TOP-DOWN FABRICATION OF SILICON PHOTONIC STRUCTURES FOR HOSTING SINGLE-PHOTON EMITTERS

HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

Nagesh S. Jagtap[1, 2], M. Hollenbach[1, 2], C. Fowley[1], Y. Berencén[1], W. Lee[3], G. V. Astakhov[1], A. Erbe[1], M. Helm[1, 2]

[1]Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany | [2]Technische Universität Dresden, Dresden, Germany |
[3]Korea Research Institute of Standards and Science, Daejeon, South Korea

Introduction

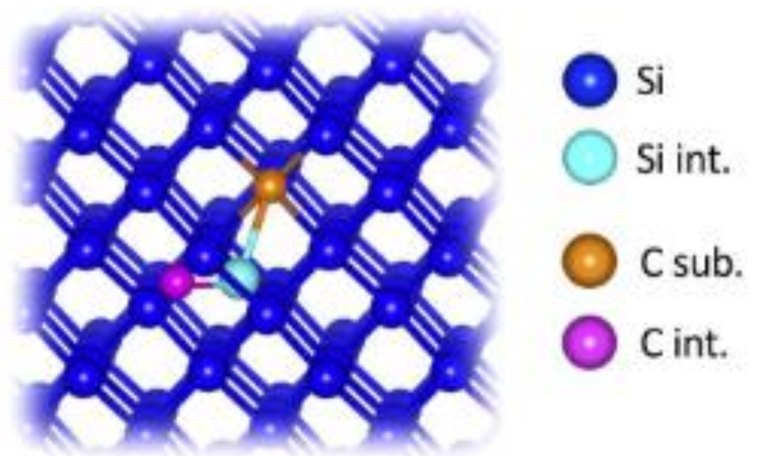


Fig. 1 G center's atomic configuration [1]

G center in silicon is carbon-silicon molecule occupying a single lattice site. With several possibilities, not all of them are optically active. The optically active configuration is an interstitial-substitutional C pair (C_iC_s) coupled to an interstitial Si atom *(Si_i)*. Figure 1 shows atomic configuration of a typical G center.

With the goal of creating single G centers in a controllable way, we implanted carbon with the energy of 5.5 keV which results in implantation depth of 20 nm below the surface of the Si device layer in a commercial SOI sample (refer figure 2).

Figure 3 shows the confocal PL spectrum of a sample carbon implanted with the fluence of 1 X 10^{12} cm^{-2} and ZPL at a wavelength of 1.28 µm (telecom O-band) was observed. It is the optical fingerprint of the G center. Thus we have demonstrated that G centers can be created in silicon efficiently with carbon implantation and silicon can host single photon emitters. [1]

