ALP-4-SiC project focusing on atomic layer processing for silicon carbide-based quantum photonic circuits

Max Planck Institute is designing and characterizing photonic components while Fraunhofer IISB contributes SiC technology.

Silicon carbide (SiC) is a promising material platform for photonic integrated circuits (PICs) and miniaturized solid-state quantum systems. In the ALP-4-SiC project – Atomic Layer Processing for SiC for Applications in Photonics and Quantum Communication — researchers from the Max Planck Institute for the Science of Light (MPL) and the Fraunhofer Institute for Integrated Systems and Device Technology IISB are jointly developing basic technologies for the production of highly efficient photonic circuits. Using optical waveguides and ring resonators as examples, they are demonstrating how atomic layer processing (ALP) can be used to significantly improve the optical properties of photonic devices made of SiC. ALP-4-SiC is 100% funded by the German Federal Ministry of Research, Technology, and Space (BMFTR) as part of the "Scientific Preliminary Projects" (WiVoPro) initiative.

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In the project ALP-4-SiC (Atomic Layer Processing for SiC for Applications in Photonics and Quantum Communication) — which is part of the 'Scientific Preliminary Projects (WiVoPro, Quantum Technologies in Germany)' program of the German Federal Ministry of Research, Technology, and Space (BMFTR) — the Max Planck Institute for the Science of Light (MPL) and the Fraunhofer IISB (Institute for Integrated Systems and Device Technology), both in Erlangen, Germany, are jointly developing basic technologies for the production of highly efficient photonic integrated circuits (PICs) and miniaturized solid-state quantum systems based

Researcher at Fraunhofer THM inserting a wafer into the transfer chamber of a deposition/etching cluster for structuring using atomic layer etching. © Daniel Karmann/Fraunhofer IISB.

on silicon carbide (SiC).

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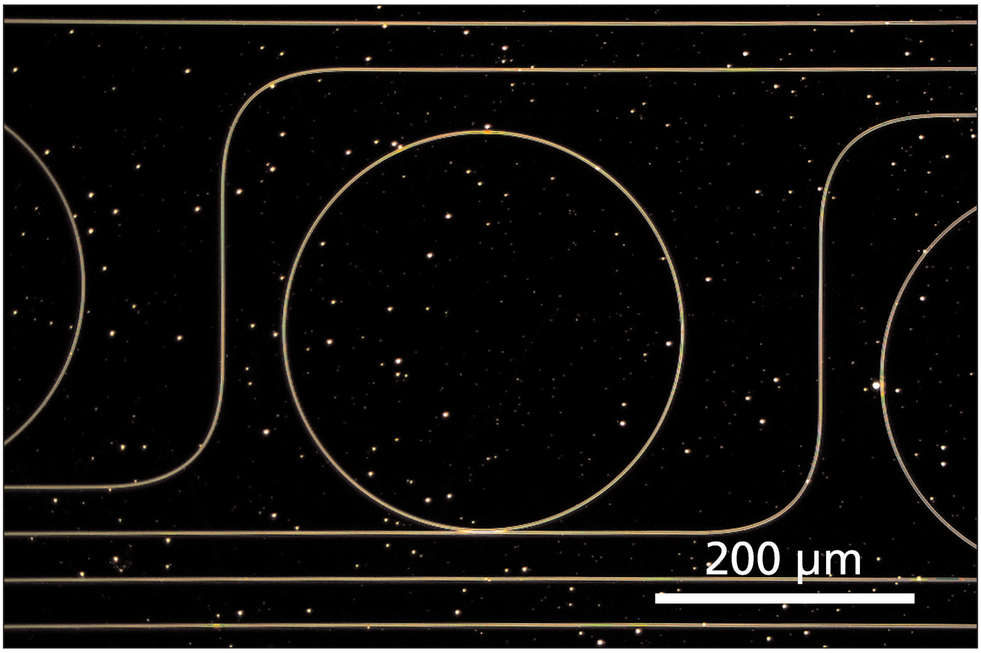
Robust, connectable, quantum-compatible: silicon carbide as a key quantum material



Optical ring resonator with a diameter of 200_m on a SiC substrate. © Pascal Del'Haye/MPL.

As a wide-bandgap (WBG) semiconductor material, silicon carbide (SiC) is a promising technology platform for solid-state quantum systems due to its unique physical properties. In recent years, SiC has become established in power electronics, but it is also highly attractive for developing photonic microsystems and photonic integrated circuits (PICs) because it can be used to manufacture optical devices, light sources, and sensors.

SiC is also of interest due to nonlinear optical effects that can be exploited to modify the color of laser light. For instance, it can be used to convert infrared light into visible light very efficiently.

The possibility of integrating point defects in the form of color centers that function at room temperature means that SiC may even allow the direct integration of quantum functionality in the future.

"This makes silicon carbide an ideal platform for photonics, electronics, and quantum applications," says Dr Pascal Del'Haye, who heads the project at MPL.

SiC could therefore be used to produce all the elements required for the construction of powerful, miniaturized quantum systems. It is compatible with microelectronics and microphotonics, and offers new quantum electronic functions. Since it is compatible with the easily controllable CMOS processes of classic silicon technology, it is reckoned that SiC would be suitable for the industrial mass production of quantum PICs.

