Metamaterials Offer Communications Breakthroughs

TINY, DETAILED STRUCTURES MANIPULATE SOUND AND ELECTROMAGNETIC WAVES IN NEW WAYS

An expert in the field of metamaterials, Professor Xin Zhang (ME, ECE, BME, MSE) and her lab have recently developed two new structures that can manipulate sound and electromagnetic waves. Although they are different, both offer two forms of wave control in their own spectrums and performance yet seen in other devices.

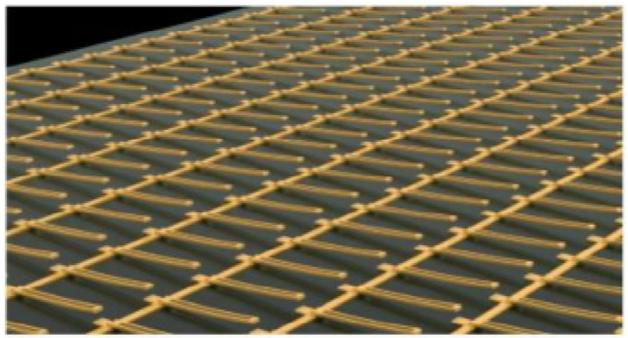
Metamaterials are tiny, 3D-millimeter-sized constructions that get their properties from their structures rather than their base material and are built to extend functionality beyond the limitations of natural materials. A metasurface, which is essentially a 2D metamaterial, is designed with a repeating pattern that can manipulate a wave.

The acoustic metasurface's design was based on the marriage between a well-known class of structures known as space-coiling metamaterials, and a classical acoustic element, a horn. By building an almost hybrid of these shapes, the engineers were able to simultaneously tune both the phase and amplitude of sound waves using one structure, which had never been done before. Their work has been published in *Nature Communications*.

This new design has the capacity to shape myriad applications ranging from biomedical ultrasound to non-destructive testing and sonar. In the future, it could be used to control high-intensity ultrasound waves to focus on a very specific shape to destroy cancerous tissue without hurting viable tissue. Also, by being able to alter acoustic waves, engineers could control sonar and have it hit a specific target without the fear that it could be picked up by another.

The second metamaterial manipulates waves from the terahertz region of the electromagnetic spectrum. Electromagnetic waves are anything from radiowaves to microwaves as well as visible light and X-rays, which all radiate at different frequencies, giving them unique properties.

The terahertz region sits between microwaves and infrared light on the spectrum and technology to operate on the terahertz frequency, known as submillimeter radiation, is considerably less developed than other areas.



The microcantilevers arranged in a repeating pattern make up the metamaterial that could help close the terahertz gap. When current runs through the material, the cantilevers snap down and form a grid-like structure.

IMAGE PROVIDED BY PROFESSOR XIN ZHANG

One reason for the terahertz gap is that the development of electronics has not reached the ability to receive and transmit such high frequency waves yet. The metamaterial developed in Zhang's lab, a collaboration with Professor Richard Averitt's group at the University of California, San Diego (formerly of BU physics), has the ability to tune the transmission of terahertz waves, which opens the door to closing the technology gap. The work, published in *Optica* and featured as the cover image, demonstrates a metasurface with an array of micro-cantilevers, or beams only attached on one end—picture a rung on a ladder with just one side of the ladder connected to it.

Engineers can choose what kind of wave the metamaterial will transmit and its properties by changing the amount of voltage they send through the material. Any substance that can conduct electricity has a resonant property, and by manipulating that property with voltage changes, the engineers can alter the transmitted wave.

When current is applied to the metamaterial, the cantilevers snap shut, thus forming a grid pattern and connecting the rung to the other side of the ladder; that transformation of the metamaterial increases its capacity to hold the electric charge flowing through it, otherwise known as its resonant property. Resonance is the phenomenon when vibrations from one source affect another—like when glass shatters from a very high frequency sound. When the electrical charge is able to spread out, the metamaterial will then resonate at a lower frequency, and its resonant property will change—which is how the terahertz wave is manipulated.

The device can also shift wave polarization from circular to linear, meaning that it can focus a wave in a particular direction. Currently only about 30 percent of the original power of the wave is transmitted, but altering the geometry of the metamaterial could increase that percentage.

