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PCM materials & Devices: *in-situ* TEM imaging

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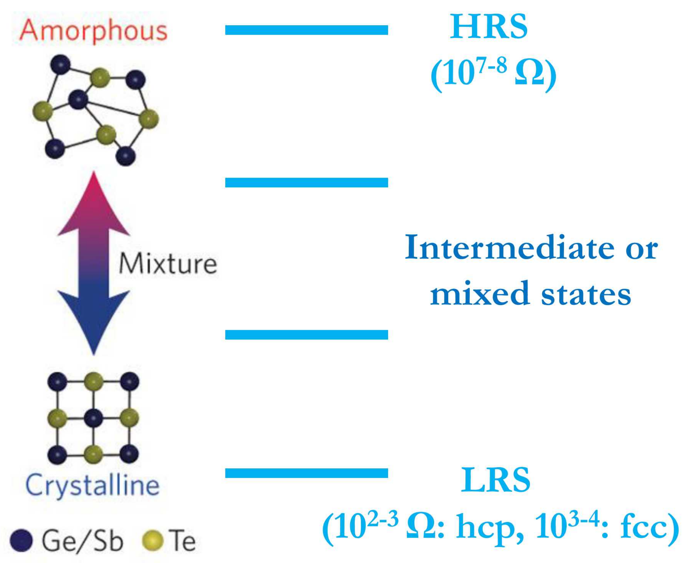
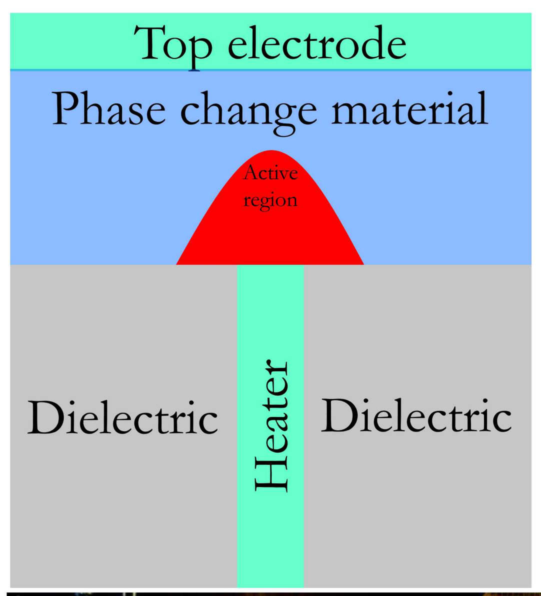
Introduction

PCMs are investigated for many applications. These devices are chalcogenide-based and use self heating to switch quickly between amorphous and crystalline phases, generating orders of magnitude differences in the electrical resistivity.

To understand the mechanisms underlying the fast, reversible, phase transformation, information about the atomic structure and defects structures in phase change materials class is key.

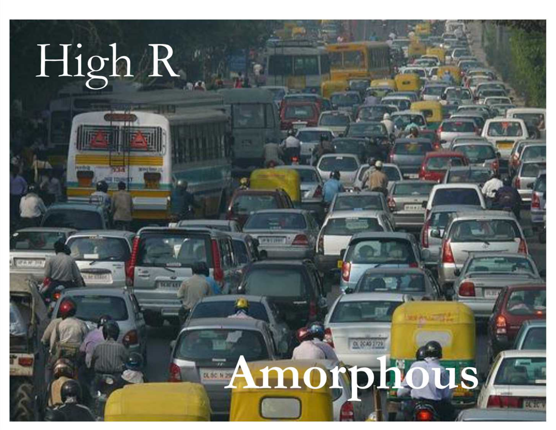


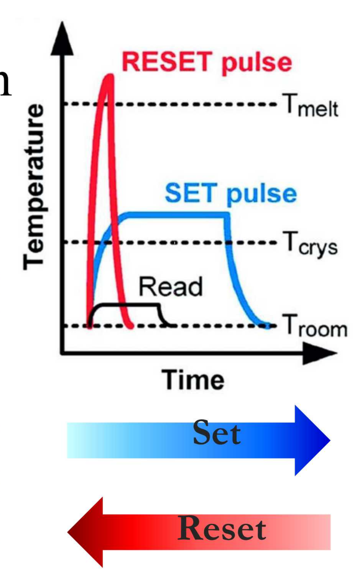
Multi-level cell (MLC) operation
Kuramochi, *et.al. Nature Photonics* 9.11 (2015): 712-714.

