ESRF	**Experiment title:** **Grazing incidence diffuse x-ray scattering from defects in ion implanted silicon at ultra-low energy for future generation devices**	**Experiment number**: SI872
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Report:

During this experiment the influence of the preamorphisation treatment on the structural properties of Si after As dopant-implantation and annealing was investigated.

The implantation of high dopant doses in the ultra-low energy (ULE) regime may give rise to ion-channelling which leads to an increased junction depth after annealing. To prevent the ion-channelling, industrial ULE implants are performed on Si substrates, bombarded by amorphising implants (PAI) prior to the dopant implant. In addition to limiting the channelling of the dopant ions, the PAI treatment introduces End-Of-Range (EOR) damage. A total of 6 samples was characterised, whose preparation is summarised in Table 1.

Table 1: (001) Si samples characterised using GI-DXS. When indicated, a PAI treatment was performed with Xe ions at 130 keV to a dose of $2x10^{14}$ cm^{-2}. All samples were implanted with As ions to a dose of $2x10^{15}$ cm^{-2}. RTA means Rapid Thermal Annealing

Sample	PAI treatment	Annealing conditions
PAI as-implanted	Yes	No annealing
NoPAI as-implanted	No	No annealing
PAI 600	Yes	Furnace at 600ºC for 20min.
NoPAI 600	No	Furnace at 600ºC for 20min.
PAI spike	Yes	RTA spike annealing at 1130ºC
NoPAI spike	No	RTA spike annealing at 1130ºC

To investigate the defect structure in the EOR layer, grazing-incidence diffuse x-ray scattering (GI-DXS) measurements were performed at an X-ray penetration depth of $\Lambda \approx 400$nm by choosing an incident angle slightly above the critical angle for total external reflection.

The symmetric component of defect-induced DXS, I_{sym}, [1] was evaluated for the two sample series as a function of q as shown in Fig. 1(a). The I_{sym} from sample No-PAI as-implanted decays with q^{-2}, typical for the Huang Diffuse Scattering (HDS) from point defects located in the EOR damage region, most likely di-interstitials [2].

The 600°C-annealed samples show a q^{-2} decay of I_{sym} for q>0.09Å^{-1}, which is attributed to the presence of small "magic" clusters [2] that have formed during the epitaxial regrowth. The increase of intensity for q smaller than 0.09Å^{-1} is caused by the presence of the crystalline dendrites at the amorphous to crystalline interface, as explained in Ref. [1]. The I_{sym} for sample PAI and NoPAI 600 is reduced by a factor of 2 as compared to NoPAI as-implanted, indicating a partial annihilation of the defects. The DXS from the two 600°C samples shows the same intensity except for the q-range from 0.08 to 0.22 Å^{-1}. The additional scattering on the PAI 600 is explained by the analysis of the corresponding intensity distribution along q_z, as reported below.

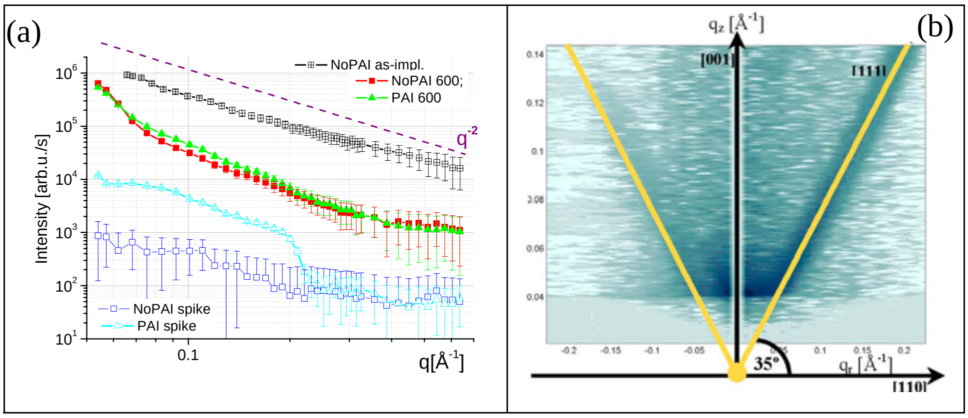

Figure 1: (a): Symmetric part of the diffuse intensity in radial direction close to 220 for all annealed samples at a scattering depth Λ≈400nm. The dashed line indicates the q^{-2} decay expected for the HDS. An intensity offset was applied for the signal from the different annealing treatments. (b): Reciprocal space map of defect-induced DXS intensity in the q_r-q_z plane close to the 220 Bragg reflection for sample PAI spike. The intensity streak points in the [111] direction with an angle of 35 deg with respect to the radial direction [110] (note the different scales for q_z and q_r).

For the spike-annealed samples, a strong reduction of the DXS intensity, I_{sym}(NoPAIspike)≈10% I_{sym}(NoPAIas-impl.), indicates the annihilation of the point defects. For PAI spike, the main feature is the presence of an intensity hump located in the *q*-range between 0.04 to 0.22 Å^{-1}. The origin of this hump is understood from the reciprocal space map in the q_r-q_z plane reported in Fig. 1(b). The hump-effect in the integrated intensity is due to the presence of strong DXS intensity streaks along the [111] directions, with an inclination of 35deg with respect to q_r // [110] direction. As discussed in Ref. [4], these diffuse intensity streaks are typical for extrinsic stacking faults (SF's) and proves that SiI's in the EOR region have aggregated to form faulted dislocation loops (FDL's) [2]. From the q_z-resolved measurement (not shown here), the diameter of the SF is found as (505±5) Å for the PAI spike.

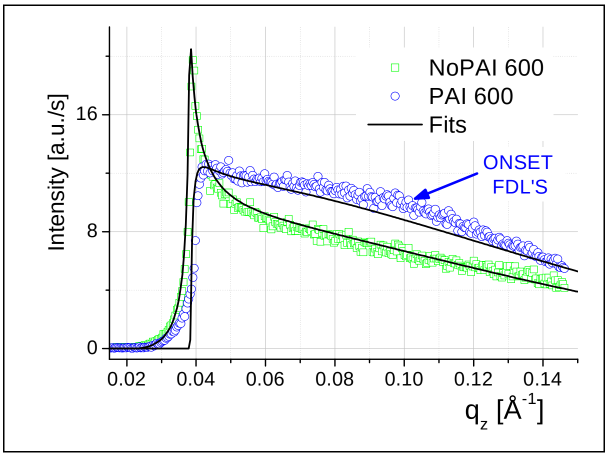

Figure 2: Defect-induced diffuse intensity distribution along q_z measured at q_r=0.14 Å^{-1} from a scattering depth Λ≈400nm for the 600°C-annealed samples and calculated defect-induced DXS.

Depth-resolved information on the location of the EOR defects is obtained from the DXS distribution as a function of q_z. The defect-induced DXS from PAI 600 and NoPAI 600 has been simulated using a code from V. Holý [3]. The fits are shown in Fig. 2 together with measured data. The results of the simulation enable to located the depth *d* of the EOR damaged layer: *d*=(125±10) Å, for NoPAI 600, and *d*=(1000±200) Å, for PAI 600. In addition, for PAI 600, a broad hump-like DXS distribution is observed in the range from q_z = 0.065 to 0.125 Å^{-1} indicating the onset of FDL's formation.

The formation of extended defects such as FDL's was not observed for the NoPAI sample series, where the surface acts as a strong sink for the excess Si interstitials present in the EOR damage defects.

All the results from the EOR defect characterisation in the PAI *vs.* NoPAI sample series are in agreement with the "excess interstitial" model [2].

References:

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