ESRF	**Experiment title:** Diffuse scattering between Bragg reflections (Zwischenreflexstreuung) on As and B implanted Si under grazing incidence and exit conditions	**Experiment number:** HS 59
Beamline: ID 10	**Date of experiment:** from: 09/03/97 to: 13/03/97	**Date of report:** 27/02/98
Shifts: 12	**Local contact(s):** Douglas Abernathy	*Received at ESRF:* 12 MAR. 1998

Names and affiliations of applicants (* indicates experimentalists):

U. Beck [1] *, Z. Kovats [1] *, T.H. Metzger [1*], C.-H. Chang [2*], J.R. Pate1 [2*], G. Grübel [3*], J. Peisl [1]

[1] Sektion Physik der Ludwig-Maximilians-Universität München, Geschwister-Scholl-Platz 1, 80539 München, Germany

[2] Stanford University (SSRL/SLAC), P.O. Box 4349, MS 69, Stanford, California 94309-0210, USA

[3] ESRF

Report:

Ion implantation is the key technology in device fabrication but due to progressing miniaturization the defects connected with this process show an increasing impact on the electrical properties. The control of device quality therefore requires a thorough understanding of the near-surface point defects created by implantation and subsequent annealing. The aim of our experiment was to acquire a depth resolved determination of defect shape and position for Si(001) implanted with As and B - the most important dopants for Si devices. This ought to be achieved by investigating the diffuse scattering between surface reflections [l] in the geometry of grazing incidence and exit angles. Due to the shift of the beamtime from the original date it was not possible to use the HPOG monochromator initially requested. From preliminary experiments we found no significant difference of this diffuse "Zwischenreflexstreuung" between pure Si and the implanted samples. Instead the defect-induced diffuse intensity was concentrated in an area of about 10% of the Brillouin zone around the Bragg points. Therefore we decided to thoroughly study this region of the q_x-q_y-reciprocal plane around the (220)-reflection.

To measure the diffuse scattering we used a position sensitive detector (PSD) which was mounted parallel to the sample surface and rotated around the surface normal to the scattering angle of the (220) surface reflection of Si. A slit in front of the PSD provided a well defined integration over the exit angle, while a small slit immediately after the sample ensured sufficient resolution in the scattering (hk) plane. Angular and radial (hk)-scans through the Bragg reflection were used to map out the reciprocal space containing 10% of the Brillouin zone around the Bragg peaks. This new measuring geometry combines a high resolution set-up with a fast data collection by means of a PSD in the scattering plane.

We determined the reciprocal space map in the vicinity of (220) for As and B implanted samples with different implantation doses and post-implantation annealing treatments, but we concentrate in the following on the results for the B samples.

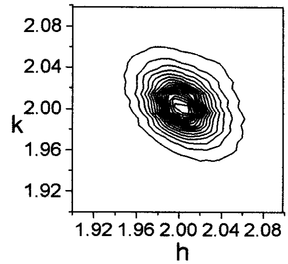

Fig. 1: B induced diffuse intensity distribution close to Si(220) reflection

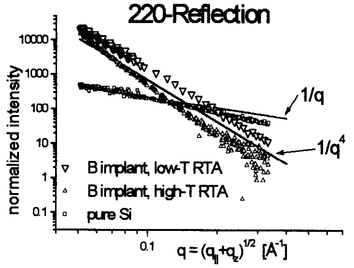

Fig. 2: Test of the q dependence of the diffuse intensity in <1-10> direction

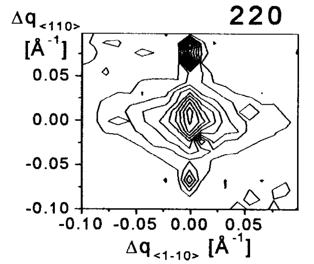

Fig. 3: Implantation induced diffuse satellite peaks in <110> direction

Fig. 1 shows the typical result after B implantation and annealing. The symmetry of diffuse scattering is totally different from that expected in the vicinity of bulk Bragg reflections for substitutional defects, i.e. there are no planes or lines of vanishing diffuse intensity. This is in agreement with theoretical calculations for this scattering geometry [2], which also predict a different power law for the decay of the diffuse intensity depending on the boundary conditions for the strain field ($\propto 1/q^2$ for relaxation only at the surface and $\propto 1/q^4$ for relaxation at the surface and at a buried interface). As shown in Fig. 2 we find a q^{-4} dependence. It is thus clearly demonstrated that for our samples the strain field of the near-surface defects can relax at two interfaces. The buried interface is probably formed by implantation induced end-of-range defects. A detailed analysis of the observed space map is still in progress. For samples additionally implanted with Si a very surprising feature has been observed. As can be seen in Fig. 3 the reciprocal space map shows satellites, which are clearly separated from the main Bragg peaks in the radial <110> direction. Such a phenomenon has not been observed previously in ion implanted material. It can be interpreted in terms of a longitudinal strain modulation. Simulation calculations for this hypothesis are currently performed and first results have been reported [3].

In order to test this promising method on a different system, we measured the diffuse scattering from pseudomorphic $Si_{0.985}C_{0.015}$ epilayers on Si(001). Due to the reduced Si-C bond length compared to the Si-Si bond, substitutional incorporated C acts as a lattice contracting point defect with a long range displacement field and therefore shows *Huang diffuse scattering.* To investigate the thermal relaxation of $Si_{1-x}C_x$ which is known to precipitate into incoherent β-SiC clusters, the diffuse scattering of a series of as grown and annealed samples was measured. Fig.4 shows the diffuse scattering in the radial direction around the (220) surface reflection. Annealing up to 650°C does not affect the defect structure, at 850°C the diffuse scattering is reduced almost to thermal diffuse scattering of a pure Si reference sample and after annealing at 1050°C, the change of q-dependence indicates clustering of a new defect type.

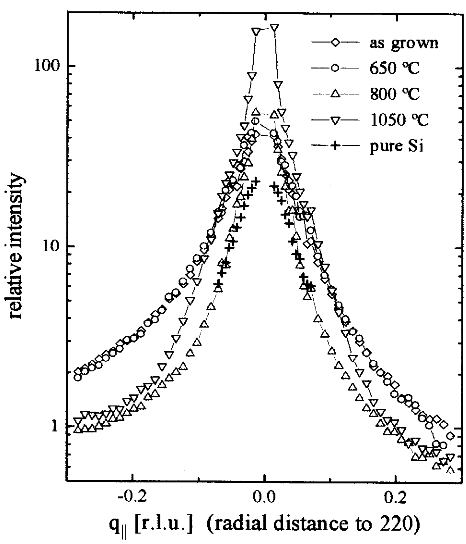

Fig. 4: diffuse scattering from $Si_{1-x}C_x$ close to the (220) surface reflection

[l] H.-G. Haubold, J. Appl. Cryst. 8 (1975) 175
[2] R.I. Barabash, M.A. Krivoglaz, Sov. Phys. Solid State 29 (1987), 1768
[3] J.R. Patel, T.H. Metzger, SSRL Users Newsletter 10/97,22