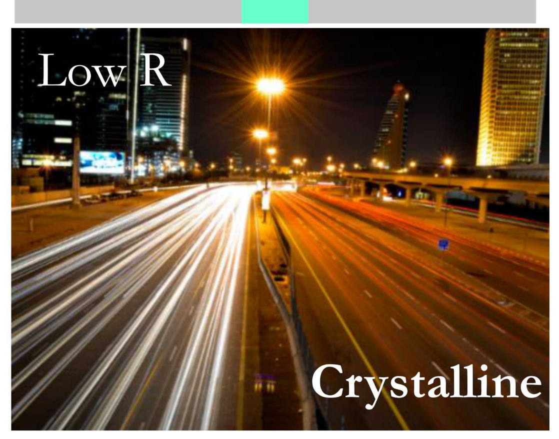


Challenge is to make them:

- Faster
- Smaller
- Low-cost
- Higher capacity
- Low power consumption

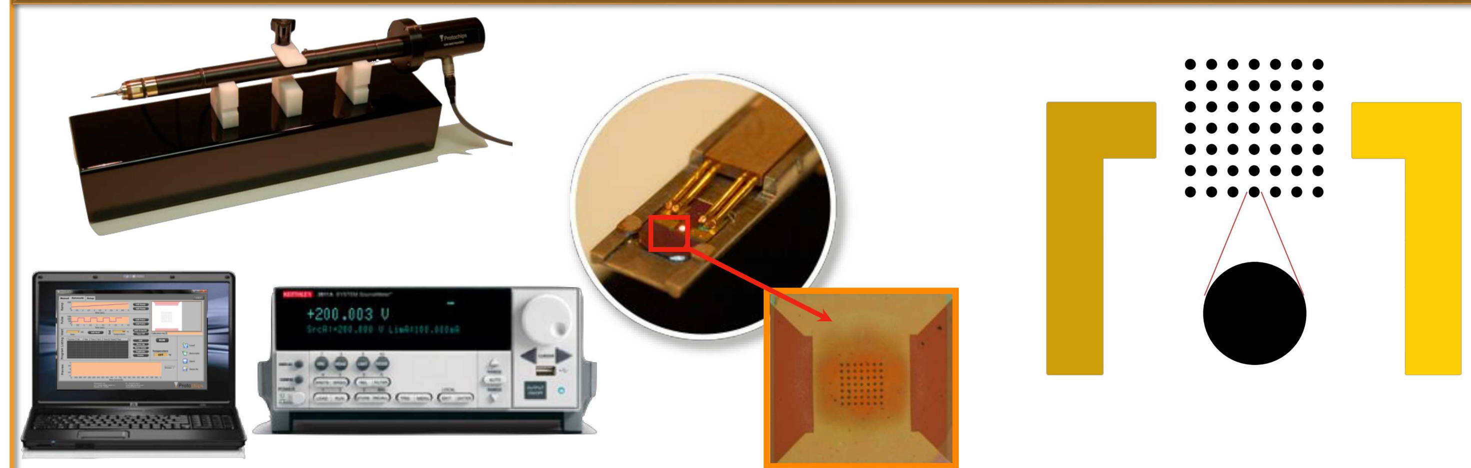






Wouters, Dirk J. et al. *Proceedings of the IEEE* 103.8 (2015): 1274-1288.

