QUANTITATIVE TEM ANALYSIS ON THE PRESSURE OF HELIUM FILLED NANO-CRACKS IN IMPLANTED SILICON

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Most recently, crack-shaped helium cavities in silicon have become an object of enormous technological interest since, when nucleated in the substrate area of lattice mismatched GeSi/Si(001) heterostructures, the plastic relaxation of these overpressured nano-cracks represents a most efficient pathway in the reduction of the threading dislocation density inside the GeSi epilayers [1]. For these purposes, the elastic stress fields associated with the nano-cracks, whose size and spatial arrangement may be well adjusted by proper process control during helium implantation and subsequent thermal annealing, act as nucleation sources during the formation of dislocation dipoles gliding to the heterointerfaces from the substrate thus circumventing the formation of threading dislocations usually penetrating the epilayers from the free surface. In this context the ratio p/μ of the nano-crack pressure to the silicon shear modulus is a most critical parameter with respect to the efficiency of the relaxation process [1].

In the present study helium filled nano-cracks formed in silicon upon implantation at room temperature and on subsequent thermal annealing at 350˚C for 3 min > τ > 20 min have subjected to a detailed analysis. Diffraction contrast in micrographs taken under two-beam imaging conditions arises largely from the elastic strain fields associated with the distorted crystal in the proximity of the nano-crack (Fig. 1a). Quantitative information on the p/μ ratio is obtained by the comparison of experimental intensity line profiles (Fig. 1b) measured perpendicular to the crack plane with simulated profiles (Fig. 1d). These simulations are based on analytical expression of the elastic strain distribution of a Griffith crack [2] assuming linear theory of elasticity. Dynamical electron scattering is taken into account in the framework of the column approximation [3] using experimentally used imaging and specimen input parameters (specimen thickness t obtained by CBED, effective deviation parameter s measured from diffraction patterns and crack radii r determined by large angle tilt experiments) together with a continuous variation of the p/μ ratio. Systematic analyses demonstrate that under suitable imaging conditions, the positions of the line profile intensity minima are most sensitive exclusively on the the p/μ ratio, which ensures a non-ambiguous determination of the nano-crack pressure.

Independent of the anneal time, the experimental results demonstrate $0.07 < p/\mu < 0.17$ for crack radii in the range 70 nm > r > 20 nm (Fig. 2). The observed behaviour $p/\mu \propto 1/\sqrt{r}$ gives evidence that the nano-cracks are still in equilibrium under the anneal conditions applied here [2, 4]. Moreover, the measured pressure values are in the order of the theoretical shear stress ($\approx 0.2\ \mu$) for plastic relaxation indicating an intrinsic instability of the nano-cracks to relax, e.g. by the formation of dislocation dipoles [4]. It may, hence, be concluded that each nano-crack may contribute with one dislocation segment at least to the relaxation of a GeSi epilayer grown on top of the implanted Si(001) substrate.

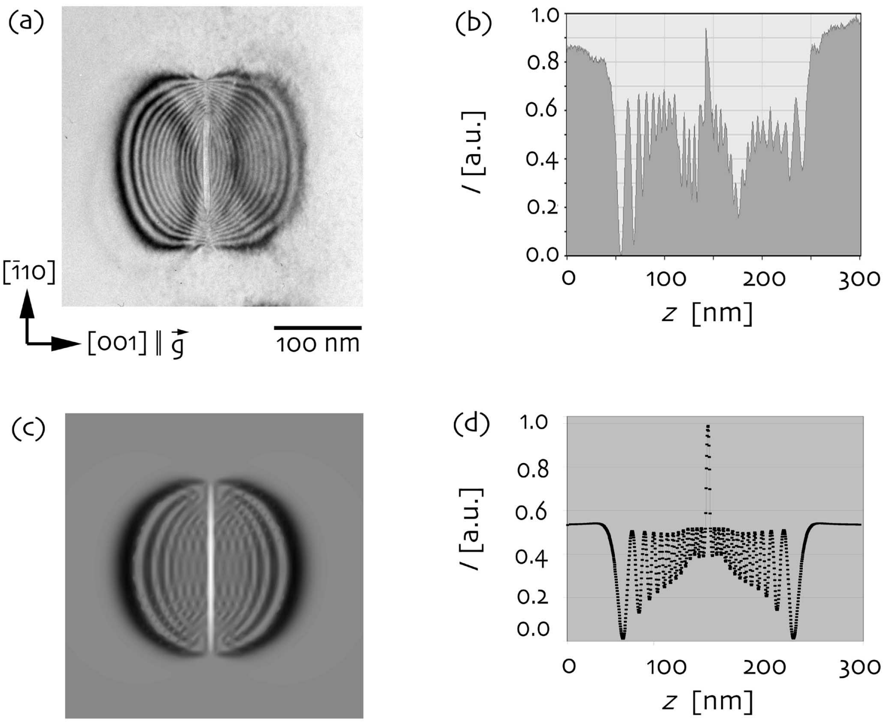

Figure 1: (a) Bright-field micrograph of a helium filled nano-crack in silicon taken from a cross-sectional sample oriented along the [110] direction and recorded under two-beam imaging conditions. (b) Intensity line profile measured perpendicular to the crack plane. (c) Calculated image assuming **g** = (004), an effective deviation parameter $s = 0.035$, a sample thickness $t = 280$ nm, $U = 200$ kV, an imaginary part of the Fourier coefficient of the lattice potential of 0.05 thus taking absorption into account, a nano-crack radius $r = 52$ nm and $p/\mu = 0.08$ together with the (d) correspondingly calculated intensity line profile. Intensity minima positions of the experimental profile (b) well coincide with the calculated positions (d) indicating an optimal adaption.

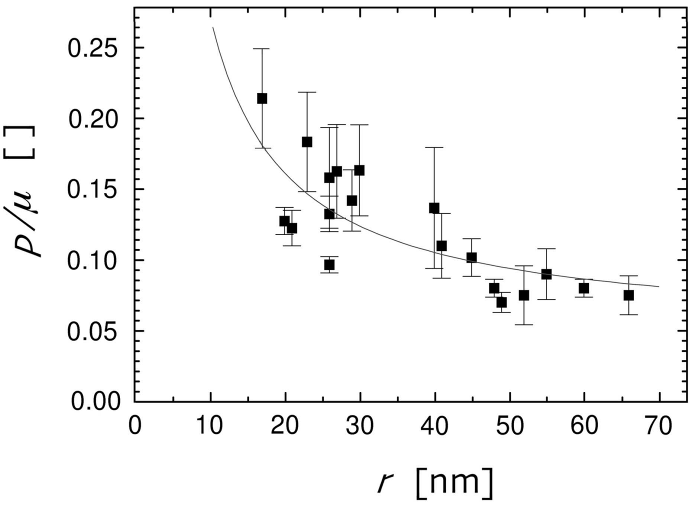

Figure 2: Experimentally measured nano-crack pressure to silicon shear modulus p/μ ratio in dependence on the radius r of various cracks. The solid curve represents a $p/\mu \propto 1/\sqrt{r}$ adaption to the experimental data (●); error bars are due to uncertainties in the measurement of imaging parameters (t, s) from experimental images.

References

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