

"We are trying to create this kind of a fiber optic waveguide on chip," Agarwal explains. "So it's like a fiber, but on a chip, and therefore what we need is a core with a high (refractive) index and a cladding with a low index." Silicon carbide and silicon oxide have a large enough difference in their refractive indices that they work together well as the core and cladding for a waveguide.

The researchers achieved the record quality factor in this study using the plasma enhanced chemical (PECVD) process to deposit the silicon carbide, at a temperature that is compatible with complementary metal-oxide semiconductor (CMOS) silicon chip processing, and developing a method to pattern and etch the silicon carbide ring resonator, which is coupled to a straight waveguide.

Overcoming challenges

MIT graduate student Ma overcame several processing challenges to make the high-quality resonator. When Ma began working on silicon carbide materials for this study about three years ago, there was no existing recipe for how to etch a pattern into the amorphous silicon carbide material when it is deposited on a silicon dioxide substrate. "Silicon carbide is a very rigid and physically and chemically hard material, so, in other words, it's very difficult for it to be removed or etched," Ma says.

To deposit and etch the silicon carbide waveguide on silicon oxide, Ma first used electron beam lithography to pattern the waveguides and reactive ion dry etching to remove excess silicon carbide. But his first attempts using a typical polymer-based mask didn't work because the process removed more of the mask than the silicon carbide. Ma then tried a metal mask, but grain boundaries from the mask carried over to the silicon carbide, leaving behind rough sidewalls in the waveguides. Roughness is undesirable because it increases photon scattering and light loss. To resolve the issue, Ma developed a technique using a silicon dioxide-based mask for the reactive ion etching. During the process development, Ma worked closely with Qingyang Du, an MIT postdoc, and Mark K. Mondol, assistant director of the

NanoStructures Laboratory in the MIT Research Laboratory of Electronics.

"We came up with the right type of chemistries in this reaction and controlled the gas flows and the plasma, or, in other words, the details of the processing recipe," Ma says. "This recipe is really selective to etch silicon carbide compared to silicon dioxide, which made it possible for us to shape the silicon carbide photonic devices and have a smooth waveguide sidewall," Ma says. The smooth sidewall is critical for maintaining the optical signals in the photonic device, he notes.

The main sources of light loss in these resonators are absorption of photons in the ring material and/or scattering of photons caused by edge roughness of the ring device. "Danhao's processing yielded smooth sidewalls, which enabled low loss and a high Q (quality) factor resonator," Agarwal explains.

"The beauty of this silicon carbide material and the technique that we used here in the paper is that the PECVD process of silicon carbide is an inexpensive process, standard in the silicon microelectronics industry," says Ma, whose research concentration is materials design and engineering for integrated photonics. "Use of the existing microelectronics processes will make the adoption of silicon carbide into the integrated photonic and integrated electronic platforms easier." The PECVD and reactive dry ion etching processes he used don't require the lattice matching and other critical demands of epitaxial growth on silicon, and is substrate-agnostic, Ma says.

Better performance

Tan has studied silicon nitride materials and other CMOS materials for their nonlinearity for several years. "For (amorphous) silicon carbide, you would have a better enhancement when cast as a resonator compared to ultra-silicon-rich nitride, and it also has a higher nonlinear refractive index than stoichiometric silicon nitride, which is prolific in nonlinear optics," Tan says.

Several kinds of photon absorption known as two-photon and three-photon absorption are typically