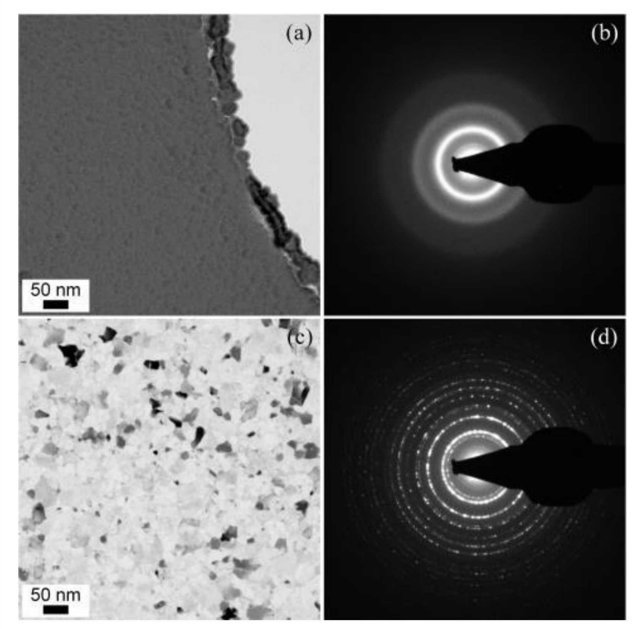
In-situ Heating: Aduro Heating Holder



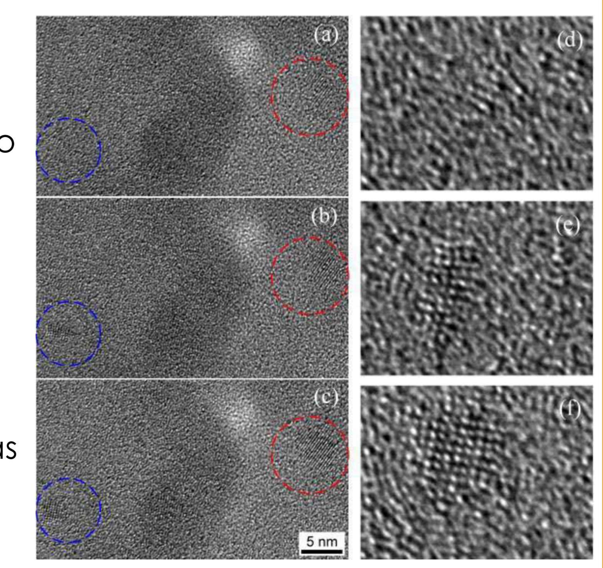
Courtesy: Protochips

Ceramic membrane

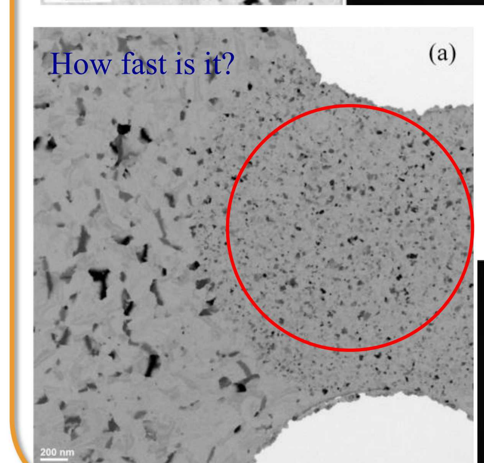
- Schematic of chips that are used for the heating experiments.
- The thick part of the support film is silicon carbide.
- Viewable area is 7x7 array of holes in SiC with holey C or SiN_x



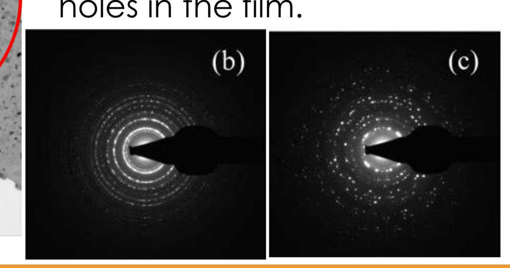
The chuck was heated from RT to 100 °C at 0.5 °C/s and then to 125 °C at 0.1 °C/s. Crystallization began at ~ 115 °C and no changes were observed after 80 s. The film was held at 125 °C for 10 min, then cooled to RT at 0.5 °C/s



Three successive images of a GST film before heating. The red-dashed circles show growth of a crystallite and the blue ones show the appearance and growth of another crystallite. Nucleation/growth was due to electron beam.

