Composition of Ge(Si) islands in the growth of Ge on Si(111) by x-ray spectromicroscopy

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Introduction

The epitaxy of Ge on Si(111) in a temperature range from 400˚C to 700˚C leads to the nucleation of 3D structures, which are expected to confine charge carriers.

Applications may span from lasers to quantum computing building blocks, to be easily integrated with the existing Si based technology.

After the completion of a thin wetting layer, islands nucleate and evolve from coherent triangles, bound by <1-10> oriented facets, to irregular ripened atoll-like structures.

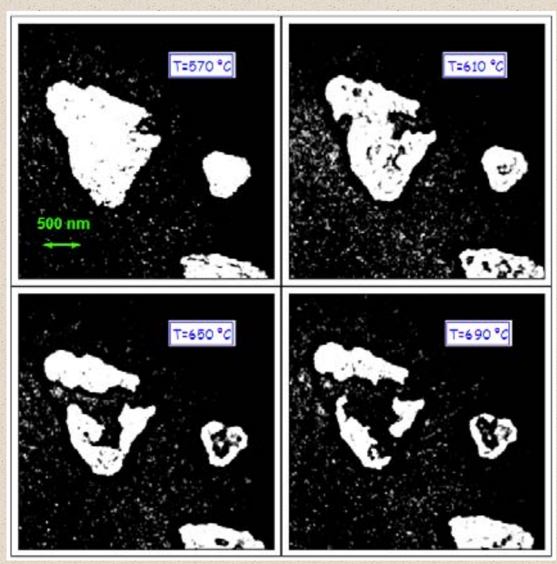
Strain relaxation and entropy are expected to drive Si–Ge intermixing within the wetting layer and islands [1].

Critical issues

Despite numerous experimental efforts, several problems still prevent the implementation of self–assembled quantum dots for technological applications:

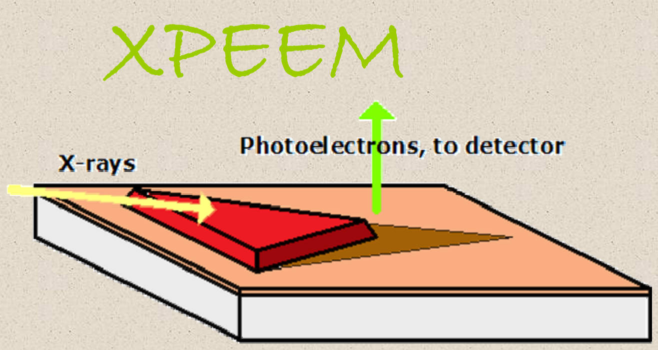
- ❖The size and shape uniformity of the islands;
- ❖The ordering of the dots on the substrate;
- ❖The stability of the islands (see the images on the right);
- ❖The stoichiometry inside individual 3D structures.

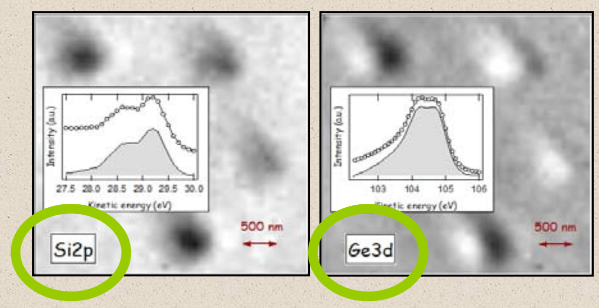
The latter ultimately determines the morphological and electronic properties of the system.



Snapshots from a LEEM movie acquired while annealing a sample prepared by depositing 10 ML Ge on a Si(111) surface at 500 °C.

Our goal: **gaining insight in the chemical inhomogeneities within islands and intermixing dynamics.**





10 ML Ge were deposited by MBE on Si(111) substrates kept at temperatures ranging from 400 to 600 °C.

Areas of the surface rich in Si appear bright or dim in the XPEEM images taken at the Si2p or Ge3d core levels, respectively.

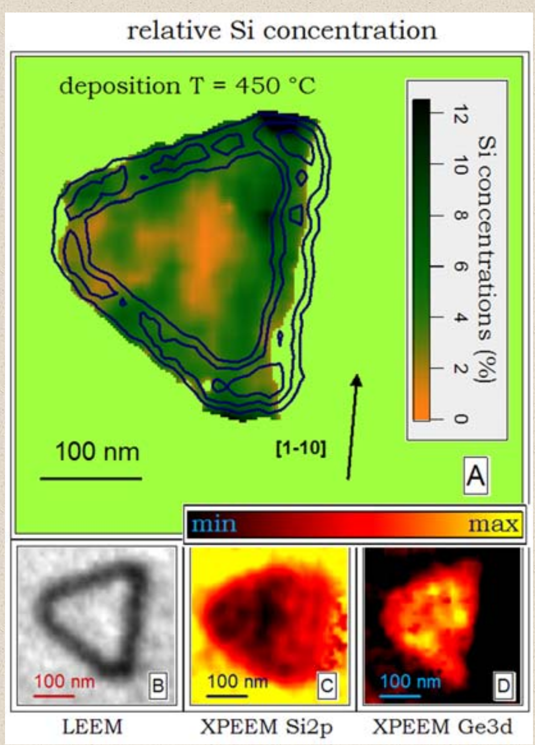
Experimental technique

Intermixing in individual nanostructures has been studied mainly by cross sectional techniques, yielding a “side view” of the concentration profile.

