Researchers present revolutionary light-emitting silicon

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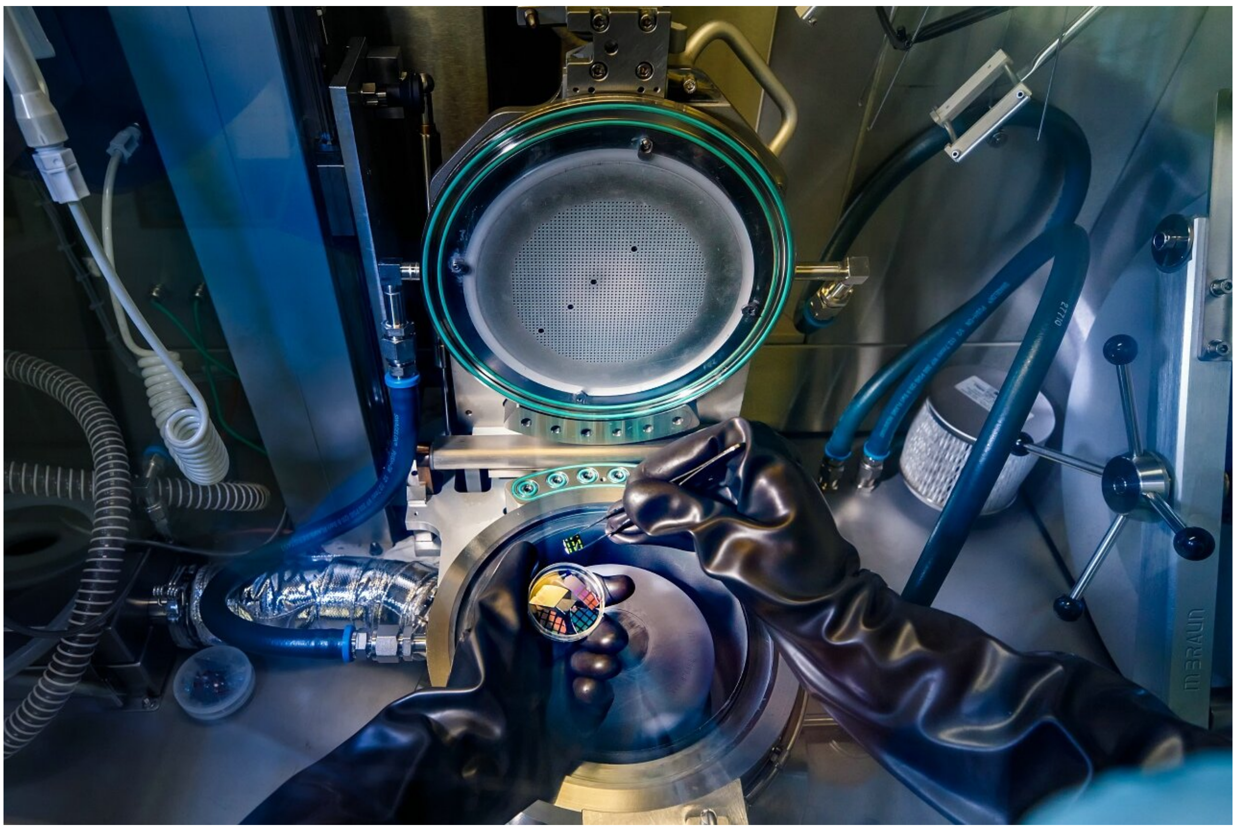
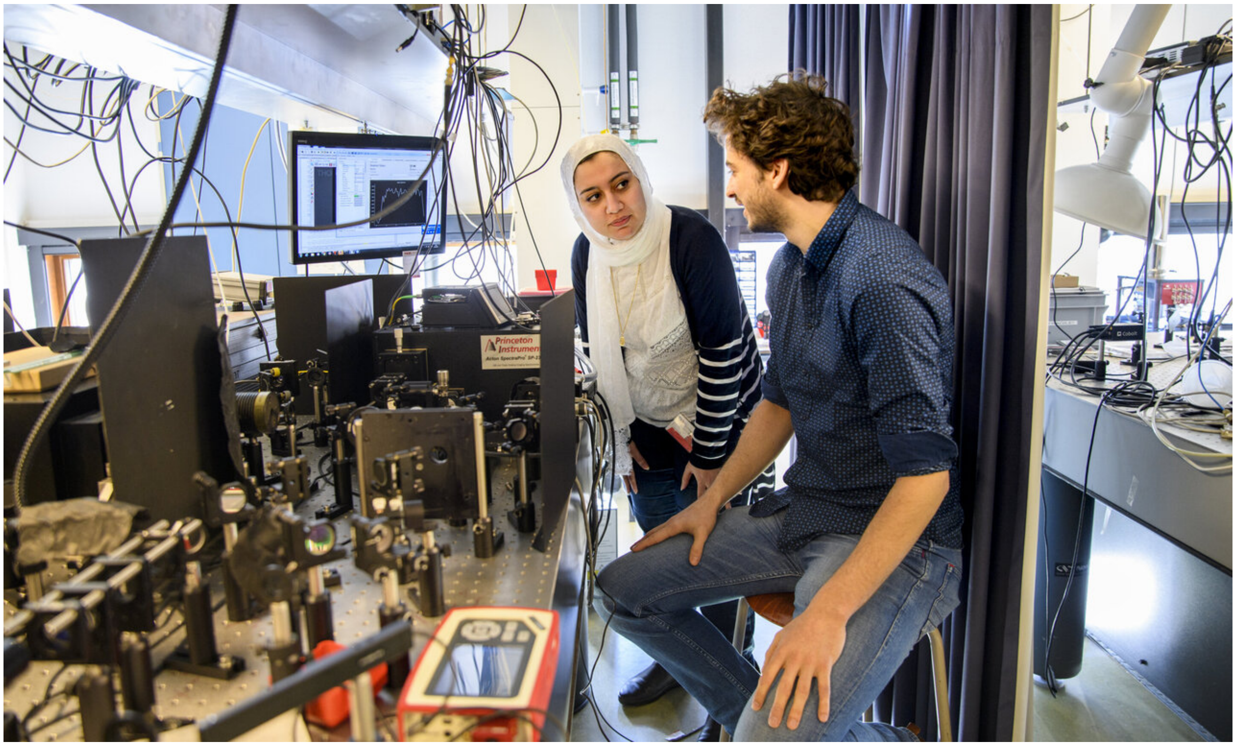