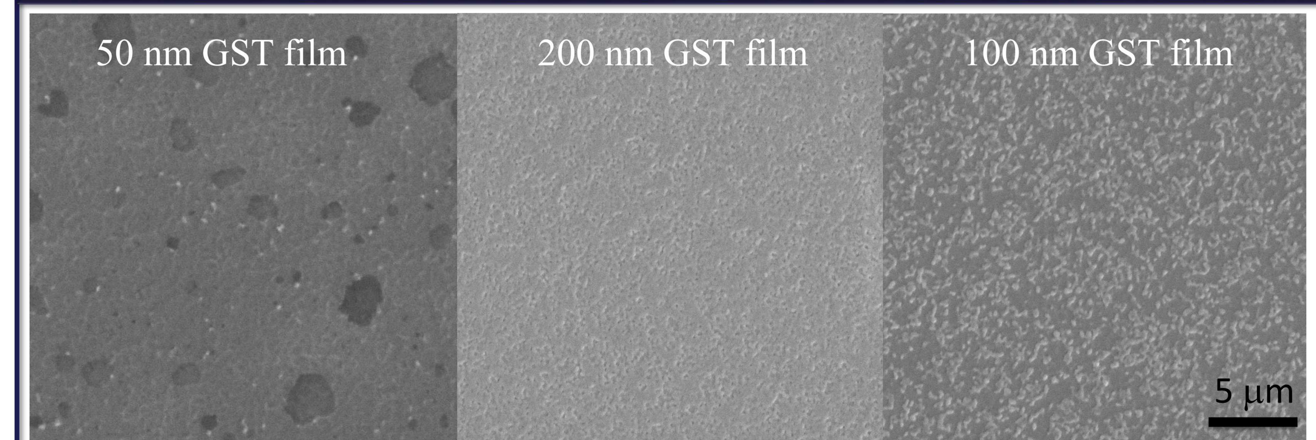


(a) Low-mag BF image showing the electron beam irradiated area with smaller grain size.. The white circular regions are holes in the film.

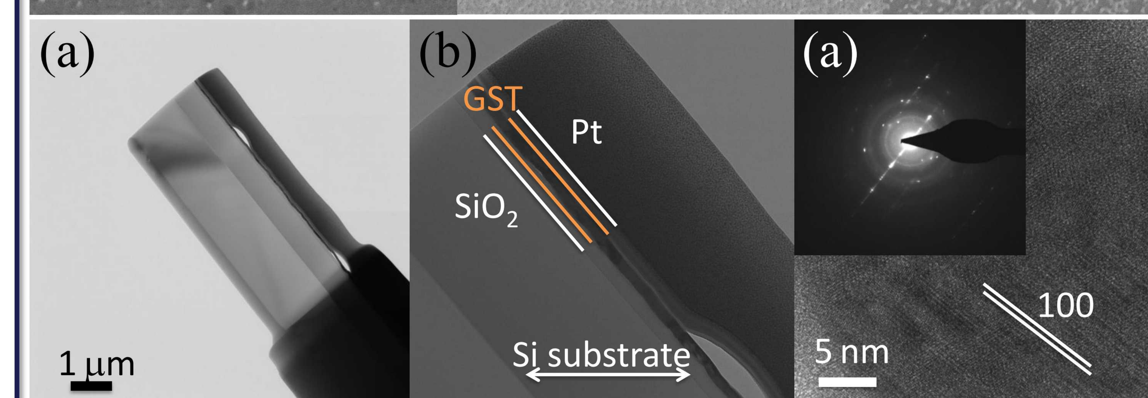


(b, c) Diffraction patterns from the region with the smaller and larger grains, with same d-spacing.