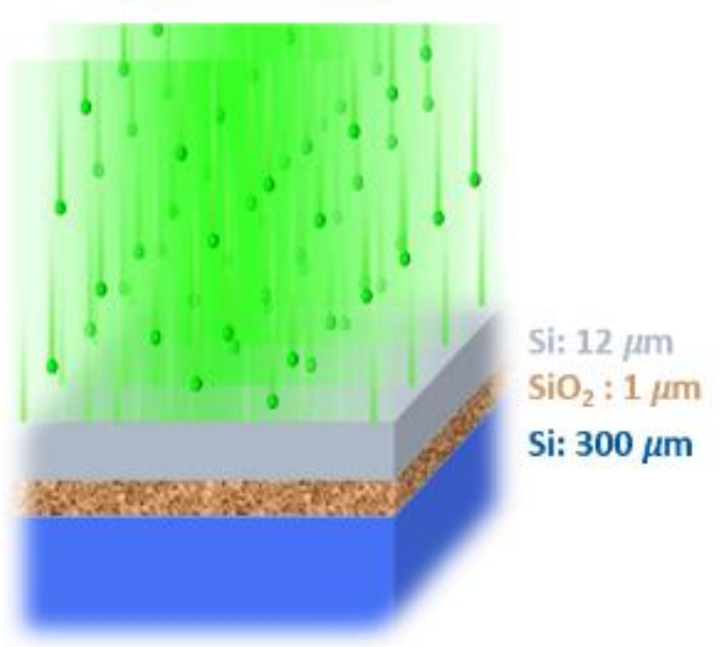


Fig. 2 Carbon implantation on SOI sample

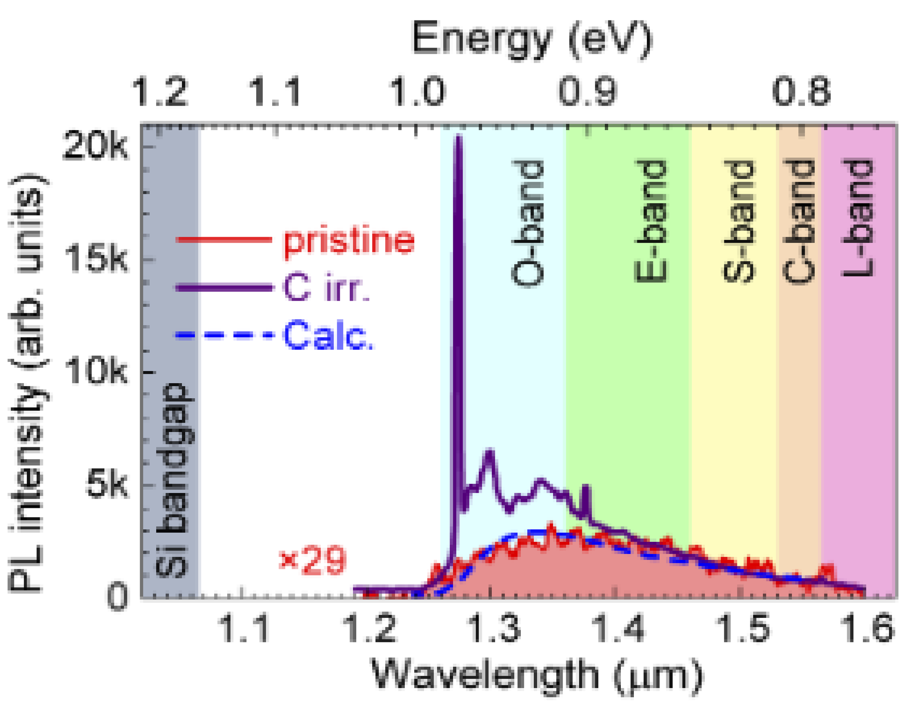


Fig. 3 Optical properties of G centers [1]

Photonic Structures

In order to integrate a single G center in a quantum photonic integrated circuit, one of the approach is to fabricate photonic structures. We would like to create pillars to host G centers. This will also lead to enhancement in the PL signal owing to waveguiding effect. We designed the fabrication scheme with pillar arrays of different diameters and with the pitch of 5 µm. It is also very important for photonic applications to separate structures by several magnitudes of the wavelength to avoid crosstalk.

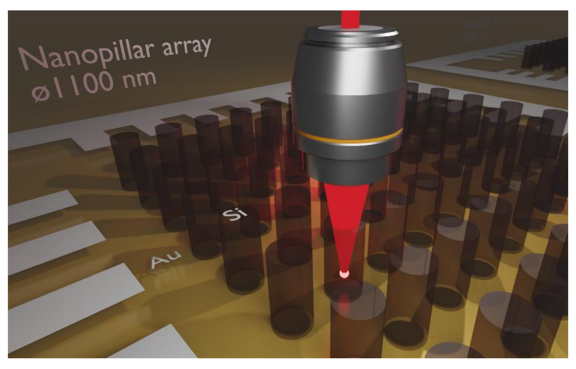


Fig. 4 Pillar as a photonic structure

Fabrication of Pillars

Our goal is to implant carbon in silicon using broad beam and then fabricate the pillars using one of the top-down techniques. Ion beam-based methods such as RIE damage the crystal lattice and can create defects [2]. Hence we need to use an anisotropic etching technique which has minimal or no impact on the lattice. Metal Assisted Chemical Etching (MACEtch) fulfills our both of the process requirements. MACEtch is a simple, low-cost and defect-free anisotropic etching method [3].