Optimization of first microphotonic devices paves way for SiC quantum chips

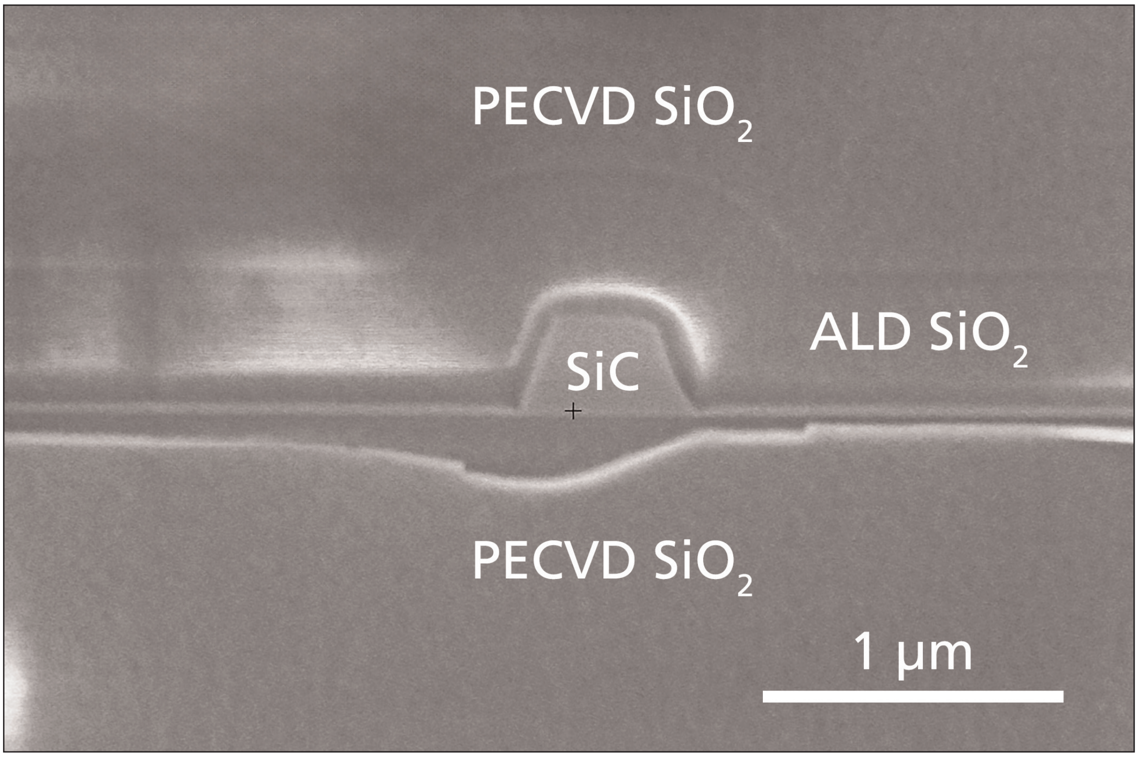
To fabricate PICs, standardized microphotonics devices with minimal optical losses are needed, requiring optical waveguides and ring resonators that can efficiently guide or store light in tiny structures. While waveguides perform the function of loss-free optical lines, resonators consist of rings in which the input light completes up to a million cycles. The photon storage times achieved in this way allow these devices to be charged with high circulating optical power, enabling a variety of nonlinear optical effects. For example, microresonators can convert laser light of a specific wavelength into an optical frequency comb, i.e. a light source consisting of several discrete frequencies, which can be used, for example, for very fast parallel data transmission in telecoms networks.

Another useful effect is the interaction of counterpropagating light. The nonlinear optical coupling of counter-propagating light in ring resonators leads to spontaneous symmetry breaking that allows light to circulate in only one direction, i.e. clockwise or counterclockwise. This can be used, for example, to implement chip-integrated optical diodes, photonic switches, or optical sensors, which enable the construction of more complex photonic systems.

However, the quality of the photonic devices manufactured on SiC substrates is not yet optimal, and the relatively high surface roughness causes optical losses in the waveguides and resonators. Flawless surfaces are essential to ensure that photons can move quickly and do not tunnel outwards. A promising solution is to smooth the component surfaces using atomic layer etching (ALE) to create well-defined interfaces and to minimize loss and scattering centers.

Bridging the gap between basic research and process development in ALP-4-SiC project

To develop a novel manufacturing process for complex photonic devices based on silicon carbide, basic and application-oriented research must collaborate intensively. In the ALP-4-SiC project, MPL and the Fraunhofer IISB via its Fraunhofer Technology Center for High-Performance Materials THM in Freiberg, Saxony (a research and transfer platform of Fraunhofer IISB and the Fraunhofer Institute for Ceramic Technologies



Cross section of a photonic structure in silicon carbide (SiC on insulator, SiCOI). © Pascal Del'Haye/MPL.

and Systems IKTS) are pooling their expertise. MPL has extensive experience in the design and characterization of photonic components, while the IISB contributes its expertise in SiC semiconductor technology and atomic layer processing.

The new approach of integrating atom layer-based processes for photonic devices with significantly improved optical properties is reckoned to have great potential for the future commercialization of integrated photonic devices. In the medium term, manufacturers of ALE process equipment in particular could tap into new customer groups and, in return, position photonics suppliers with innovative products in a rapidly growing market. However, the long-term effects of the availability of a universal, practical, scalable technology platform for integrated quantum optoelectronic circuits based on SiC cannot be predicted at this stage, it is noted. ■

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