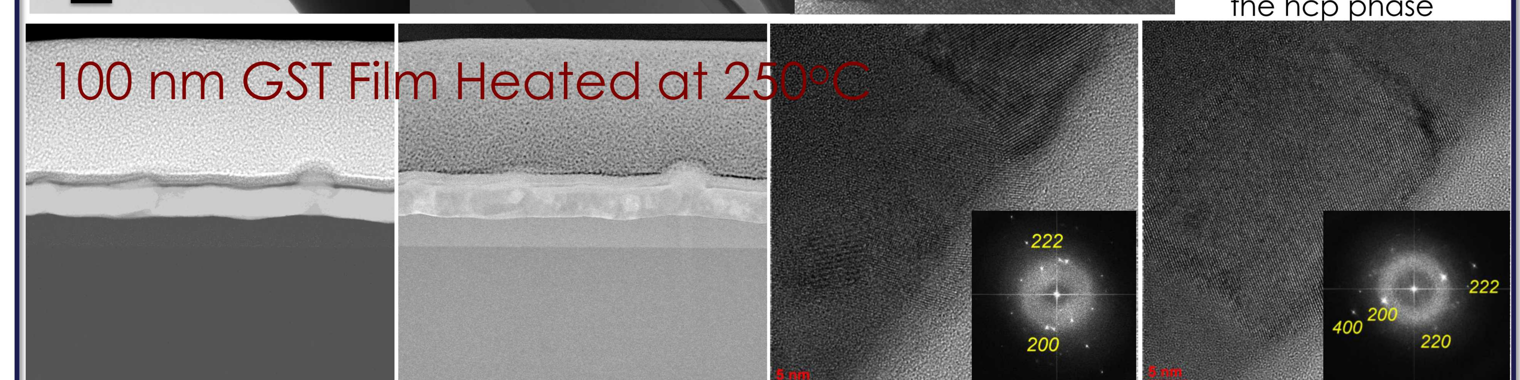
Materials Characterization



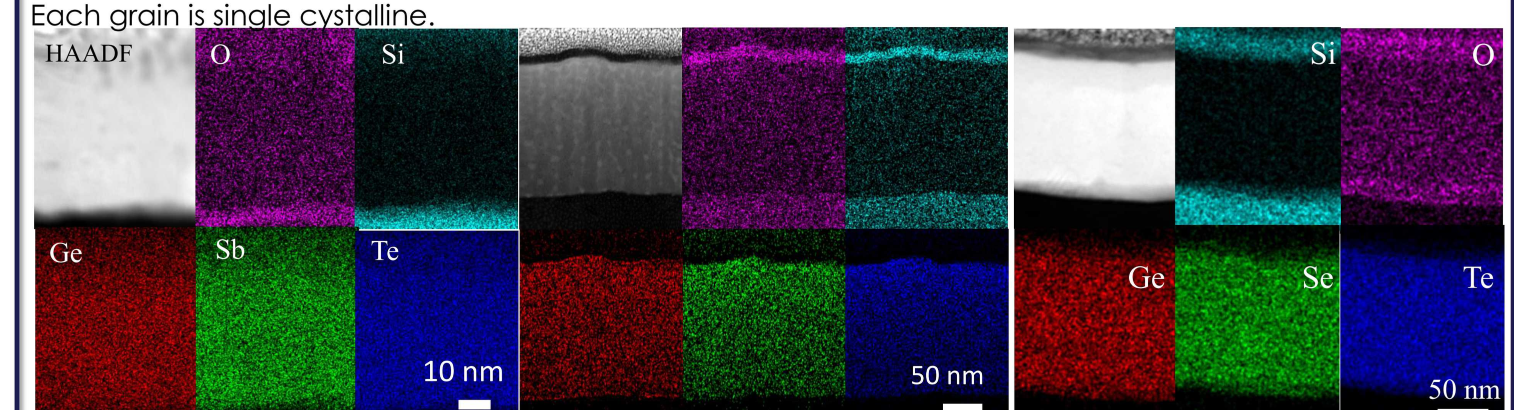
SEM image of the as-deposited GST films : Surface topology



(a) FIB cross-section of the heated GST film
(b) Area selected from the low-mag image showing the different layers of the cross-section,
(c) high-resolution TEM image shows the hcp phase

