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Nanophotonics Advance Could Boost Biomolecular Studies and Sensor Capabilities

By Mark Dwortzan

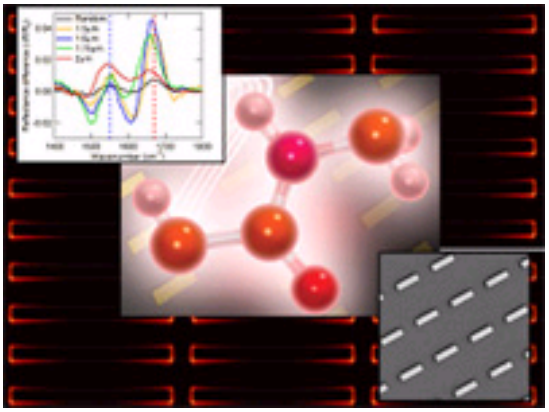
An interdisciplinary team of researchers led by Assistant Professor Hatice Altug (ECE) has created a highly sensitive, infrared (IR) absorption spectroscopy technique that can identify specific proteins and other molecules using far less sample material than what conventional spectrometers require. Exploiting recent advances in nanophotonics, the technique constitutes a powerful new tool for biomolecular studies and drug discovery, and could considerably enhance biological and chemical sensor detection capabilities.

Asst. Professor Hatice Altug (ECE)

Infrared absorption spectroscopy uses infrared light to excite the bonds that connect atoms within molecules, causing them to vibrate at a specific resonant frequency. By examining what frequencies of light are absorbed by a material, scientists can determine what kind of bonds it contains, and thus identify the material.

Because absorption signals are often weak, conventional IR spectroscopy requires large samples of target molecules in many layers. To overcome this limitation, the research team used tiny gold nanoparticles as highly efficient "nanoplasmonic" antennas that greatly amplify the signal received from an individual protein molecule.

"Our technique enhances the signal by a factor of up to 100,000," said Altug. "Because our technique is ultra-sensitive, we don't need a large number of molecules from which to obtain signals. In fact, we can obtain signals from even a single-molecule-layer thick protein film."



Vibrational signatures of protein molecules can be dramatically enhanced by strategically arranged arrays of rod-shaped nanoantennas.

Altug and her collaborators — Professor Shyamsunder Erramilli (BME, Physics); Research Professor Mi Hong (Physics); graduate student Ronen Adato and post-doctoral fellow Ahmet Ali Yanik in Altug's lab; and Tufts University bioengineers David Kaplan, Fiorenzo Omenetto and Jason Amsden — report on this unprecedented achievement in this week's online edition of *Proceedings of the National Academy of Sciences.*

Nanoantennas Dramatically Improve Detection Capability

To obtain the high sensitivity needed to detect vibrations from an extremely small sample of silk protein molecules, the team designed a 50-by-50 array of gold, rod-shaped nanoantennas and tuned their resonant frequency to match that of the bonds within the sampled molecules.

The 2,500 strategically configured antennas focus infrared light on nearly 145 silk protein molecules deployed at the tip of each nanoantenna. The light, in turn, excites the bonds within the molecules to vibrate at their signature 6.6 micron wavelength. After absorbing a significant fraction of the incoming IR light, the silk protein molecules reflect the rest back through the nanoantennas. Upon receipt of the reflected signal, the spectrometer deduces the vibrational signature of the silk protein molecules.

Combining theoretical calculations and advanced nanofabrication techniques, Yanik and Adato obtained up to a 100,000-fold enhancement of the molecules' vibrational signatures and whittled the sample thickness down to a single layer of protein.

Drawing on seed funding from an ENG Dean's Catalyst Award and ongoing support from the National Science Foundation, Massachusetts Life Science Center and Department of Defense, Altug and her co-investigators are now applying their novel IR spectroscopy technique to other kinds of molecules.

"Our plasmonic method is quite general and can be adapted to enhance the

infrared fingerprints of other biomolecules, such as nucleic acids and lipids," said Altug. "It therefore provides a general purpose toolkit for ultra-sensitive vibrational spectroscopy of biomolecular systems."

Drug Discovery Implications

Because the technique requires only one-layer, two-nanometer-thick samples, it may ultimately enable scientists to obtain much more accurate and useful data.

"The sensitivity of our technique can be high enough to provide spectroscopy at the single-molecule scale," said Altug, "and a single-molecule response can be very different from that of an ensemble of molecules."

Studying protein molecules in one layer offers yet another advantage.

"Conventional IR spectroscopy requires a large number of proteins, usually 5,000 to 10,000 layers of them in one stack that resembles a baklava," said Erramilli. "With our single-layer substrate we can capture proteins in their native environment."

As a result, the new technique could be used to improve our understanding of how protein molecules interact and how external forces alter their shape and behavior — questions of fundamental importance in biochemistry and drug discovery.

The method may also help amplify biological and chemical sensing capabilities in defense and other applications.

"Chemical sensors detect the presence of specific molecules via molecular fingerprints, telltale vibrational frequencies of the molecules' bonds," Altug explained. "Our technique's ultra-sensitivity enables us to pick up clear, identifiable response signals even from a trace amount of a chemical."