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TOPOGRAPHIC EXPOSURES OF REAL SILICON STRUCTURES ON THE VEPP-4 SR BEAM

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Studies have been made of the strain fields and the inclusions in various silicon structures by methods of X-ray topography, including section exposure, on the white SR beam of the VEPP-4 storage ring.

Exposures in Laue reflection of real silicon structures have been made at the experimental station "Topography and Diffractometry" on the VEPP-4 storage ring white SR beam ([1]). These exposures were aimed at ascertaining the capabilities of topography, including the section method ([2]), for imaging of defects of various sorts in a real structure as well as the strain fields caused, in the main, by couplings of different elements of the given structure with each other.

The MDS structure created on an n-type silicon substrate - a wafer of a (100) cut - is an example of such an object. A dielectric film of 0.55 μm thickness (SiO_2) was formed by oxidation of the surface of this wafer in 1100 °C steam. An aluminium film was vacuum-deposited on the oxidized surface of the substrate and then this was covered by a solid layer of photoresist. The round islets of aluminium film of 0.7 mm in diameter were obtained by the lithographic process. The layer of silicon dioxide between the islets was etched to the substratum. For exposure the wafer was placed perpendicularly to the incident SR beam. Fig. 1 shows the topographs which have been obtained for one exposure at two different reflections. Relative to the direct SR beam, reflection (a) is in the vertical direction, while reflection (b) is in the horizontal one. The fields of the strains at the edges of the islets as well as the precipitates are seen with a good contrast. The latter are seen also on the section topograph (refs. [1,2]) presented as fig. 2.

Section topographical exposure also visualizes the

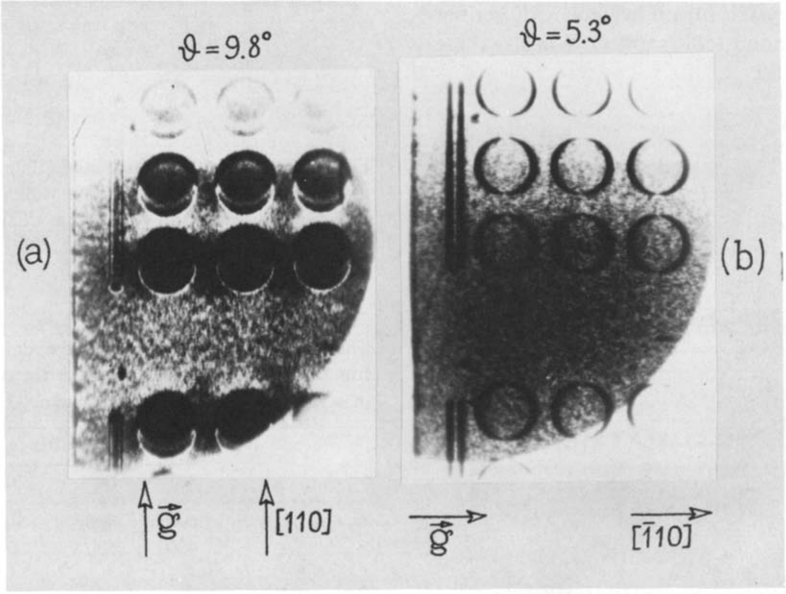

Fig. 1. Topographs of the (100) wafer of single-crystal n-type silicon with MDS islets of 0.7 mm diameters, i.e. aluminium films vacuum-deposited on silicon dioxide of 0.55 μm thickness. Both reflections were obtained for one exposure.

