Laser-assisted material composition engineering of SiGe planar waveguides

Antoine F. J. Runge[1], Yohann Franz[1], Callum Littlejohns[1,2], Katarzyna Grabska[1], Mehdi Banakar[1], Sakellaris Mailis[1] Fredric Y. Gardes[1], and Anna C. Peacock[1]

1) Optoelectronics Research Centre, University of Southampton, SO17 1BJ, UK
2) Silicon Centre of Excellence, Nanyang Technological University, 639798, Singapore
a.f.runge@soton.ac.uk

Context

Slicon-germanium (SiGe) is an emerging composite material that offers substantial advantages compare to silicon (Si) such as extended transparency window and higher hole and electron mobility that allows for the fabrication of optoelectronic devices [1-3]. The electronic and optical properties of the $Si_{1-x}Ge_x$ alloy can be significantly changed by adjusting the material composition through x. However, the material composition of SiGe structures has, to date, been determined by the diffusion temperature used during the fabrication process. In this work, we report the compositional modification of SiGe planar microstructures using continuous wave (C.W.) laser radiation. Our results reveal that the laser processed areas display a strong compositional modification of the material and the creation of Ge rich micro volumes.

Experimental setup

- We use an Argon ion C.W. laser, emitting up to 1W at 488 nm [4].
- Optical power is adjusted using a set of half wave plate and polarization beam splitter.
- Laser beam is focused on the sample top surface using a 10X microscope objective.
- Sample position is controlled using a set of high precision linear stages.

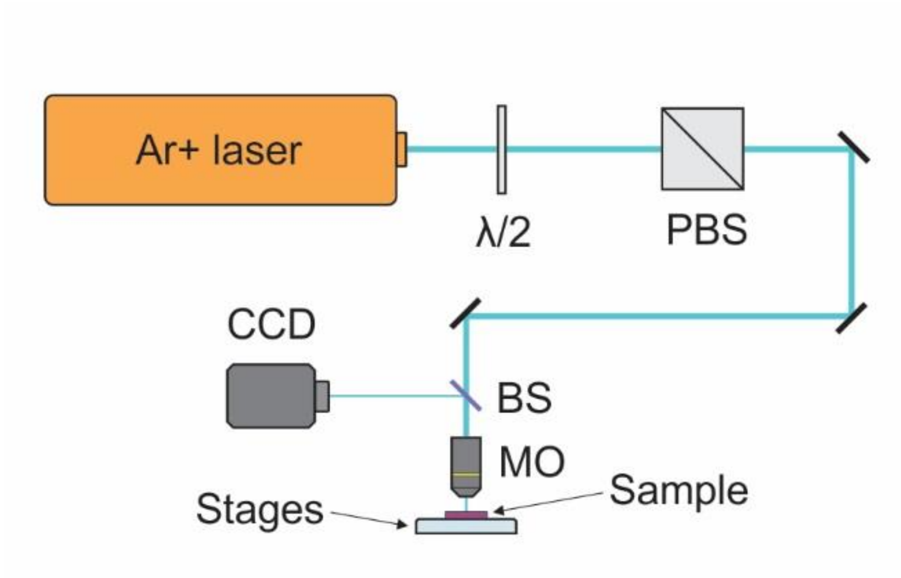

Fig. 1: Experimental laser setup. PBS; polarization beam splitter, BS; beam splitter, MO; microscope objective, CCD; camera

- Laser beam is focused on the sample top surface using a microscope objective.
- Sample position is controlled using a set a high precision linear stages.
- A beam splitter and a CCD camera are used to image the surface of the sample.

Material characterization

- Processed SiGe structures are characterized using visible optical microscopy and Raman spectroscopy.