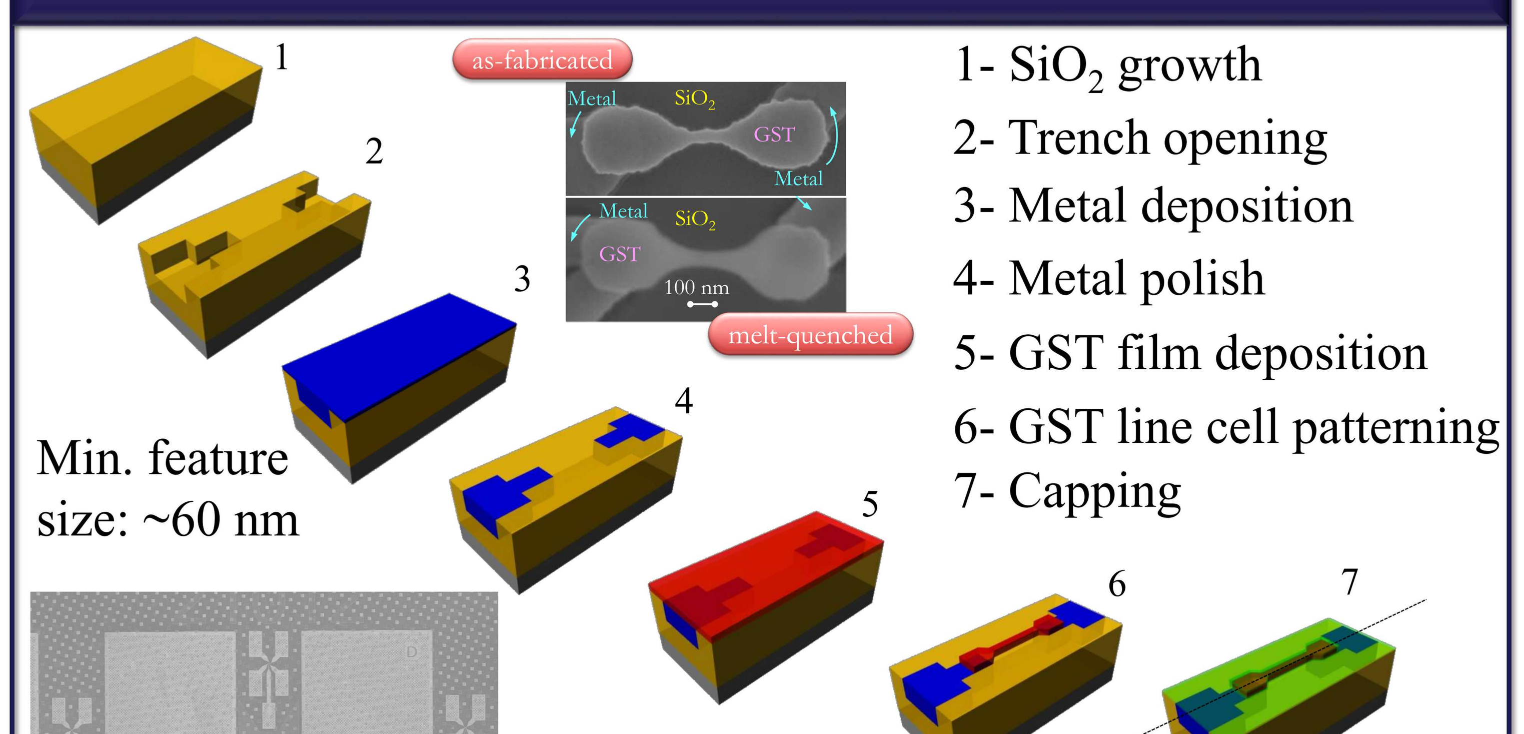


STEM-HAADF BF & DF image of a 100nm GST film heated at 250°C; HR-TEM image and its corresponding FFT shows fcc phase. The average grain size of the nanocrystallite is around 25-30 nm on an average. Each grain is single cystalline.



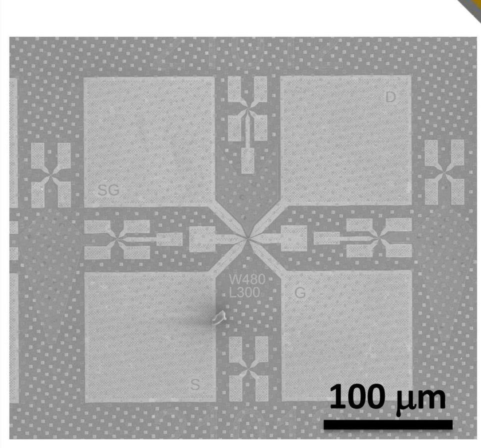
Comparison of chemical mapping of the annealed vs as deposited GST films. The chemical mapping of the film confirms $Ge_2Sb_2Te_5$ composition of GST. An extra layer of SiO_2 is observed as a thin coating over the film (~10 nm). This was from the oxidation of SiN_3 capped layer.

