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HRTEM study of growth-correlated properties of (Si,Ge) islands

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The materials system (Si,Ge) is subject of vivid fundamental research. On the one hand this is due to the well developed Si technology and on the other hand (Si,Ge) island structures can form by self-organization owing to the lattice mismatch between Si and (Si,Ge) (Stranski-Krastanov growth). The size of the islands strongly depends on the Ge content [1]. In this work the influence of the growth procedure on the size, the structure, and the deformation of the islands is studied by means of c_S-corrected high-resolution TEM assisted by image analysis applying both DALI for strain analysis [2] and QUANTITEM for determining the chemical composition [3].

(Si,Ge) islands were grown by two different epitaxial procedures, viz. by liquid phase epitaxy (LPE) and by molecular beam epitaxy (MBE), respectively. The growth temperature was 600 °C for both experiments. While LPE proceeds quite near to the thermodynamic equilibrium, the MBE growth is limited by transport and diffusion phenomena. The LPE-grown samples contain a single layer of uncapped $Si_{1-x}Ge_x$ islands with $0.3 \le x \le 0.5$. The samples grown by MBE comprise a 5-fold stack of buried islands separated by a 25 nm thick Si spacer layer, where the topmost island layer remained uncapped. The nominal composition of the MBE-grown $Si_{1-x}Ge_x$ islands is $x \approx 1$.

The HRTEM image of a single LPE-grown $Si_{0.5}Ge_{0.5}$ island is given in FIG 1a. The island is {111}-facetted and has a base length of about 50 nm and a height of 25 nm. Image analysis using DALI was applied to the area framed in FIG 1a. The result is shown in FIG 1b. Here, the difference *u* between the local lattice constant and that of the reference lattice was determined. The slope of the function *u(z)* distinctly changes at three positions numbered in FIG 1b. Every individual slope stands for a certain lattice constant which depends on both the chemical composition as well as on the strain. Larger slope hints to an increasing Ge content. At an island height of about 15 nm the slope decreases down to zero indicating the same lattice constant as (Si,Ge) alloy of the reference area has, which is not expected from the growth. For clarification the Ge distribution was investigated using energy-filtered TEM as well as energy-dispersive X-ray spectroscopy. Both methods reveal an increase of the Ge content starting from the island base and reaching the nominal value at 2/3 of the island height. Consequently, the decrease of the lattice constant at the top of the island found by digital HRTEM image analysis has to be attributed to relaxation.

The buried (Si,Ge) islands of the MBE-grown samples are lens-shaped and show a lateral size of about 50 to 100 nm which is rather the same as for the islands grown by LPE (cf. FIG 2). Unlike to this, the vertical size ranges only between 5 and 10 nm. The nominally higher Ge content as well as the immediate capping of the islands are regarded as reasons for this smaller height. The strain was analyzed using DALI and the Ge content was determined applying QANTITEM to HRTEM images.

References:

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[3] C. Kisielowski, P. Schwander, F.H. Baumann, M. Seibt, Y. Kim, A. Ourmazd, Ultramicroscopy **58** (1995) 131.