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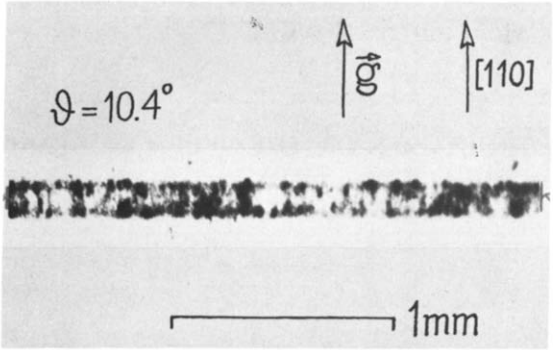
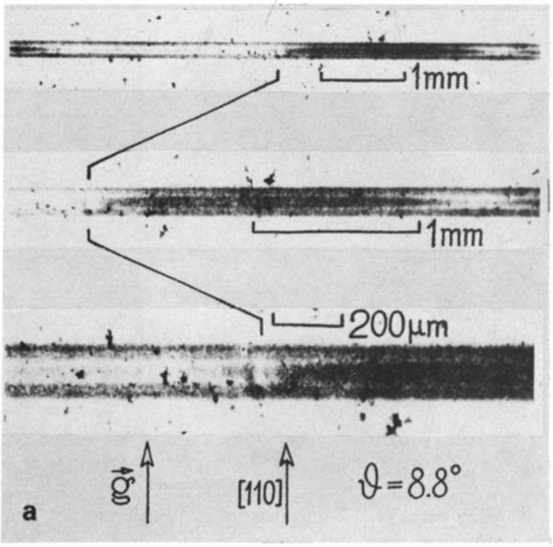
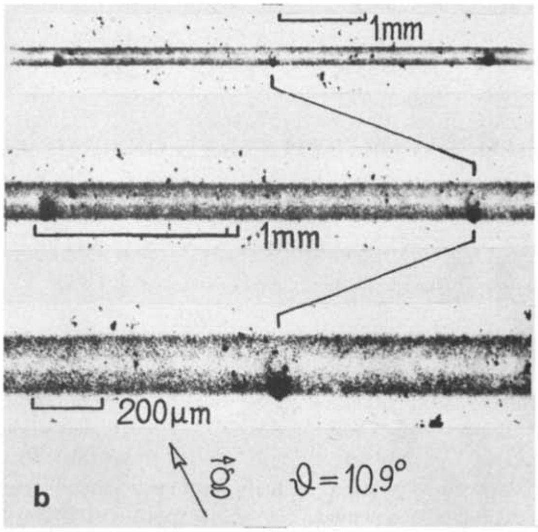


Fig. 2. A section topograph of the single-crystal silicon (100) wafer (see the caption to fig. 1).

strain fields that occur at the edges of the silicon-dioxide film of 0.44 μm thickness, created on a silicon substratum with a (100) cut (n-type phosphorus-doped silicon). 2×2 mm^2 windows were made in the dioxide film (fig. 3). As before, for exposure the wafer was oriented perpendicularly to the direct SR beam, while the dioxide film with windows in it was placed on the back of the wafer. Accordingly, the images of the strain fields adjoin those edges of the section reflections which face the projection of the direct beam onto the photoplate. No images of these fields are seen on reflection (a) oriented in a vertical direction with respect to the direct SR beam. Interference patterns of the distribution of the wave-field intensity on different reflections under the windows in the dioxide film and between them require thorough analysis and interpretation.

Of considerable importance are X-ray topographic exposures of single-crystal silicon wafers with scriber marks made by a diamond tool (scriber). When making





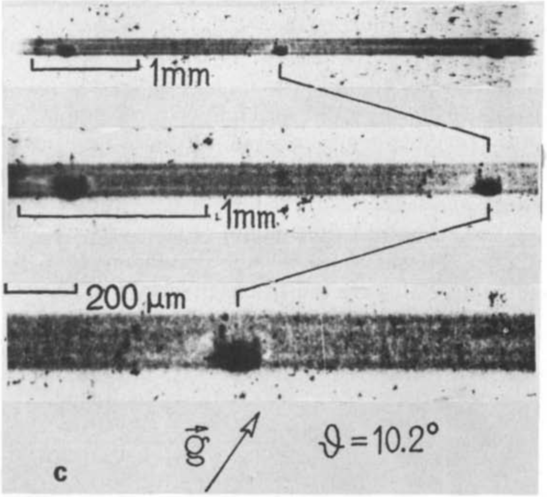


Fig. 3. Section topographs of the (100) wafer of single-crystal n-type phosphorus-doped silicon with 2×2 mm^2 windows in the silicon dioxide film of 0.44 μm thick on the surface of the wafer. All three reflections were obtained for one exposure.

Table 1
The size D of the image of the deformation region as a function of the load on the cutter for two different directions of scribing and the anisotropy factor as a function of the load

	Load on the cutter (g)			Direction of enscribing
	30	60	120	
D, (μm)	600	700	850	$[11\bar{2}]$
	400	500	700	$\langle 110 \rangle$
Anisotropy factor $D_{[11\bar{2}]}/D_{\langle 110 \rangle}$	1.5	1.4	1.2	

the marks, the cutting speed, 50 mm/s, and the angle between the cutting edge of the scriber and the surface of the wafer, 10–12°, were the fixed parameters. Three identical silicon wafers of a (111) cut, with scriber marks drawn at 30, 60 and 120 g loads on the cutter, were studied. On each wafer, in two different places the marks were drawn along two mutually perpendicular directions: [112] (polar directions) and ⟨110⟩ (nonpolar ones). During the exposure the silicon wafers were placed perpendicularly to the SR beam. The reflections were considered in which the projection of the diffraction vector onto the photoplate made an angle close to $\pi/2$ with the marks. In this case, the contrast, i.e. the size of the image of the deformation region, is largest.