X-Ray photoemission electron microscopy (XPEEM) allows obtaining laterally resolved photoelectron spectra.

X–Ray excited photoelectrons are energy–filtered and transferred onto a screen. This results in an image of the surface with chemical contrast.

XPEEM may yield a 2D “top view” mapping of the island composition gradients in the topmost layers (~2 nm from the surface with 0.5 nm photoelectron escape length [2]).



A: Si concentration map, averaged over a depth of ~ 2 nm from the surface.

B: LEEM image of the same 3D island grown at 450 °C. The rather regular perimeter points to an early ripening stage [2].

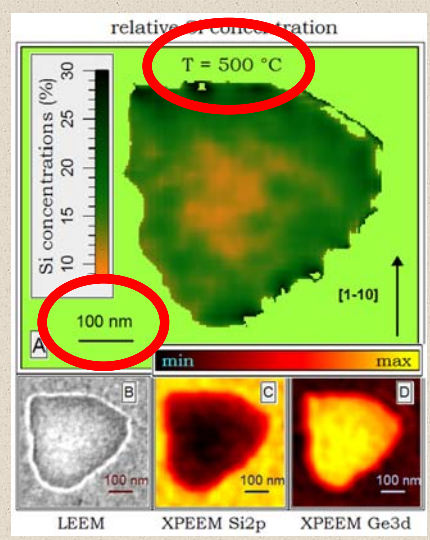
C: XPEEM Si2p. The overall Si2p signal is measured by integrating the XPEEM spectra with an energy resolution of ~0.25 eV and a lateral resolution of ~30 nm.

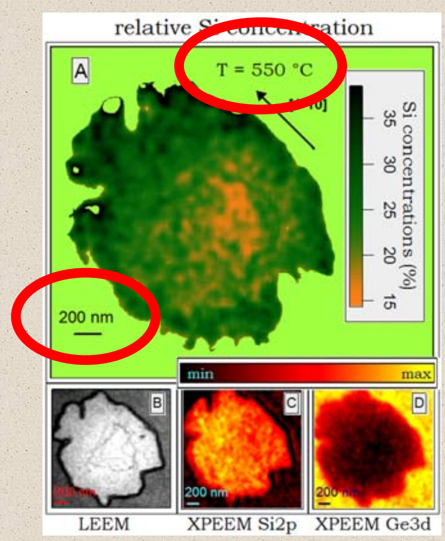
D: XPEEM Ge3d.

The island features Si–richer edges with respect to the centre, though the Si–depleted central part displays no obvious pattern to its shape.

Intermixing is mainly entropy–driven through surface diffusion.

The effective carriers confining region is expected to shrink to the core of the island.





Islands ripening

The average surface Si content increases both with deposition temperature and lateral dimensions of the islands [3].

The inhomogeneity in stoichiometry featuring Si–richer islands edges with respect to the centres is consistently observed.

Surface inter–diffusion phenomena overwhelm bulk mass exchanges in the temperature range 400 to 600 °C.

Conclusions

❖ **The Si surface content in Ge(Si) islands grown by deposition of 10 ML Ge on Si(111) is inhomogeneous at the nanoscale: islands edges exhibit more Si than the centres in the temperature range 400 to 600 °C.**

❖ **This points to the overwhelming role of surface diffusion with respect to bulk exchanges in driving intermixing.**

❖ **The effective carriers confining region of the islands are expected to be located at their cores.**

Acknowledgements:
F. Ratto is grateful to ICCS and FQRNT for graduate fellowships. S.K. Kulkarni would like to thank DST India for the support. F. Rosei acknowledges funding from INRS start–up funds, NSERC of Canada, and salary support from FQRNT and CRC programs.

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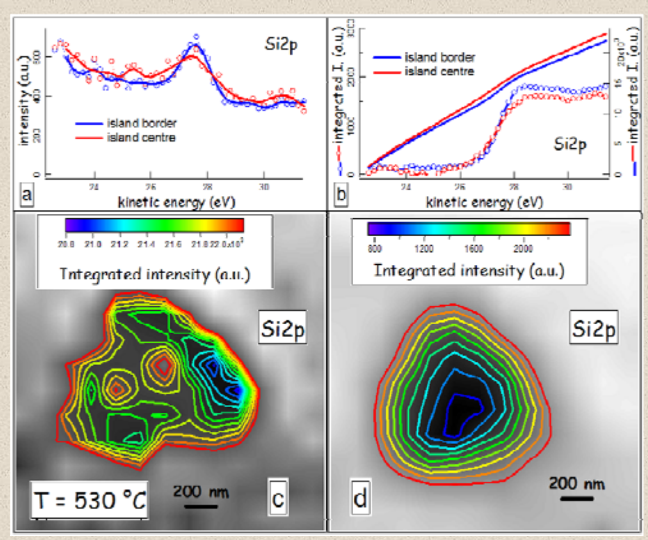
a) Representative spectra measured at the island border (blue) and centre (red);

b) Integrated intensities: raw data (lines); background subtracted data (circles);

c) 2 X 2 μm² XPEEM raw Si2p integrated image: the island centre appears brighter than the periphery;

d) 2 X 2 μm² XPEEM Si2p image resulting from background subtraction and successive integration: the centre has a lower Si concentration than the borders.

Deposition temperature was 530°C.



Spectra analysis

Inelastic background subtraction is extremely important. It may reverse the contrast within individual islands [4].