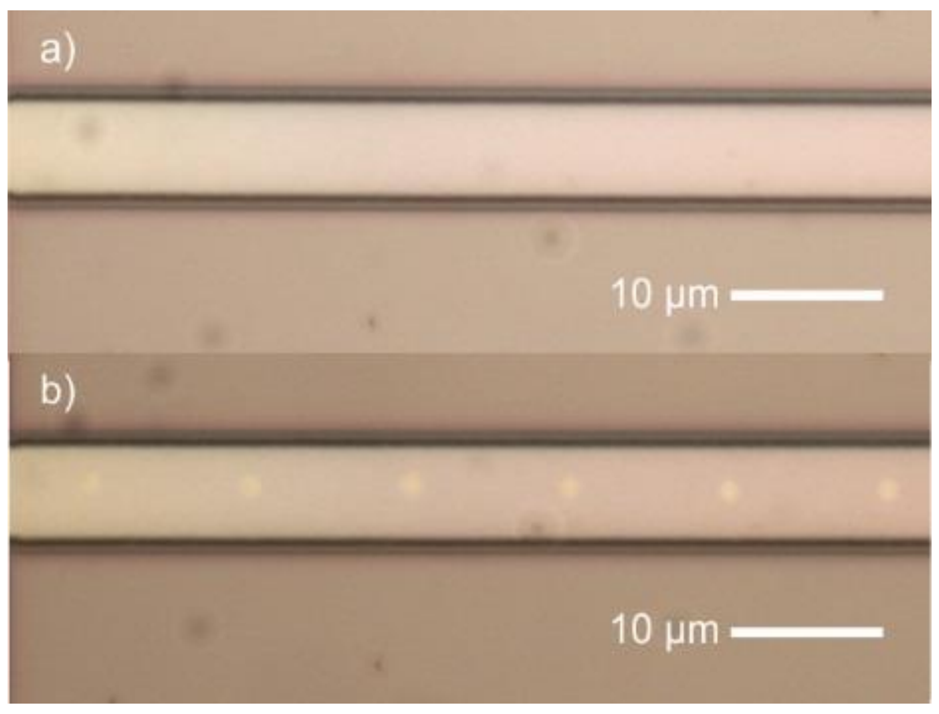

Fig. 2: Microscope images of the top surface (a) before and (b) after laser processing.

- We observe a clear change in reflectivity on the top surface of the processed sample.
- Increase in Ge content leads to a higher refractive index.
- 1.5 µm diameter spot corresponding to the focused laser beam size.

