Engineers tune a nanoscale grating structure to trap and release a variety of light waves

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People debating politics are well-advised to shed more light than heat. Engineers working in optical technologies have the same aspiration.

Light waves transmit data with much greater speed than do electrical signals, says Qiaoqiang Gan, a Ph.D. candidate at Lehigh University in Bethlehem, Pa. If they are guided with sufficient precision inside the tiny circuits of an electronic chip, they can bring about applications in spectroscopy, sensing and medical imaging. And they can hasten the advent of faster all-optical telecommunication networks, in which light signals transmit and route data without needing to be converted to electrical signals and back.

To enable light waves to store and transmit data with optimal efficiency, engineers must learn to slow or stop light waves across the various regions of the spectrum.

Gan and his adviser, Filbert J. Bartoli, department chair of electrical and computer engineering, made a major contribution to this effort last year when they developed a graded metal grating structure capable of slowing or stopping terahertz (THz) light waves. The achievement, said Bartoli, "opened a door to the control of light waves on a chip" that could help reduce the size of optical structures, enabling them to be integrated at the nanoscale with electronic devices.

Gan and Bartoli reported their results in June in *Physical Review Letters* (PRL), an influential international journal. Their article was coauthored

by Yujie J. Ding, professor of electrical and computer engineering, and Zhan Fu, a Ph.D. candidate advised by Ding. The researchers are affiliated with Lehigh's Center for Optical Technologies.

Recently, Bartoli's team recorded a second major advance. Working again with Ding, they demonstrated that their grating structure could be scaled down in size to a dimension compatible with light waves in the telecommunications portion of the spectrum.

THz waves measure several hundred microns in length (1 micron is one-millionth of a meter) and are suitable for security applications. Wavelengths in the telecommunications range of the spectrum measure 1330 to 1550 nanometers (1 nm is one-billionth of a meter) and are suitable for optical communications.

The three researchers reported their progress in a second PRL article, titled "Rainbow Trapping and Releasing at Telecommunication Wavelengths." The article was published in the journal's Feb. 6 issue.

In the current article, the researchers also address a phenomenon called loss in metals, in which the metal materials of a chip, instead of simply propagating light, also absorb it and dissipate it as heat. Metal loss occurs more strongly with telecommunications light waves than with THz light waves.

To use trapped light waves for telecommunications, says Gan, it is necessary to release them from the grating structure. Gan and his colleagues accomplished this by covering the structure with dielectric materials.

"By tuning the temperature of the dielectric materials, we were able to change the optical properties of the metal grating structure," he said. "This in turn enabled the trapped light waves to be released."

The Lehigh researchers describe their structure as a "metallic grating structure with graded depths, whose dispersion curves and cutoff frequencies are different at different locations." In appearance, the grating resembles the pipes of a pipe organ arranged side by side and decreasing gradually in length from one end of the assembly to the other. The degree of grade in the grating can be tuned by altering the temperature and modifying the physical features on the surface of the structure.

The structure arrests the progress of light waves at multiple locations on the surface and at different frequencies. Previous researchers, Gan says, had been able "to slow down one single wavelength within a narrow bandwidth, but not many wavelengths over a wide spectrum."

Most of the initial work on this project has been theoretical, using mathematical equations and computer simulation. Bartoli's group has now moved to the next stage, which includes fabricating and characterizing the structures.

"It will be challenging," Gan says, "to achieve a grade of grating depths which range from very shallow to as much as 50 nanometers on a 200-nm substrate. To do this, we are using the focused ion beam milling facilities in the materials science and engineering department. We have already fabricated many structures and will now try to characterize the graded gratings with near-field scanning optical microscopy in Prof. Volkmar Dierolf's lab in the physics department.

"We are pursuing promising applications based on these structures. These include biosensing and bioimaging."

An article in the Feb. 14 issue of the British journal *New Scientist* said the results obtained by Bartoli's team "suggest that one day we might be able to slow down light long enough to store it as a 'rainbow' or colors -

an advance that would revolutionize computing and telecommunication networks."

Light is stored for a few pico-seconds in the grating structure, the *New Scientist* article notes. But this, according to physicist Ortwin Hess of the University of Surrey in the United Kingdom, "is quite significant for many applications."

Source: Lehigh University