Strain Properties and Crystal Quality of thin Si-layers above SiGe Quantum Dots

N. Hrauda\textsuperscript{1}, M. Keplinger\textsuperscript{1}, T. Etzelstorfer\textsuperscript{1}, E. Wintersberger\textsuperscript{1,2}, J. Stangl\textsuperscript{1}, J.J. Zhang\textsuperscript{3}, V. Jovanovic\textsuperscript{1}, and G. Bauer\textsuperscript{1}

\textsuperscript{1}Institute for Semiconductor Physics, JKU Linz, Altenberger Str. 69, 4040 Linz, Austria
\textsuperscript{2}HASYLAB / DESY, Notkestr. 85, D-22603 Hamburg, Germany
\textsuperscript{3}IFW Dresden, Helmholtzstrasse 20,01069 Dresden, Germany
\textsuperscript{4}DIMES, TU Delft, Feldmannweg 17, 2628CT Delft, The Netherlands

Tensile strained Silicon channels are an important object of interest for the design of field effect transistors with enhanced electron mobility\cite{1}. We showed that in Si channels grown on top of SiGe islands tensile strain values of about 0.8\% \cite{2} can be realized. To gain more insight on the strain properties within the channel, x-ray diffraction (XRD) experiments were performed on a series of Silicon-Germanium (SiGe) islands with different Si coverages and a set of fully processed field effect transistors to investigate the influence of device processing on the Si layer which acts as conducting channel in those devices.

SiGe islands were grown on Si (001) wafers with 2D pit-patterned fields (800 nm period) sized 400×400 \(\mu\text{m}\). After the growth of a 36 nm Si buffer layer at 450 - 550\(\text{°C}\), 6 monolayers of Ge were deposited at 720\(\text{°C}\) leading to the formation of dome-shaped islands with \{1 0 5\},\{1 1 3\} and \{15 3 23\} facets present (average base-width/height: 220 nm/45 nm). The Si-capping of the islands was performed at 360\(\text{°C}\). Coverages of 5, 10, 20 and 30 nm were used for investigations as well as an uncapped reference sample. XRD experiments were performed at Beamline P08, Petra III at an energy of 8.048 keV. Reciprocal space maps (RSM) around the symmetric (004) and the asymmetric (224) Bragg peak were recorded in coplanar geometry. The incident x-ray beam was confined to a size of 0.2×0.2 mm to eliminate contributions from islands on flat areas surrounding the patterned fields. We combine XRD techniques with Finite Element Method (FEM) simulations based on the Comsol Multiphysics Package \cite{3}. To verify the model, the calculated displacement fields are used to simulate RSMs for comparison with the measurement. The diffuse SiGe signal

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure1.png}
\caption{Section a) depicts line plots of the in-plane strain along a vertical line through the center of the respective FEM models (see inset) for capped and uncapped islands; note the tensile-strained Si-cap sections marked by a circle. In section b) the according measurements (colourplot) are shown superimposed by XRD simulations based on FEM models (contours).}
\end{figure}
narrows towards the crystal truncation rod (CTR) with increasing capping layer thickness indicating a decrease of relaxation within the SiGe island, at the same time reducing the tensile strain in the Si cap layer. Due to the lattice mismatch of 4.2% between Si and Ge, the relaxation states of those two components act counter-productively - a more relaxed SiGe island induces higher tensile strain in a Si capping layer, whereas the thicker the capping layer gets, this layer is able to relax more and thereby applies more compressive strain to the buried island. Thus it seems like a thin Si capping layer would be desirable, as it has the highest tensile strain. However, fabrication processes such as etching steps, annealing or ion implantation performed after the epitaxial growth have a significant influence on the Si channel which has to be taken into account. Therefore a set of dotFET devices based on SiGe islands covered by nominally 30 nm Si was investigated. During processing, the Si layer is partially implanted with As ions to form the conducting source and drain areas. To melt and recrystallize the volume damaged by this process, excimer-laser annealing (ELA) was applied at different doses.

Those XRD measurements were carried out at Doris Beamline D4 at an energy of 8.945 keV. RSMs around the asymmetric (115) Si Bragg Peak were recorded, including the SiGe signal and the CTR. From the period and intensity of the oscillations along the CTR we derive that of the initial 30 nm of Si cap layer, only 23-25 nm are left. Differences in it’s crystal quality are obvious comparing the not-annealed sample (Fig.2a) with the annealed ones (Fig.2b-g) where the CTR is much more pronounced. However, to distinguish the effects of the different doses during laser annealing, a higher dynamic range would be needed to discern more features in reciprocal space.

References