The reconfigurable metasurface will help bridge the terahertz gap and can be used to develop novel imaging and sensing terahertz technologies. Closing the gap could also allow for faster communications, like transmitting data faster than 4G or 5G data speeds on mobile electronics.

—LIZ SHEELEY

Turning Cells On and Off

NGO TEAM CREATES CELLULAR CONTROL SYSTEM FROM HEPATITIS C GENOME

The field of synthetic biology—where scientists redesign existing biological systems to do new jobs—offers the promise of a more nuanced approach to treating disease than pharmaceutical drugs: cellular therapies that can work more precisely and selectively. One long-standing goal of modern biology is a type of immunotherapy that allows us to tweak the immune system to do our bidding, and for some cancers, it's already proving effective.

But for immunotherapy—and for all medicines based on living human cells—there's a sticky problem: once you train cells to attack a tumor, or kill bacteria or build cartilage in an arthritic knee, how do you turn them off when the job is done?

"A challenge for doctors will be to control these living entities while they are in the body, allowing them to carry out their curative properties while not letting them get out of hand," says Assistant Professor John Ngo (BME). "This is a new paradigm, and the rules regarding how to control therapeutic cells still remain to be written."

Ngo and his collaborators have come up with a tool that offers a means of control, and it comes from a seemingly unlikely source, the hepatitis C genome. When paired with a widely available antiviral medication, the new system offers a novel tool: a highly specific way to turn engineered cells on and off, with an existing, proven medication. The team published their findings in *Nature Methods*.

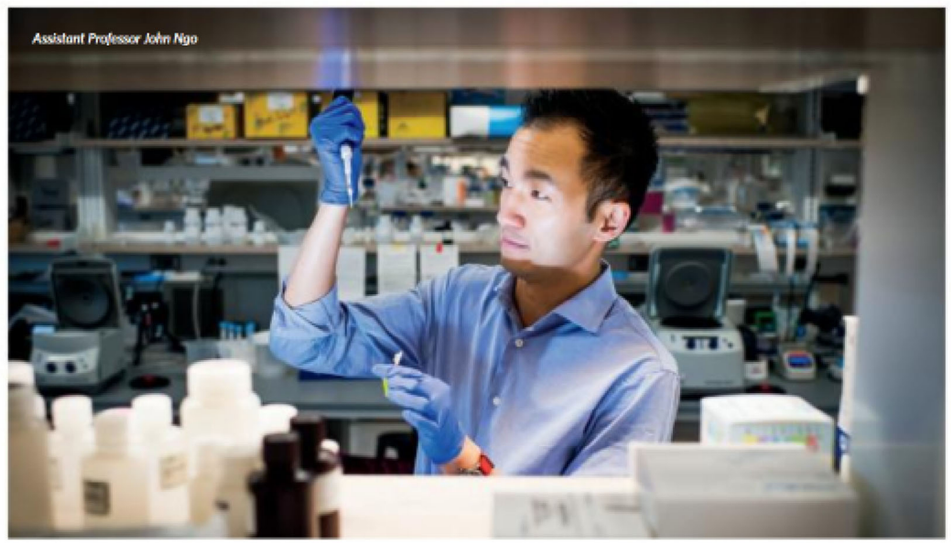
"The big question is, can we engineer cells to do what we want for therapeutic applications?" says Assistant Professor Wilson Wong (BME), who shared a BU Ignition Award for related research with Ngo. Wong's ultimate goal is to remove immune system T-cells from patients, genetically engineer them to find cancer, and then return them to a patient's body, controlling them with a system like Ngo's.

"This work shows that we can repurpose existing medicines to control therapeutic cells in a way that is not only selective, but also efficient from the drug-development standpoint, because these drugs already exist," says Ngo. "A convenient benefit of the system is that we already know exactly how long these drugs stick around for."

The system is modular, and can be used to build and disconnect different types of molecules that turn different genes on and off. Ngo and Wong hope the system will offer a new tool for cancer researchers, and may eventually lead to tailored cancer therapies. "Everybody is racing toward getting a more controllable system," says Wong.

"The system is very modular and very generalizable," says Ngo. "We don't know what type of systems will be the most useful yet in terms of having genes turn on or off, so having tools that can be used to engineer drug control into lots of different cell features will be very important. I think if we're creative enough, we can figure out how to control essentially any protein using this type of technology."

—BARBARA MORAN



Assistant Professor John Ngo

PHOTOGRAPH BY JACKIE RICCIARDI