Fabrication of $Ge_2Sb_2Te_5$ Line Cells



1- SiO_2 growth
2- Trench opening
3- Metal deposition
4- Metal polish
5- GST film deposition
6- GST line cell patterning
7- Capping

Min. feature size: ~60 nm

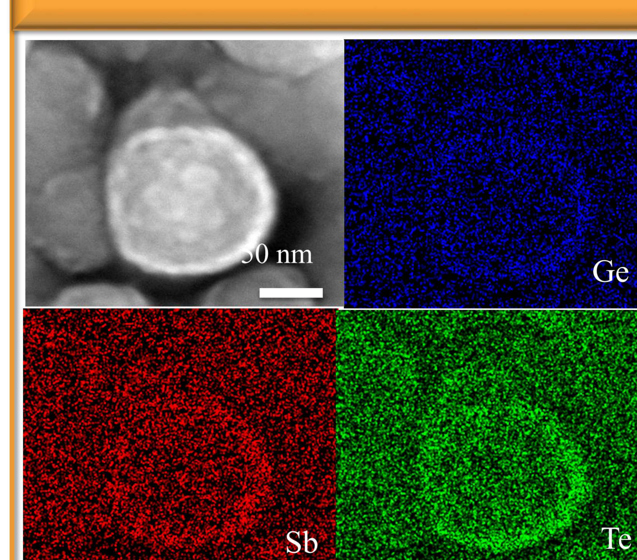


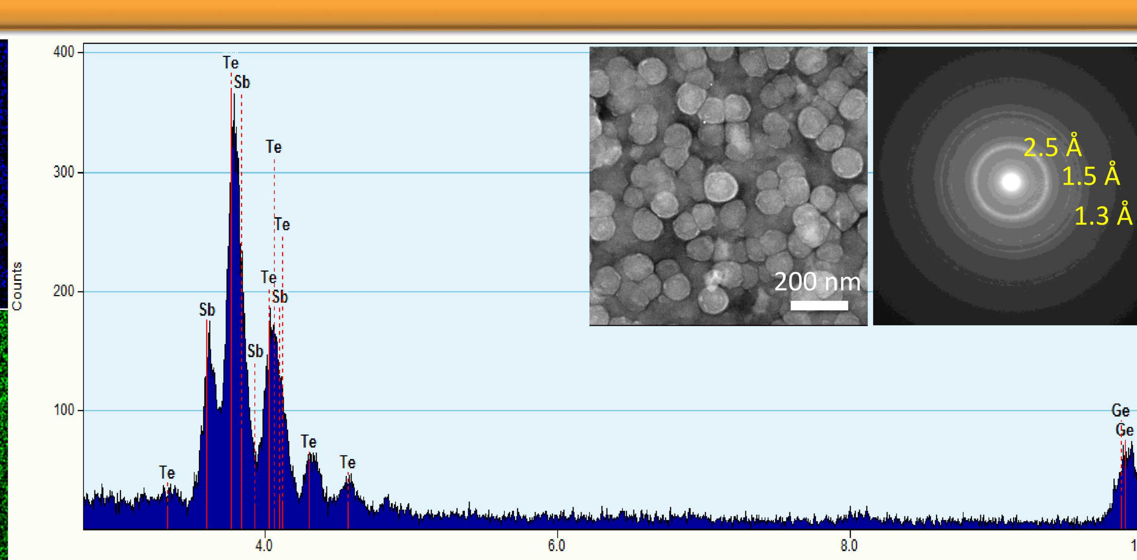
The cells lie at the center of several square-shaped units throughout the dye

- 50 nm thick
- On SiO_2
- Bottom metal contact
- Capped by Si_3N_4.

Dirisaglik, Faruk, et al. *Nanoscale* 7.40 (2015): 16625-16630.

