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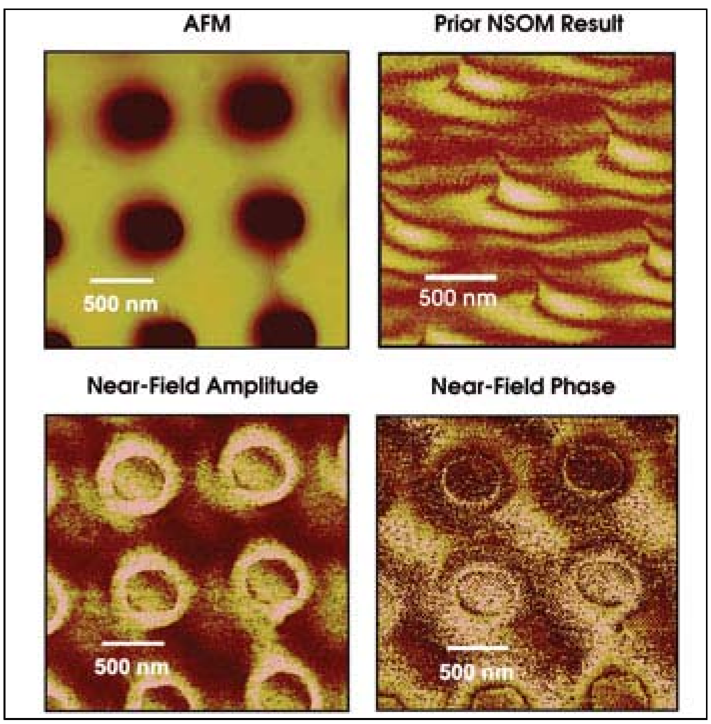
Getting the ‘Hole’ Picture Up Close

by Hank Hogan

Plasmons — local electron oscillations in metal films — hold great promise as the basis for sensors and optical switches. A challenge with such substrates has been pinpointing the location of the highest plasmonic signal -- knowledge of which could be used to engineer better devices.

Near-field scanning optical microscopy offers the highest resolution possible for this search, but the technique has difficulty imaging periodic arrays because the near-field information is swamped by far-field diffraction and scattering, leaving investigators with a blurry picture.



On the upper left is an atomic force microscope image of periodic nanowells, the type of structure that could form the basis for a plasmonic sensor. Below it are images from an apertureless near-field scanning optical microscope (NSOM) that were collected with a heterodyned approach in which two beams — sample and reference — were used. The combination enables clear imaging of the nanowell structure. On the upper left is the NSOM result when using a single beam, which is not clear because of scattering and diffraction effects of the nanowell array. Courtesy of Gary P. Wiederrecht, Argonne National Laboratory.

There may be a solution, thanks to a group from Argonne National Laboratory in Illinois, the University of Illinois at Urbana-Champaign, the Institute of Electro-Optical Science and

Engineering in Tainan City, Taiwan, and the University of Technology of Troyes in France. Instead of the single illuminating beam typical of near-field scanning microscopy, the investigators used two beams, applying a heterodyne detection scheme in a novel way. This approach enabled them to overcome a highly diffractive and highly scattering substrate.

"We can eliminate the far-field diffracted light in periodic structures so as to detect the optical near-field," said Argonne's Gary P. Wiederrecht.

In a typical apertureless near-field scanning microscopy setup, an atomic force microscope is operated in tapping mode: A sharp tip mounted at the end of a cantilever vibrates up and down with an amplitude of a few tens of nanometers. The tip is brought within a few nanometers of the sample surface, and a laser beam illuminates the tip, producing near-field information about the surface below the tip.

In this homodyne method, there is also a background signal, which makes image analysis difficult — particularly for the substrates used in plasmonic studies.

In contrast, the heterodyne method — which Wiederrecht noted was invented by Rainer Hillenbrand and Fritz Keilmann of Max Planck Institute of Biochemistry in Martinsreid, Germany — uses both an illumination and a reference beam, creating the latter from the former through frequency shifting. The signal from the sample is combined with the reference beam, allowing extraction of near-field information.

In experiments, the researchers used two acousto-optic modulators to make the reference beam, with a Coherent Inc. krypton laser as a light source. They used a Veeco Instruments Inc. atomic force microscope and a Hamamatsu photomultiplier tube for a detector.

With this setup, they imaged arrays of gold-coated nanowells of a size below the laser's wavelength. For example, they successfully imaged wells of 400-nm depth, 450-nm diameter and 800-nm periodicity.

The technique could be used to determine the very highest signal areas in periodic plasmonic-based sensor structures. The researchers also see it being employed to resolve subwavelength fields in photonic band gap structures and to determine the material excitation from which the optical field is derived.

"The strong signal enhancement achieved with heterodyne detection takes the sensitivity of near-field microscopy to a new level. It is most powerful when extracting the optical near-field from high levels of far-field noise," Wiederrecht said.

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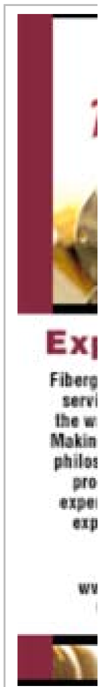

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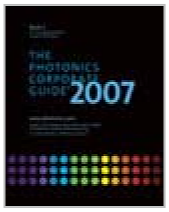

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