisolation devices, or drug delivery devices in biological environments. Once implanted within the body, medical device function may be inhibited by the adsorption of cells and proteins in a process known as biofouling. Currently, hydrogels, phospholipids, and other organic materials have been used to modify the tissue-medical device interface and reduce adsorption. An ideal tissue-medical device interface would be thin and highly porous in order to allow the medical device to quickly detect changes in the surrounding environment. Now researchers have proposed the use of diamond-like carbon (DLC)-coated nanoporous alumina for a biosensor membrane.

As reported in the August 8, 2008 issue of *Biomedical Materials* (DOI: 10.1088/1748-6041/3/3/034107), R.J. Narayan of the University of North Carolina (UNC), Chapel Hill; N.A. Monteiro-Riviere of UNC and North Carolina State University; R. Crombez of Eastern Michigan University; and their colleagues have analyzed coated alumina membranes for morphology, mechanical strength, and biocompatibility of DLC-coated alumina membranes. To prepare the membranes, researchers used the ultraviolet pulsed laser deposition technique to deposit thin films of diamond-like carbon, gold, and titanium on nanoporous alumina membranes (pore size = 100 nm) at 25°C for 2 min. The surface properties were characterized using a Nanoscope IIIa scanning probe microscope and the mechanical properties were determined using the Nano-indenter XP system. Cell viability was determined by incubating the membranes in a human epidermal keratinocyte culture and evaluating mitochondrial activity.

Imaging revealed a smooth surface containing a high number of pores that were also monodisperse in appearance on the DLC membranes. Additionally, by changing the parameters of the deposition process, such as electric field strength and processing temperature, the size of the pore can be altered. A comparison of the uncoated alumina membranes and the DLC membranes showed that the DLC membranes had a lower hardness value and Young's modulus, attributed to the larger pore sizes of the DLC membrane. The 24-h MTT assay demonstrated the human epidermal keratinocyte cell viability was highest in the uncoated membranes; and that the viability of the DLC-coated membrane was significantly higher than that of the gold- and titanium-coated membranes. The researchers said that the diamond-like carbon-coated membranes have potential use in a large number of medical applications.

TARA D. WASHINGTON

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https://doi.org/10.1557/mrs2009.5 Published online by Cambridge University Press