ESRF	Experiment title: Strain relaxation and interracial roughness studies of $Si_{1-x}Ge_x$ and $Si_{1-y}C_y$ layer structures	Experiment number: HC-498
Beamline: 10	Date of experiment: from: 23/01/96 to: 28/01/96	Date of report: 20/02/96
Shifts: 14	Local contact(s): A, Souvorov	*Received at ESRF:*

Names and affiliations of applicants (* indicates experimentalists):

* P. Zaumseil, Institut fur Halbleiterphysik, D-15204 Frankfurt(Oder), Germany
* G. Fischer, Institut fur Halbleiterphysik, D-15204 Frankfurter), Germany
* G. Bauer, Institut fur Halbleiterphysik, Universitat Linz, A-4040 Linz, Austria
* A. Darhuber, Institut fur Halbleiterphysik, Universitat Linz, A-4040 Linz, Austria
* J. Stangl, Institut fur Halbleiterphysik, Universitat Linz, A-4040 Linz, Austria

V. HoI y, Dept. of Solid State Physics, Masaryk University, 61137 Brno, Czech Republic

Report:

1) Using specular reflectivity measurements at wavelengths corresponding to the Ge K absorption edge, the interface roughness of Si/SiGe multiquantum well structures has been investigated for samples with Ge contents ranging from 26% to 50%. The nonsecular reflectivity has been used for studies of the roughness correlations both in the (001) in plane as well as along growth direction [001]. Data are shown on samples (which were grown by MBE) and which consisted of 10 periods (D= 209Å and D= 206Å with SiGe layer thicknesses of 24Å and 26Å).

The non specular scans have been performed both in ω and 20 directions that enabled us to determine both the horizontal and vertical correlation lengths. The experiments were performed in various azimuthal directions, since the samples were grown on (unintentionally) miscut Si-wafers (miscut angles: 0.25,0.7 degrees) . It turned out that in contrast to earlier claims, the interface roughness does not increase with increasing Ge content (in the range up to 50%). As shown in Fig. 1 the structural quality of the Si/SiGe multilayer is indeed very good, as evidenced from the comparison of measured and calculated specular reflectivity curves. This makes it possible to determine reliable values of the root mean square roughnesses which are for these samples in the range of 5 to 7 Å. Consequently, in the Ge range from 20 to 50%, the increasing lattice strain is apparently not decisive for the observed interface roughness. Most likely the other growth parameters determine the interface morphology.

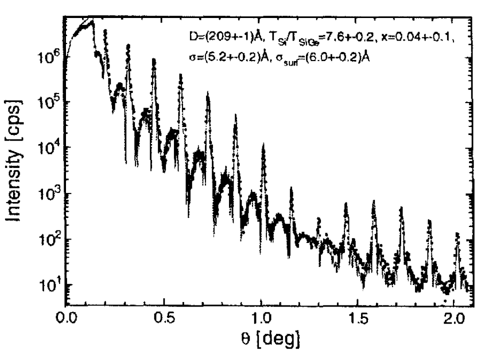

Fig. 1

Due to miscut, terraces occur on the vicinal surface which influence the subsequent BE growth. Therefore the roughness profile of the interfaces is strongly anisotropic, This anisotropy is clearly observed and shown in Figs 2 and 3 in the ω-scans for two orthogonal directions . In the direction perpendicular to the miscut, the roughness can be described by a Gaussian correlation function and no distinct spatial frequency of the roughness profile can be deduced. However, in the direction along the miscut, (Fig.3) a well defined characteristic width between adjacent interface signatures of the order of 1 µm was found. The structure can be modeled by means of the Markov-chain theory. The most probable model is a mixture of a castellation and a stair case morphologies.

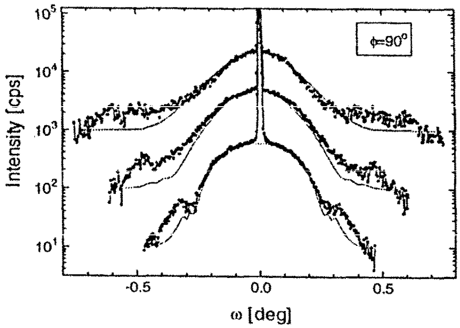

Fig. 2

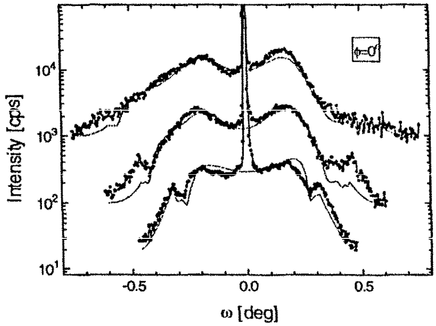

Fig. 3

For the correlation between subsequent interfaces (roughness replication) a characteristic length of 2000Å has been found, i.e. extending over several periods. From the distribution of the diffusely scattered radiation in reciprocal space around (000) it follows that the direction of maximum replication is inclined with respect to the growth direction by about 60 degrees, This behaviour is most probably caused by growth kinetics induced by the terraces,

2) The rocking curve (RC) of a SiGe heterobipolar transitor structure with a 45 nm thick Si-cap layer and a 42 nm thick graded SiGe layer was measured at different wavelengths (0.8, 1.05, 1.25 and 1,54 Å) over a very long angular range {-4000". ...4000"). These RC's will be used for direct strain profile calculations with high depth resolution.

3) A set of samples with 120 nm thick $Si_{1-y}C_y$ layer grown by MBE with two different silicon growth rates (0.25 Å/s and 0.5 Å/s) and substrate temperatures between 350 and 600°C was investigated to determine at constant power of the carbon sublimation source the concentration of substitutional incorporated carbon and the structural perfection. Fig. 4 shows that the concentration of substitutional carbon decreases with increasing temperature. Measurements of the diffuse scattering near the $Si_{1-y}C_y$ peak demonstrate the structural perfection of all layers independent of the substrate temperature. This allows a detailed modeling of the growth kinetics of $Si_{1-y}C_y$ layer deposition.

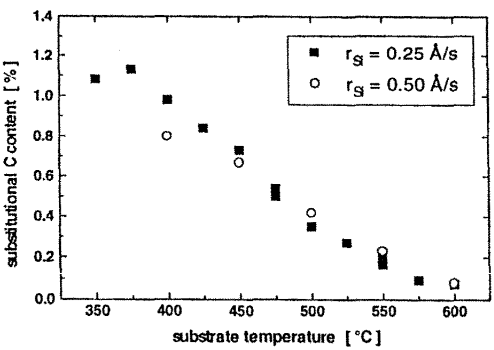

Fig. 4

4) The specular reflectivity of capped $Si/Si_{0.7}Ge_{0.3}/Si$ samples was measured after 9 hour annealing at different temperatures. Below 900°C an enhancement of the interface roughness was observed due to plastic relaxation. At higher temperatures the intensity oscillations vanish completely due to the now dominating interdiffusion processes.