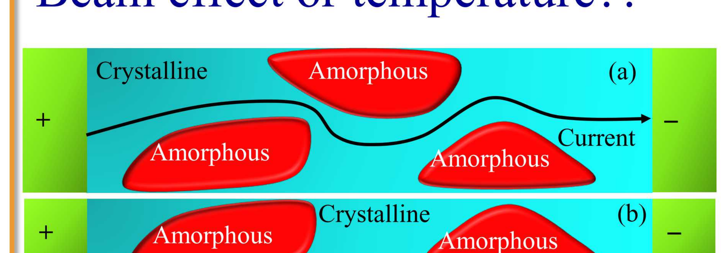
Conclusion & Future Directions



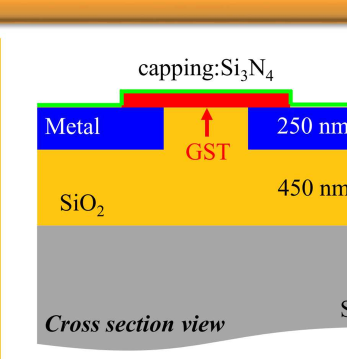


XEDS plot of the heated GST films; SAD pattern shows d-spacing not matching with either of the fcc or hcp phase.

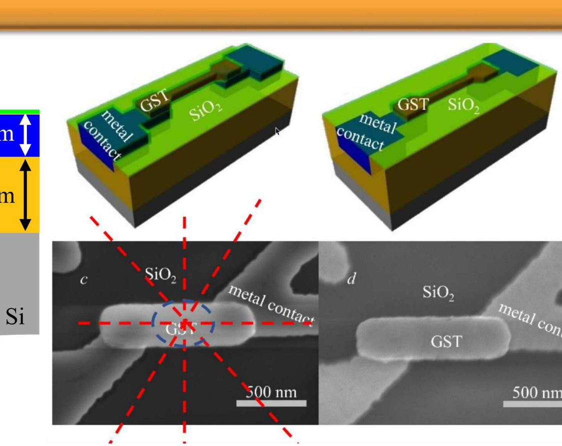
Segregation of Tellurium from the GST nanoparticles: Beam effect or temperature??

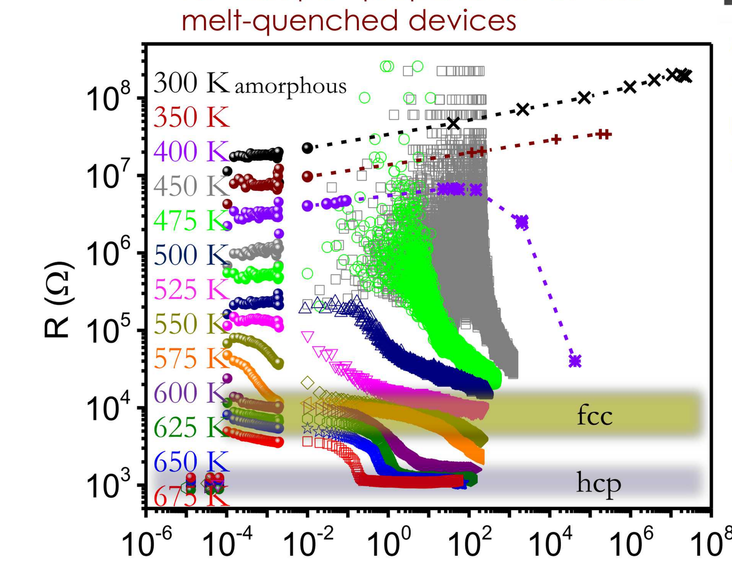


Wider cells are likely to sustain conduction paths around one or more smaller amorphized volumes and thereby, can be more controllably programmed to several intermediate states with one or more smaller amorphized volumes. Contrarily, in the narrower cells a single amorphized volume is more likely to effectively block conduction and leave the cell in the fully reset state.



FIB sample preparation of the melt-quenched devices





Dirisaglik, et al. *Nanoscale* 7.40 (2015): 16625-16630.

Cross-sections of interest (any that cut through the active region – in blue, between the ends of metal contacts)

The aim is to correlate the microstructure with results from electrical characterization, building on R vs T measurements on various thicknesses GST thin films, using TEM to study the atomic structure of the crystalline phase: better understanding of resistance drifts of the metastable phases, void formation and elemental segregation upon cycling.

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