Germanium-based photonics offer promise for novel sensors and faster internet

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Mid-infrared light, which has a wavelength longer than visible light but shorter than microwaves, has many important applications in remote sensing and communication technologies. Researchers in Japan have demonstrated the successful operation of several new photonic components that can effectively guide the passage of mid-infrared light. The research may lead to a faster internet and sensitive detectors for important molecules like carbon dioxide. The team presents their results at the Optical Fiber Communication Conference and Exhibition (OFC), held March 20-24 in Anaheim, California, USA.

The researchers built the new components from the material germanium (Ge). Like silicon, which is commonly used in conventional near-infrared photonics, germanium is a group IV semiconductor, which means it is in the same column of the periodic table and has similar electrical properties. Germanium has several properties that make it particularly well-suited to transmit and guide mid-infrared light, said Jian Kang, a Ph.D. candidate in the Takagi-Takenaka group in the Department of Electrical Engineering and Information Systems, University of Tokyo, Japan.

Germanium has high optical transparency in the mid-infrared range so mid-infrared light can easily pass through it. Compared to silicon, germanium has a number of other optically interesting properties. These include a higher refractive index, which means light passes more slowly through it. Germanium also has a larger third-order nonlinearity, an optical effect that can be exploited to, for example, amplify or self-focus beams of light. It has a stronger free-carrier effect, which means charge carrying electrons and holes in the material can help modulate light. Germanium also has a stronger thermo-optic effect than silicon, which means the refractive index can be more easily controlled with temperature.

"These properties could make Ge-based devices show higher performance or even realize new functionalities in the mid-infrared," said Kang. Furthermore, recent progress on lasers made from strained-Ge and GeSn-based materials make germanium a promising material for integrating both the light producing and light steering components on the same photonic chip, Kang said.

Kang and his colleagues designed and tested several fundamental photonic waveguide components made from germanium, including grating couplers, MMI couplers, and micro-ring resonators. Grating couplers are used to couple light efficiently from free space into a waveguide, and vice versa, MMI couplers are used as routers or couplers for light signal processing in the waveguide, and micro-ring resonators are used to filter certain wavelengths of light passing through.

The biggest challenge the team faced was controlling the device fabrication process, including the polishing and etching of the germanium wafer, Kang said.

"Currently, the Ge device performance may be not as good as state-of-the-art Si-based ones, because the study of Ge-based photonic components for mid-infrared is quite new and there remain many issues in the optimization of the fabrication process," he said. "Nevertheless, we believe that Ge-based devices have intrinsic advantages."

Germanium's attractive optical properties in the mid-infrared mean that an optimized Ge waveguide could be more compact than a similar silicon device, meaning more chips could fit into the same space, Kang noted.

Many important molecules, such as carbon dioxide, absorb and emit light in the mid-infrared when they change vibrational states, so mid-infrared photonics could serve as the basis for new sensors. Monitoring and detecting carbon emissions, hidden explosives, and health conditions like liver disease and cancer are all possible with Ge-based sensors, Kang said.

Ge-based photonic chips also have the potential to increase the bandwidth of optical fiber communications. "In a general sense, it can make the internet much faster," Kang said.

For now, Kang and his colleagues are working on improving their fabrication techniques. Afterwards they plan to build more devices, such as optical switches, and to integrate a GeSn laser and Ge waveguide devices onto the same chip.

More information: Presentation: "Design and Characterization of Ge Passive Waveguide Components on Ge-on-Insulator for Mid-Infrared Photonics," by Jian Kang, Xiao Yu, Mitsuru Takenaka and Shinichi Takagi.

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