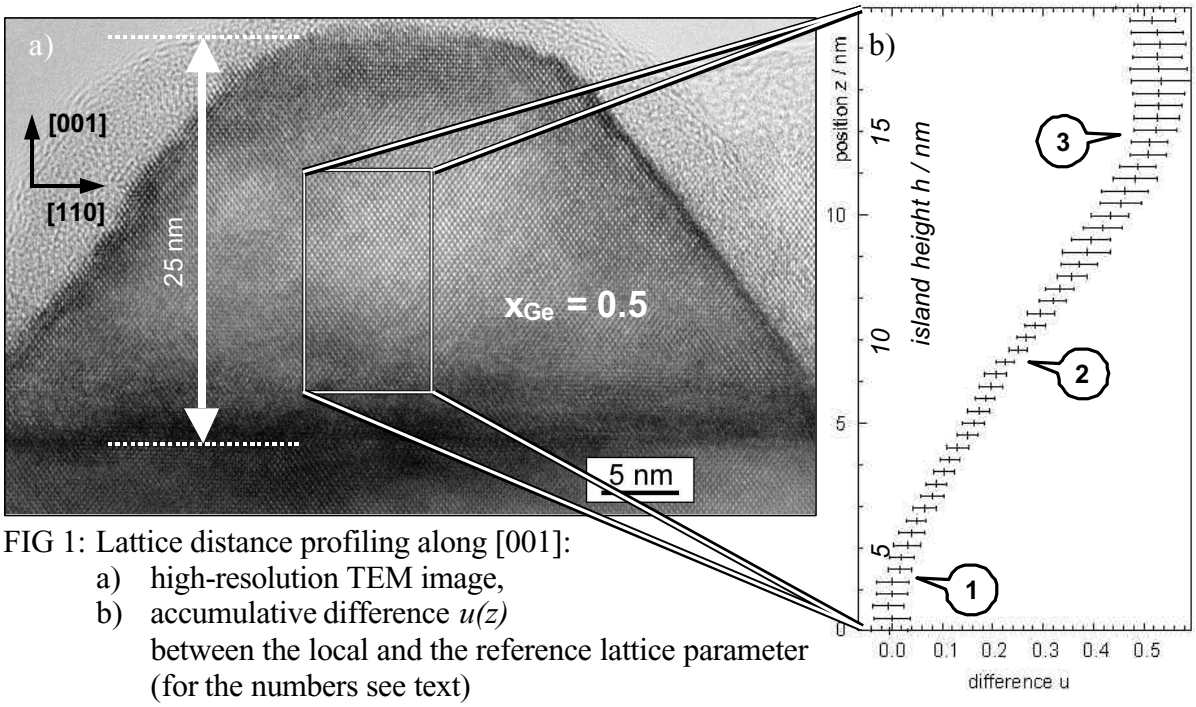

FIG 1: Lattice distance profiling along [001]:
a) high-resolution TEM image,
b) accumulative difference *u(z)* between the local and the reference lattice parameter (for the numbers see text)

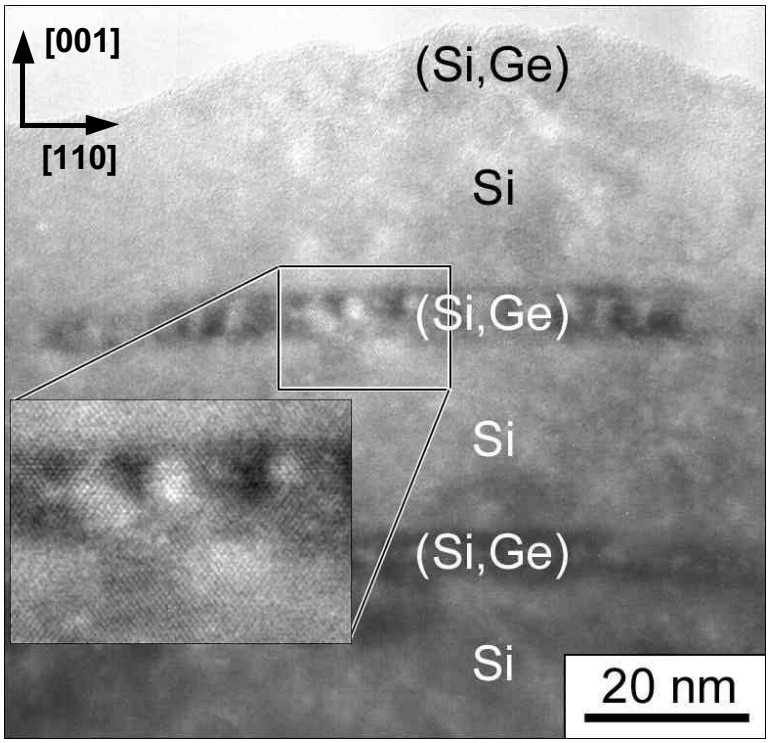

FIG 2:
TEM image of stacked MBE-grown $Si_{1-x}Ge_x$ islands on Si ($x \approx 1$);
inset: enlarged area showing high-resolution fringes.