QUALITATIVE AND QUANTITATIVE HRTEM CHARACTERIZATION OF EXTENDED DEFECTS INDUCED IN SILICON BY H-PLASMA TREATMENT

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Silicon hydrogenation is nowadays studied with the aim of developing and improving a technological method known as "smart cut" used in the fabrication of "silicon-on-insulator" (SOI) devices. The goal of our study is to characterize the defects induced in silicon wafers after exposure to hydrogen RF plasma. Si<001> wafers have been treated at 250°C under a hydrogen RF plasma at 110 MHz, for various durations. The main features observed by transmission electron microscopy (TEM) are the surface roughening and the presence of extended defects: planar defects and H bubbles. In this work a study using conventional TEM and high resolution transmission electron microscopy (HRTEM) techniques is presented on H bubbles and {111} planar defects induced in Si wafers by H plasma treatment.

Figure 1a shows a typical strain field contrast showing a four-fold symmetry, observed on a plan view specimen from a 5 silicon wafer hydrogenated during 1h. At higher magnifications, the defect core imaged under two-beam condition, reveals a cluster of nanometric bubbles with an average size below 10 nm. TEM images recorded under negative (Figure 1b) and positive (Figure 1c) defocus show, respectively, bright and dark inner fringes around the nanometric features, which is typical for TEM images of bubbles in a solid matrix [1].

The HRTEM image of planar {111} defects (Figure 2 a) have been acquired along the [110] zone axis using a JEOL 4000 EX electron microscope. The method for quantifying the strain field around the defect is based on Bragg filtering processing and geometrical phase imaging, described in [2]. The experimental HRTEM image represents a 2D periodic intensity distribution of the kind \( I(r) = A(r) \cos(2\pi g_0 \cdot r + \phi(r)) \) characterised by an amplitude \( A(r) \), a reciprocal vector \( g_0 \) and a local phase \( \phi(r) \). The local phase can be described in terms of the local displacement vector \( u(r) \) of the atomic planes with respect to a reference area on the experimental image: \( \phi(r) = 2\pi g_0 \cdot u(r) \). Using the specialised routines of the "Digital Micrograph" program, one can calculate the displacement field \( u(r) = \phi(r) / 2\pi g_0 \) and represent, as levels of grey, the elements of matrix characterising the strain field, i.e. \( \varepsilon_{xx} = \partial u_x / \partial x, \varepsilon_{yy} = \partial u_y / \partial y \), etc.

The geometrical phase images are obtained by selecting the -111 and -22-4 spots in the Fourier transform of the HRTEM image. Figure 2 c shows the computed component \( u_y \) of the strain field around the defect by the local displacement of the (-111). Quantitative image processing indicates a uniform negative rigid body displacement along OY (or [-111] direction) of the upper part of the image with respect to the bottom part. The \( \varepsilon_{yy} \) component of the strain field is represented as levels of grey in Figure 2 d. It has a compressive character with respect to the (-111) planes. A structural model of the defect is proposed based on the quantitative data obtained by GPM image processing. The resulting simulated HRTEM images are in good agreement with the experimental images of the defect.

References
Figure 1. (a) Typical four-fold symmetry strain field observed close to the [001] zone axis on a plan view specimen from a hydrogenated silicon wafer; (b) and (c) enlarged images of the core of the defect recorded in two-beam condition for negative (b) and positive (c) defocus.

Figure 2. (a) HRTEM image of the \{111\} defect in the thin region; the assigned XY coordinate system is figured; (b) Fourier transform of the HRTEM image; (c) \(u_y(r)\) component of the displacement field \(u(r)\) around the defect; (d) map of the \(\epsilon_{yy}\) component of the symmetrical strain matrix \(\epsilon_{ij}\).