CORRELATED 3D IMAGING OF DISLOCATIONS: INSIGHT INTO THE ONSET OF THERMAL SLIP IN SEMICONDUCTOR WAFERS

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Keywords: x-ray laminography, dislocations, semiconductor wafers, correlative imaging

Summary: We report on a novel correlative approach for three-dimensional (3D) imaging of dislocation networks in almost perfect crystals. The method is non-destructive and can be used for the characterization of samples with considerable lateral extension like wafers. We show results from its application to the investigation of the early slip band formation in Si wafers.

1. INTRODUCTION

During thermal processing of semiconductor wafers any microscopic flaw at the surface may trigger nucleation and expansion of dislocations [1]. These can rapidly evolve into so-called slip bands, extending considerably into initially defect-free substrate areas and entailing large-scale warpage [2] and atomic steps at the surface [1]. An understanding of the origin of slip bands and the associated plastic deformation, as well as predicting the evolution with suitable theoretical models is both of scientific interest and industrial concern.

2. EXPERIMENTAL METHOD

Our correlative approach combines three imaging methods: X-ray diffraction laminography (XDL) [3], X-ray white-beam topography (XWBT) [4], and circular differential interference contrast (CDIC) microscopy [5]. The XDL scan geometry is particularly well suited to image the 3D defect arrangement in laterally extended specimen like wafer with a few microns spatial resolution. Based on this 3D information, we may identify individual defects in an XWBT dataset by means of forward simulation, which enables the determination of Burgers vectors orientations even for more complex defect arrangements. Finally, optical CDIC microscopy links each dislocation to surface steps created by moving dislocation end points during defect propagation.

3. RESULTS

We show results of the characterization of dislocation networks induced into Si wafers after controlled mechanical damaging and subsequent thermal annealing, emulating typical aspects of industrial wafer handling and processing, see Fig.1a) and Fig.1b). In the context of surficial features, the 3D paths of the emerged dislocations and the associated Burgers vector distribution are determined even inside the complex arrangements, see Fig.1c). We relate our observations to theoretical predictions of the driving forces and identify the mobilization and multiplication of pre-existing dislocations as the dominating mechanism during thermally induced plastic deformation. We also show evidence of the undisturbed long-range emission of dislocations from regenerative sources.

Finally, we present first results from time-resolving 3D measurements of the dynamics during such thermally driven slip band nucleation as it is e.g. shown in Fig.1a). Here we take advantage of the non-destructiveness of the presented technique and its recent further development.

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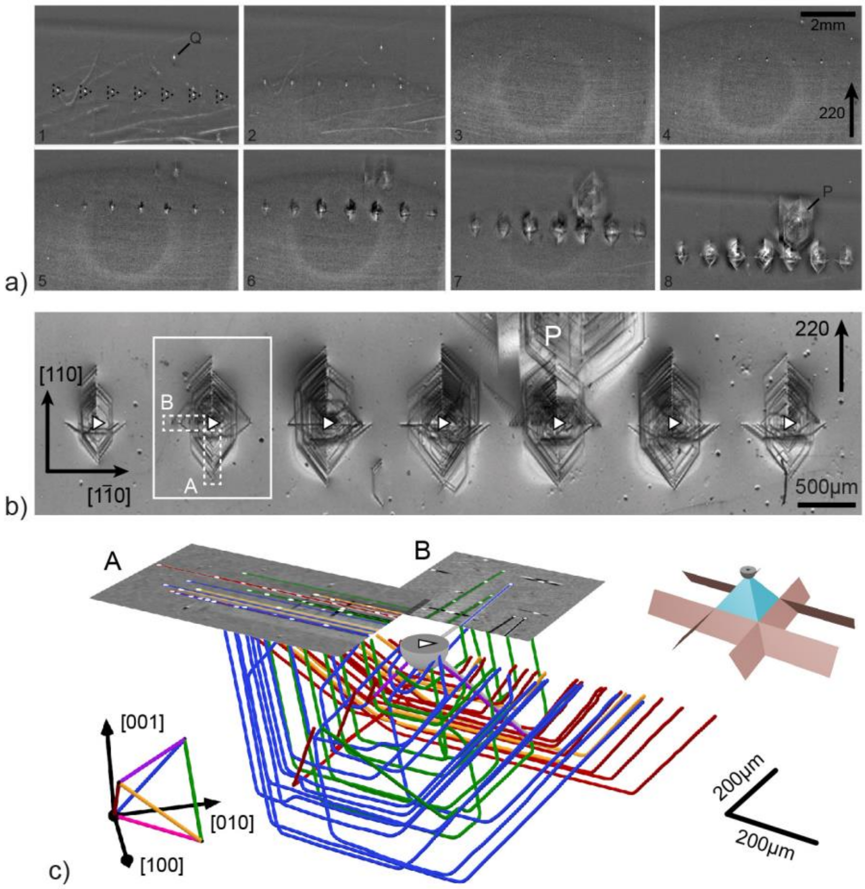

Figure 1: (a) *In situ* XWBT sequence (220 reflection, 15s separation of the shown images) of a Si wafer with seven indentations subject to thermal treatment. From each surficial damage site a complex dislocation network emerged. The network P resulted from damage Q on the sample rear-side, unintentionally. **(b)** High-resolution XWBT image (220 reflection) of the indented region recorded on film. **(c)** 3D rendering of the network marked in b), based on the combined information from XDL, XWBT, and CDIC. The 3D paths of all dislocations are represented by tubes with a radius of 3 µm (estimated spatial resolution) and the associated Burgers vector orientations are color-coded. The gray hemisphere depicts the strong deformation close to the initial damage. The surface areas marked A and B in b) are illustrated. On the right, the arrangement of the four active {111} slip bands (red, only the bottom part drawn) is schematically, indicated, which all mutually intersect nearby the point of indentation and thus leave a pyramidal region directly below defect-free (blue).