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Optomechanical Photon Shuttling Between Photonic Cavities

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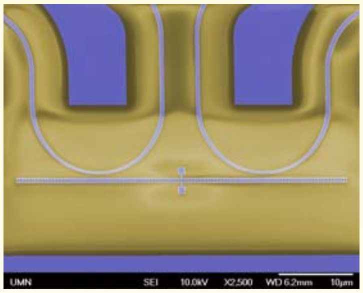
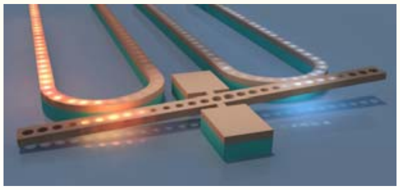
Huan Li and Prof. Mo Li, of the University of Minnesota's Department of Electrical and Computer Engineering, have developed a novel nanoscale device that can capture, measure and transport fundamental particles of light, called photons. The tiny device is just .7 micrometers by 50 micrometers and works almost like a seesaw. The device was fabricated from silicon on insulator (SOI) wafers with the Vistec EBPG5000+ system in the cleanroom at the Minnesota Nano Center. The feature size error of fabrication process was consistently within ±5 nm.

Once released from the silicon dioxide substrate with selective wet etching, the delicate device works almost like a seesaw for photons. On each side of the "seesaw benches," researchers etched one photonic crystal cavity, which consists of an array of holes. These cavities can capture photons coupled from the nearby waveguides. Even though massless, the captured photons were able to rotate the seesaw because they generated optical force. Researchers compared the optical forces generated by the photons captured in the cavities on the two sides of the seesaw by observing how the seesaw moved up and down. In this way, the researchers weighed the photons. This device is sensitive enough to measure the force generated by a single photon, which corresponds to about 1.5 fN. The research could be used to develop extremely sensitive accelerometers or gyroscopes.



The research team also used the seesaw to experimentally demonstrate for the first time the mechanical control of transporting light. When the cavity on the left side was filled with photons and the cavity on the right side was left empty, the force generated by the photons started to oscillate the seesaw. When the oscillation was strong enough, the photons spilled over along the beam from the filled cavity to the empty cavity during each cycle. This phenomenon is called "photon shuttling". The stronger the oscillation, the more photons are shuttled to the other side. Currently the team has been able to transport approximately 1,000 photons in an oscillation cycle. For comparison, a 10 W light bulb emits 10^{20} photons per second. The team's ultimate goal is to transport only one photon in a cycle so that the quantum physics of light can be revealed and harnessed. The discovery could have major implications for creating faster and more efficient optical devices for computation and communication.



The research paper has been published online and will appear in the October issue of Nature Nanotechnology. The team's research was funded by the Air Force Office of Scientific Research.

REMINDER: If your work uses the Minnesota Nano Center (formerly NFC) please add the following in the acknowledgements section of any publication: "Parts of this work were carried out in the Minnesota Nano Center which receives partial support from NSF through the NNIN program."

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CHARFAC DIRECTOR'S MESSAGE

CharFac Director, Greg Haugstad

I am very pleased to announce the addition of Dr. Javier Garcia-Barriocanal to the CharFac technical staff. Javier's principal area of activity is X-ray diffraction (XRD). He is also becoming active in our high-energy ion beam lab (channeling analysis in crystalline systems, e.g., of interstitial defects) and atomic force microscopy (AFM, for electronic property analysis). His emphasis is on hard materials such as oxides and metals, complementing that of Dr. Klaus Wormuth who joined us in fall 2013 with an emphasis on soft materials and coatings. Together with pharmaceutics postdoc Dr. Seems Thakral, these individuals have experience applying an array of XRD methods to nearly all classes of materials, and intimately understand how XRD complements Raman spectroscopy, thermal transition measurements, electric/magnetic property analysis and more.

In detail, Javier received a PhD in physics from the University of Complutense of Madrid (UCM) following masters work in materials engineering and chemistry. His PhD research focused on the sputtering growth of transition metal oxide heterostructures, characterized by X-ray diffraction experiments. In postdoctoral roles at the European Synchrotron Radiation Facility in Grenoble (France), Javier designed and conducted experiments at both synchrotron and neutron beamlines (e.g., grazing-incident X-ray diffraction and X-ray absorption spectroscopy). This was followed by a Fulbright fellowship at Minnesota with Prof. Allen Goldman on high-T_c superconductors, ozone-assisted molecular beam expitaxy, and electric transport and magneto-transport measurements. His final appointment prior to joining the CharFac was as assistant professor at UCM, where he continued his collaboration with Prof. Goldman on electrostatically doped oxide superconductors within the World Wide Materials Network (co-funded by the NSF and the MINECO Spanish Agency). The research of Javier has been focused on electronic and atomic reconstructions, charge transfer processes and disorder effects at interfaces of oxides and their role in ionic transport and on electronic and magnetic structures.

New CharFac staff member, Dr. Javier Garci-Barriocanal.

We are also excited that a recent infrastructure grant program under the Office of the Vice President for Research (and matched by our college), has yielded several new pieces of equipment. After many years of maintaining very old and partially failing coaters (to deposit conductive thin films on scanning electron microscopy specimens), we will soon replace with state-of-the-art systems. We are adding (1) a highly automated, high-throughput magnetron coater, and (2) an ion-beam coater/etcher (for extremely thin coatings or to render oxidized metals conductive). These two systems, to be placed in each of our two SEM facilities, will be much easier to maintain, more automated (to achieve a specified film thickness for a given metal type), and broader in functionality; and will allow hands-on operation by microscopy users. Other equipment additions enabled by our infrastructure grant are for Raman spectroscopy. These include (1) a new 785-nm laser (to minimize fluorescence) and a newly designed coupler for rapid experimental reconfiguration between laser types, and (2) a coupler to extend the analyzed spectral range down to 30 cm^{-1} wave number. The latter is well below our previous cutoff of 250 cm^{-1}, allowing one to probe lattice vibrations of interest in both inorganic and polymeric materials (e.g., phonon mode softenings that are precursors to second-order phase transitions).

