ESRF	**Experiment title:** Isolated germanium dots grown on silicon islands studied by X-ray diffraction	**Experiment number**: **02 02 653**
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Shifts: 15	**Local contact(s)**: H. RENEVIER and J.F. BERAR	*Received at ESRF:*

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Report:

1) Main results:

Strain and composition of isolated Ge quantum dots have been investigated by Grazing Incidence x-ray Diffraction and Anomalous Diffraction.
Ge dots are selectively grown on silicon islands (see figure 1). Ge dots are isolated (not connected by a wetting layer).

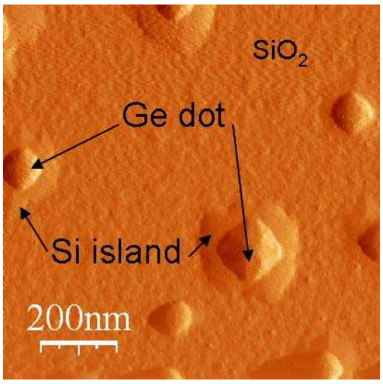

Fig. 1: Ge dots grown on silicon islands. Dots are about 110nm in diameter and 23nm in height.

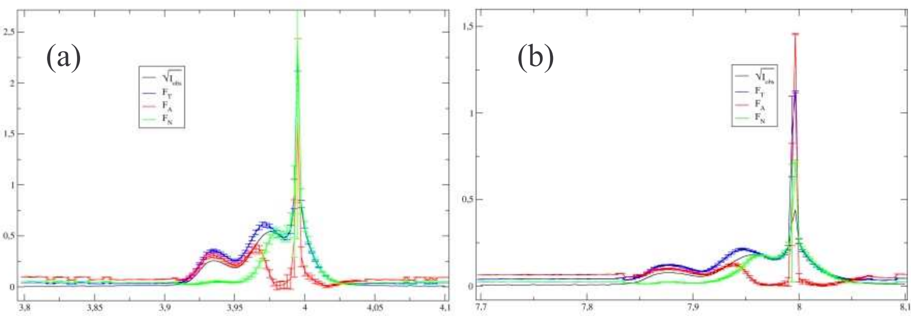

Fig. 2:Anomalous diffraction on the (440) (a) and (800) Bragg peak of silicon with the contribution of germanium (red line) and silicon (green line into the dots).

We performed radial scans around the (440) and the (800) Bragg peak of silicon at twelve different energies close to the Ge K edge. Then $F_A(\mathbf{Q})$ and $F_N(\mathbf{Q})$ were extracted by fitting the grazing incidence anomalous diffraction intensity [1]. F_A is a complex structure factor which includes the Thomson scattering of all anomalous atoms (i.e., Ge atoms) and F_N takes into account the scattering from Si atoms. The radial scans show that there are two families of germanium dots with two different strain states. The lattice parameter relaxation is about 1.5% and 0.5% for the two families (4.2% for a pure relaxed Ge). The two very sharp diffraction peaks indicate an almost perfect bimodal lattice parameter distribution. This differs from the very broad distribution always observed for Ge dots grown directly on Si(001) during the Stranski Krastanov growth mode. Moreover, the extractions of the different complex structure factors can be used to recover the average strain of the Ge quantum dots and to determine their composition. Figure 2 (a) clearly shows that silicon intermixing is negligible in the more relaxed germanium dots (a_{Ge}=5.62Å) whereas there is a strong silicon interdiffusion in the more strained Ge dots (a_{Ge}=5.56Å).

We also investigated the lattice parameter relaxation out of plane in the dots, at two different energy (close and far from the Ge absorption edge at 11103.5 eV). From the map around the (333) Bragg peak of silicon (cf fig 3), we calculated a strain relaxation of the lattice parameter out of plane of about 1.35%.

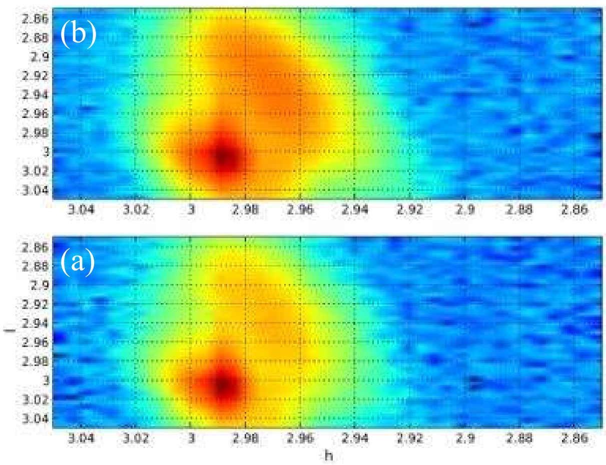

Fig. 3: Map around the (333) Bragg peak of silicon at (a) 11.103 keV and (b) 11.07 keV.

We performed similar measurements on smaller isolated Ge dots grown by the same way.

As we can see in the anomalous diffraction scan on the (800) Bragg peak of silicon (cf fig 4), the two families are shifted towards the Si bragg peak.

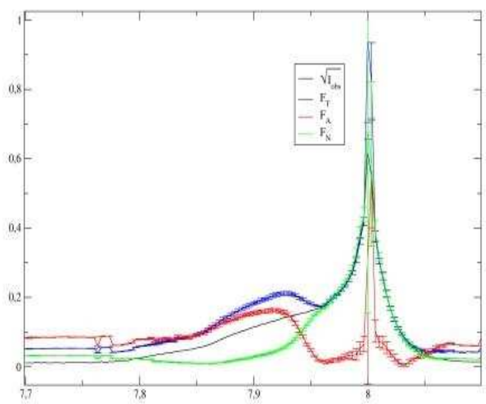

Fig. 4:Anomalous diffraction (800) Bragg peak of silicon with the contribution of germanium (red line) and silicon (green line into the dots).

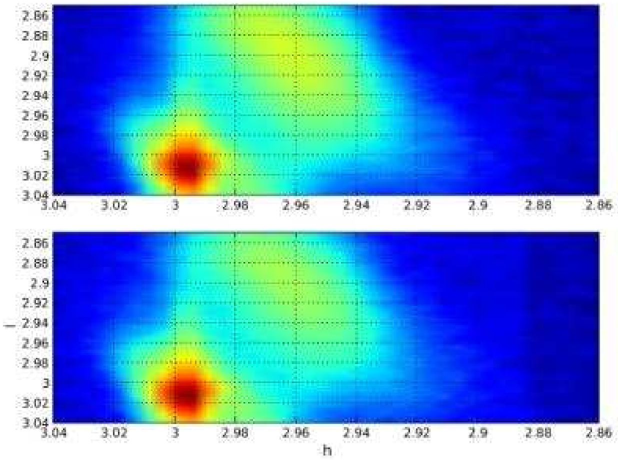

Fig. 5: Map around the (333) Bragg peak of silicon at (a) 11.103 keV and (b) 11.07 keV.

From the radial scan along the (800) Si Bragg peak (see fig4) and the map around the (333) Si Bragg peak, lattice strain relaxation in the plane and out of plane for the Ge dots was calculated at 0.9% and 2% respectively.

2) Conclusion

We show for the first time for the Ge/Si system the growth of a isolated Ge dots with a bimodal lattice parameter distribution. We report that the two families of dots have different strain state and composition.