Metal Assisted Chemical Etching (MACEtch)

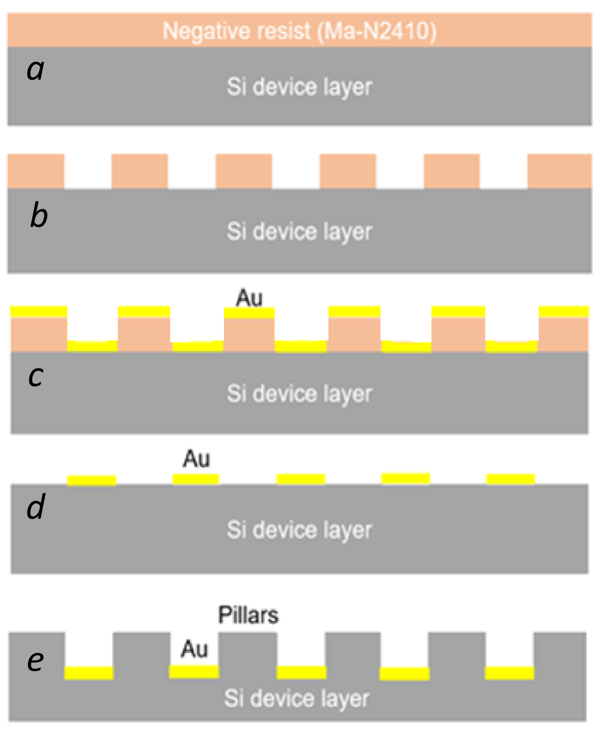


Fig. 5 Fabrication steps a) spin coating, b) pattern transfer by EBL, c) Au deposition, d) lift-off , e) MACEtch

Figure 5 shows a typical fabrication scheme. In order to protect the top surface of the pillars, sometimes MACEtch was performed before lift-off. Our preliminary experiments showed that when structures are farther apart, the long metal film tends to break-off. After introducing the frames around arrays of pillars, the highly anisotropic pillars with smooth sidewalls were obtained.

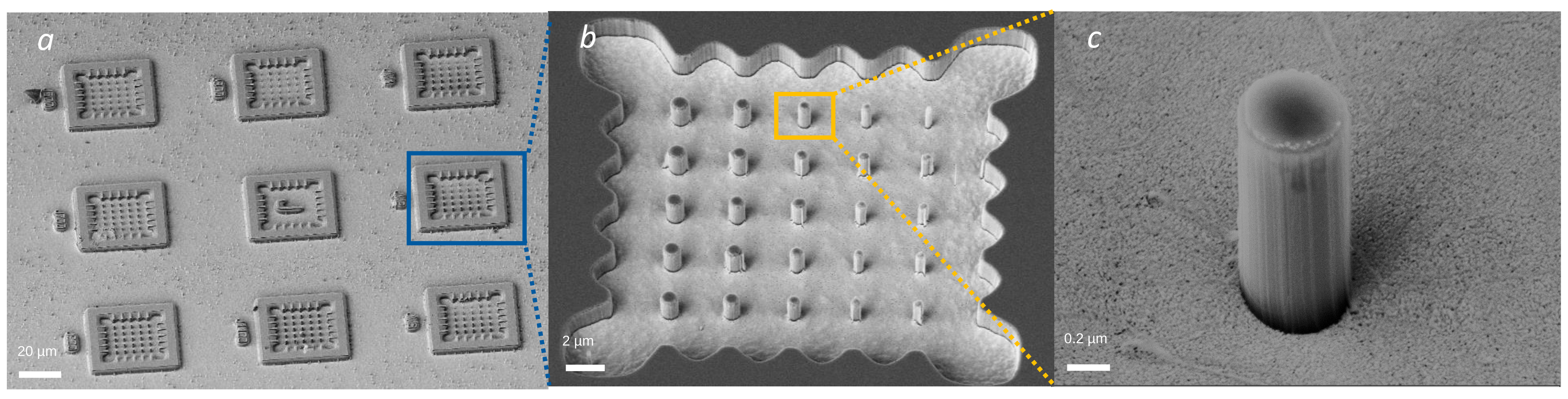


Fig. 6 SEM micrographs a) group of arrays and b) a single array of pillars with varying diameters, c) a single pillar (Ø 600 nm)