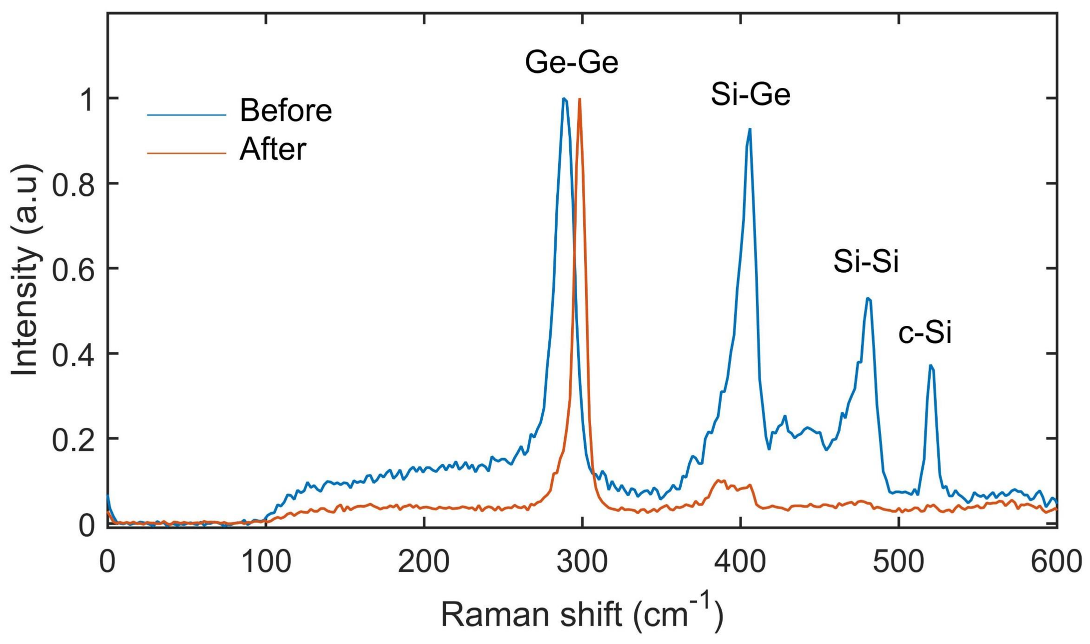

Fig. 3: Raman spectra of the SiGe structure before (blue) and after (orange) laser processing.

- Before laser processing, we observe several peaks corresponding to the different elements.
- After laser processing only the peak corresponding to the Ge is visible.

Bandgap tuning

- The electronic bandgap change is assessed by measuring the optical transmission of the SiGe waveguides.

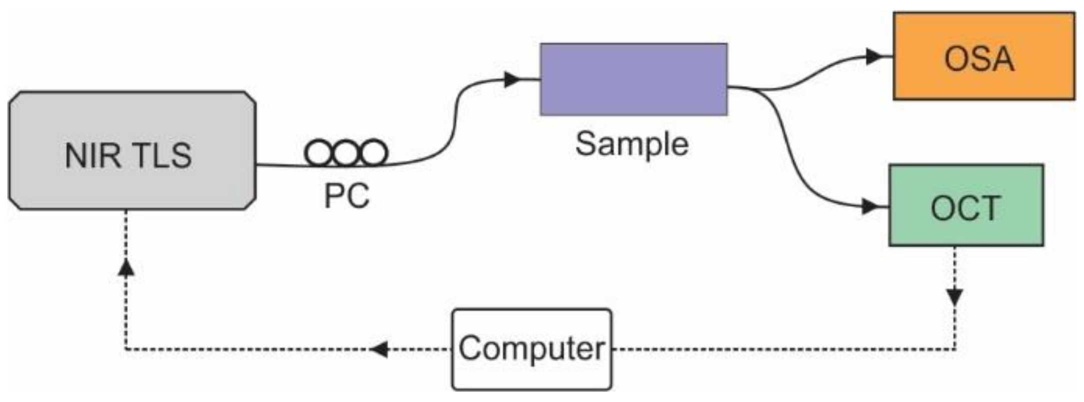

Fig. 3: Experimental setup for the measurement of the bandgap shift. NIR TLS; near infrared tunable laser source, OCT; optical component tester.

- Tunable source at telecom wavelengths is used to estimate the bandgap shift.
- The optical transmission of the processed devices exhibits a clear redshift.

Device	Intensity	Duration	Bandgap shift (nm)
1	0.1 MW/cm²	10 s	9
2	0.3 MW/cm²	10 s	18
3	0.4 MW/cm²	10 s	19

- Future work will focus on the effects of other parameters such as duration, spot size and laser wavelength.

Conclusion and perspective

We have reported on a promising technique to engineer the material composition of SiGe planar structures. The laser processed areas display a strong increase in Ge concentration. This is confirmed by measurement which exhibits a clear redshift of the optical transmission. Future efforts will be devoted to explore the effects of other parameters.

References:

[1] V. Sorianello, et al., *"High responsivity SiGe heterojunction phototransistor on silicon platform,"* Opt. Express 23, 28163-28169 (2015).
[2] C. G. Littlejohns, et al., "*Next generation device grade silicon on insulator*," Sci. Rep. 5, 8288 (2015).
[3] D. J. Thomson, et al., "*Silicon carrier depletion modulator with 10 Gbit/s driver realized in high-performance phonic BiCMOS*," Laser & Photon. Rev. 8, 180-187 (2014).
[4] N. Healy, et al., "*Extreme electronic bandgap modification in laser crystallized silicon optical fibres*," Nat. Mater. 13, 1122-1127 (2014).