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Greg Haugstad, Director

MNC DIRECTOR'S MESSAGE

MNC Director, Steve Campbell

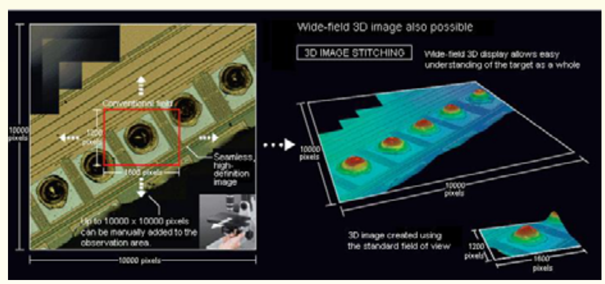
The final remaining problem with the new PAN clean room is the noise level in the lab. Users may have noticed an improvement in this problem as we have worked with Facilities Management. Additional improvements will require some hardware changes in the air handling equipment. We are currently evaluating the options and hope to get this wrapped up soon.

In the equipment area, we recently brought on line a new Keyence VHX-5000 Digital Microscope. Details are given in the next section. We also found out that our proposal to the OVPR's infrastructure program to fund new equipment in PAN was successful. We just placed an order for a refurbished Karl Suss aligner and plan to have that installed by the end of the year. Vendors of high density plasma chemical vapor deposition tools will be visiting this fall. We expect adding this tool by late spring or early summer of 2015. Finally, we plan to add another ALD tool. Tool selection will be done after the HD-PECVD system is selected.

I also wanted to let you know that our new Nanomaterials Lab opened last month. We already have 13 users working on characterizing micro and nano particles and particle suspensions. The tools are capable of measuring particle size distributions, zeta potential, and optical microscopy. The new Bio-Nano Lab, which offers facilities and equipment for cell culturing, DNA and protein analysis, fluorescence microscopy, and multiwavelength analysis of cells, opens in the next few weeks. If you have interest in either area, contact Jim Marti (jmarti@umn.edu).

Keyence VHX-5000 Digital Microscope

Conventional optical microscopy, with researchers peering through the eyepiece lens to view their samples, is an accepted and important technique for characterizing structures in microfabrication research. In the past two decades, improvements in CCD imaging technology have spawned digital microscopes – microscopes with CCD cameras to capture high quality images and supplement/replace direct viewing of the sample.



The Keyence VHX-5000E has several features which provide unique capabilities, including a motorized stage (both x-y and z motions) and software for image analysis. By adding a high accuracy motorized stage to control the stage position, a computerized digital microscope can create high resolution composite images of structures too large to view in a single image field. This is an essential feature for overcoming the limitations of small field-of-view associated with high magnification objective lenses. Software is used to stitch together these individual images into a composite picture of the entire structure and create a large area cohesive that can then be analyzed using the software to accurately determine sizes of structures, spacing between structures, and other important dimensions. Structures with vertical dimensions greater than the depth-of-focus for the objective lens will have portions of a single image out of focus. Adding motorized z-axis control allows a series of images at different heights to be captured. Software integration of these images yields a final image with all parts of the structure in focus. The Keyence is located in the Keller Hall cleanroom and is free for members trained in its use.

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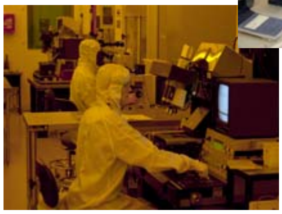

The MNC is a state-of-the-art facility for interdisciplinary research in nanoscience and applied nanotechnology. The Center offers a comprehensive set of tools to help researchers develop new micro- and nanoscale devices, such as integrated circuits, advanced sensors, microelectromechanical systems (MEMS), and microfluidic systems. The MNC is also equipped to support nanotechnology research that spans many science and engineering fields, allowing advances in areas as diverse as cell biology, high performance materials, and biomedical device engineering.

The MNC is composed of two main facilities. Our current clean room and associated labs, formerly known as the Nanofabrication Center, are housed in Keller Hall. The Keller Lab has a 3000 square foot Class 100 clean room, and an additional 4000 square feet of labs and support areas.

In late 2013, the MNC will open a new research facility in the Physics and Nanotechnology (PN) building. The new PN Lab facility will offer a larger and more advanced clean room, with state-of-the-art tools for fabricating structures under 10 nanometers in size. The MNC will also offer two new specialized labs to support interdisciplinary research in bio-nanotechnology and nano-and micrometer-scale materials.

The National Nanotechnology Infrastructure Network: www.nnin.org

The National Nanotechnology Infrastructure Network (NNIN) is an integrated networked partnership of user facilities, supported by the National Science Foundation, serving the needs of nanoscale science, engineering and technology. The mission of the NNIN is to enable rapid advancements at the nano-scale by efficient access to nanotechnology infrastructure. The NNIN supports the Minnesota Nano Center at the University of Minnesota. As a node in NSF's National Nanotechnology Infrastructure Network (NNIN), the NFC provides access to advanced multi-user facilities to both industry and academic researchers, the latter at a subsidized rate.