A look inside the Metal Organic Vapor Phase Epitaxy (MOVPE). This machine was used to grow nanowires with hexagonal silicon-germanium shells. The emission from this hexagonal-SiGe alloy showed to be very efficient and suitable to start producing an all-silicon laser. Credit: Nando Harmsen, TU/e

Emitting light from silicon has been the Holy Grail in the microelectronics industry for decades. Solving this puzzle would revolutionize computing, as chips will become faster than ever. Researchers from Eindhoven University of Technology have now developed an alloy with silicon that can emit light. The results have been published in the journal *Nature*. The team will now develop a silicon laser to be integrated into current chips.

Current technology based on semiconductors is reaching its ceiling. The limiting factor is heat, resulting from the resistance that the electrons experience when traveling through the copper lines connecting the many transistors on a chip. To continue advancing data transfer requires a new technique that does not produce heat.

In contrast to electrons, photons do not experience resistance. As they have no mass or charge, they will scatter less within the material they travel through, and therefore no heat is produced. Energy consumption will therefore be reduced. Moreover, by replacing electrical communication within a chip by optical communication, the speed of on-chip and chip-to-chip communication can be increased by a factor of 1000. Data centers would benefit most, with faster data transfer and less energy usage for cooling systems. But these photonic chips will also bring new applications within reach. Think of laser-based radar for self-driving cars and chemical sensors for medical diagnosis or for measuring air and food quality.



Shared first authors Elham Fadaly (left) and Alain Dijkstra (right) operating an optical setup to measure the light that is emitted. The emission from the hexagonal-SiGe alloy showed to be very efficient and suitable to start producing an all-silicon laser. Credit: Sicco van Grieken, SURF

Dropping electron emits a photon

Using light in chips requires an integrated laser. The main semiconductor material that computer chips are made of is silicon. But bulk silicon is extremely inefficient at emitting light, and was long thought to play no role in photonics. Thus, scientists turned to more complex semiconductors, such as gallium arsenide and indium phosphide. These are good at emitting light, but are more expensive than silicon, and are hard to integrate into existing silicon microchips.

To create a silicon-compatible laser, the scientists needed to produce a form of silicon that can emit light. Researchers from Eindhoven University of Technology (TU/e), together with researchers from the universities of Jena, Linz and Munich, combined silicon and germanium in a hexagonal structure that is able to emit light, a breakthrough after 50 years of work.

Shared first author Elham Fadaly, is operating the Metal Organic Vapor Phase Epitaxy (MOVPE). This machine grows the nanowires with hexagonal silicon-germanium shells. The emission from this hexagonal-SiGe alloy showed to be very efficient and suitable to start producing an all-silicon laser. Credit: Sicco van Grieken, SURF

Hexagonal structure

"The crux is in the nature of the so-called band gap of a semiconductor," says lead researcher Erik Bakkers from TU/e. "If an electron 'drops' from the conduction band to the valence band, a semiconductor emits a photon: light."

But if the conduction band and valence band are displaced with respect to each other, which is called an indirect band gap, no photons can be emitted—as is the case in silicon. "A 50-year-old theory showed, however, that silicon alloyed with germanium and shaped in a hexagonal structure does have a direct band gap, and therefore potentially could emit light," says Bakkers.

Shaping silicon in a hexagonal structure, however, is not easy. As Bakkers and his team mastered the technique of growing nanowires, they were able to create hexagonal silicon in 2015. They realized pure hexagonal silicon by first growing nanowires made from another material with a hexagonal crystal structure. Then they grew a silicon-germanium shell on this template. Elham Fadaly, shared first author of the *Nature* paper, says, "We were able to do this such that the silicon atoms are built on the hexagonal template, and by this forced the silicon atoms to grow in the hexagonal structure."

Silicon laser

But they could not make them emit light, until now. Bakkers team managed to increase the quality of the hexagonal silicon-germanium shells by reducing the number of impurities and crystal defects. When exciting the nanowire with a laser, they could measure the efficiency of the new material. Alain Dijkstra, shared first author and the researcher responsible for measuring the light emission, says, "Our experiments showed that the material has the right structure, and that it is free of defects. It emits light very efficiently."

Creating a laser is now a matter of time, Bakkers says. "By now, we have realized optical properties that are almost comparable to indium phosphide and gallium arsenide, and the materials quality is steeply improving. If things run smoothly, we can create a silicon-based laser in 2020. This would enable a tight integration of optical functionality in the dominant electronics platform, which would break open prospects for on-chip optical communication and affordable chemical sensors based on spectroscopy."

In the meantime, his team is also investigating how to integrate the hexagonal silicon in cubic silicon microelectronics, which is an important prerequisite for this work. This research project has been funded by the EU project SiLAS, coordinated by TU/e professor Jos Haverkort.

More information: Direct-bandgap emission from hexagonal Ge and SiGe alloys, *Nature* (2020). DOI: 10.1038/s41586-020-2150-y , nature.com/articles/s41586-020-2150-y

Provided by Eindhoven University of Technology

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