Figure 6 shows pillars fabricated with varying diameters using MACEtch. PL confocal microscopy of one of such a unimplanted sample after fabricating pillars did not show any G centers (results not shown). This proves that MACEtch is a defect-free top-down technique which has a potential in the field of quantum photonics.

References

[1] *Hollenbach, M. et al. (2020), Optics Express, 28(18), 26111*

[2] *Cloutier, S. G. et al. (2005), Nature Materials, 4(12), 887–891*

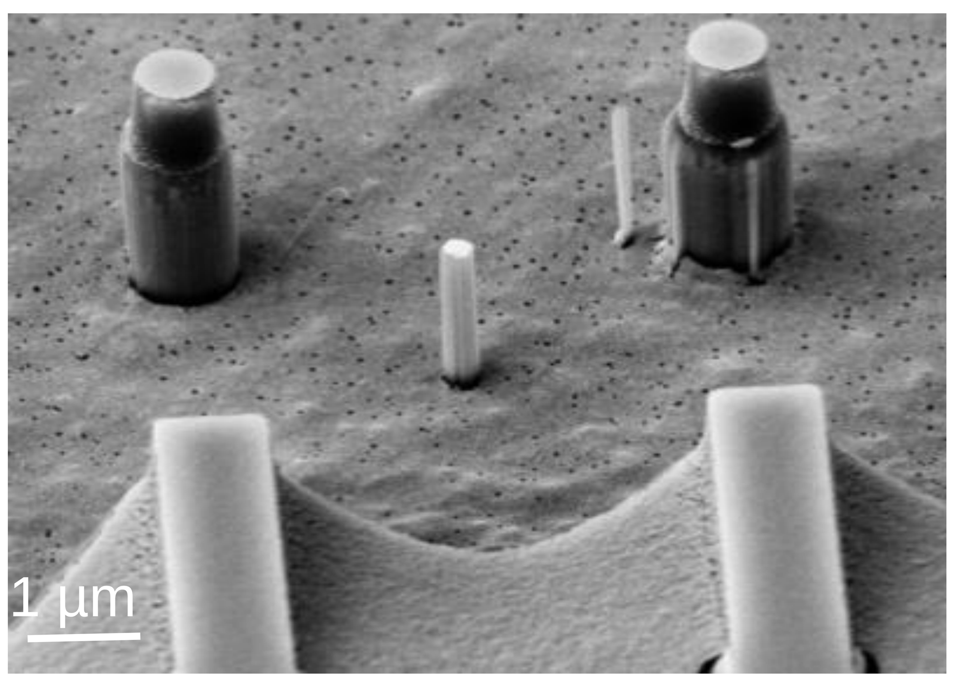
[3] *Huang, Z. et al. (2011) Advanced Materials, 23(2), 285–308*

Acknowledgements

Support by the Nanofabrication Facilities Rossendorf (NanoFaRo) at the IBC is gratefully acknowledged.

Conclusions & Outlook

- Si has a potential to host single photon emitters.
- We have shown that MACEtch is defect-free top-down and hence one of the most suitable fabrication methods for applications where crystal defects are of special importance.
- Carbon irradiation parameters (energy, fluence) need to be optimized to create a single G center in a pillar.



Institute of Ion Beam Physics and Materials Research · Nanoelectronics
Nagesh S. Jagtap · n.jagtap@hzdr.de · www.hzdr.de

TECHNISCHE UNIVERSITÄT DRESDEN

DRESDEN concept