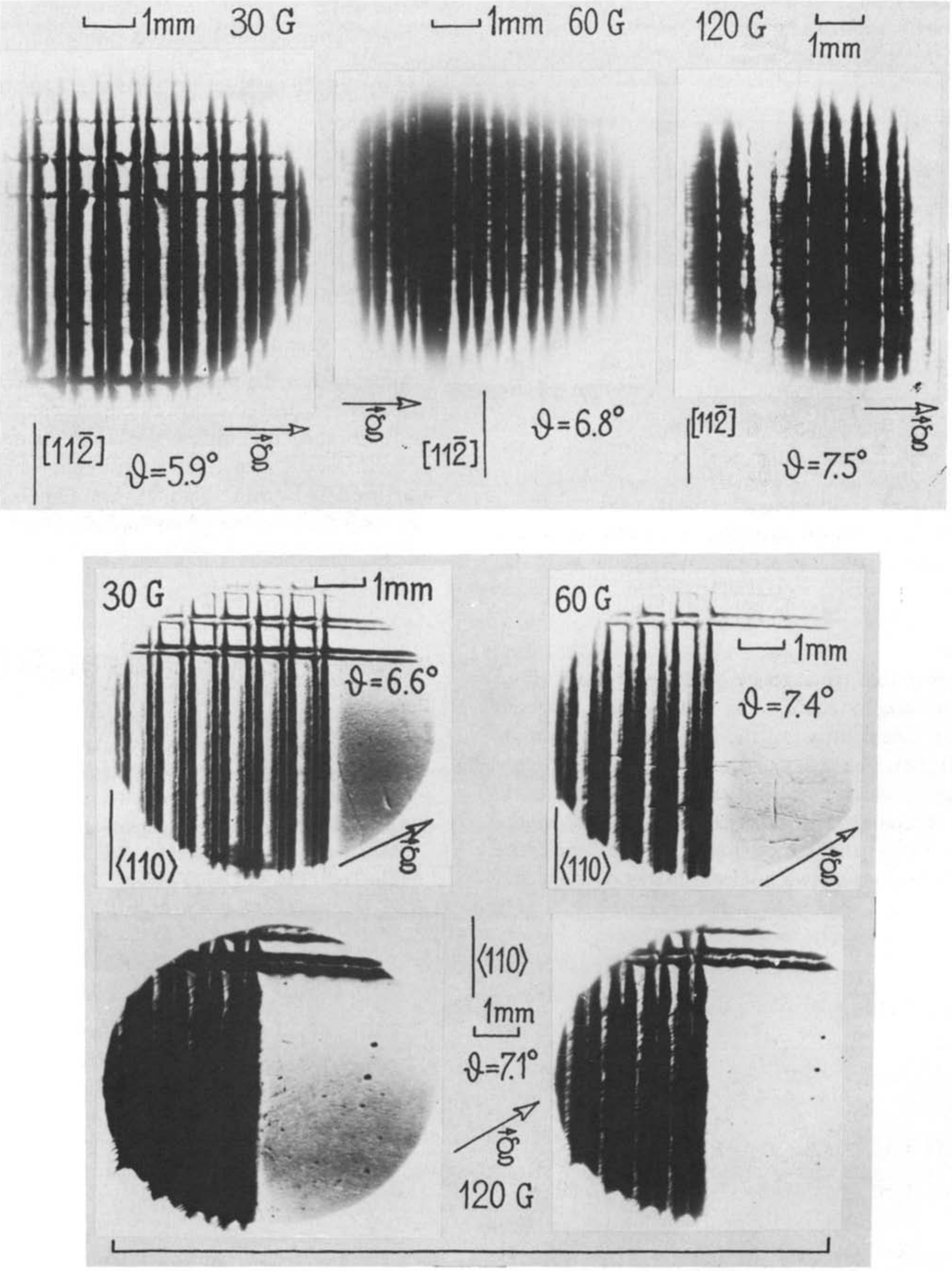


Fig. 4. Topographic visualization of the regions of deformations accompanying the scriber marks on single-crystal silicon (111) wafers.

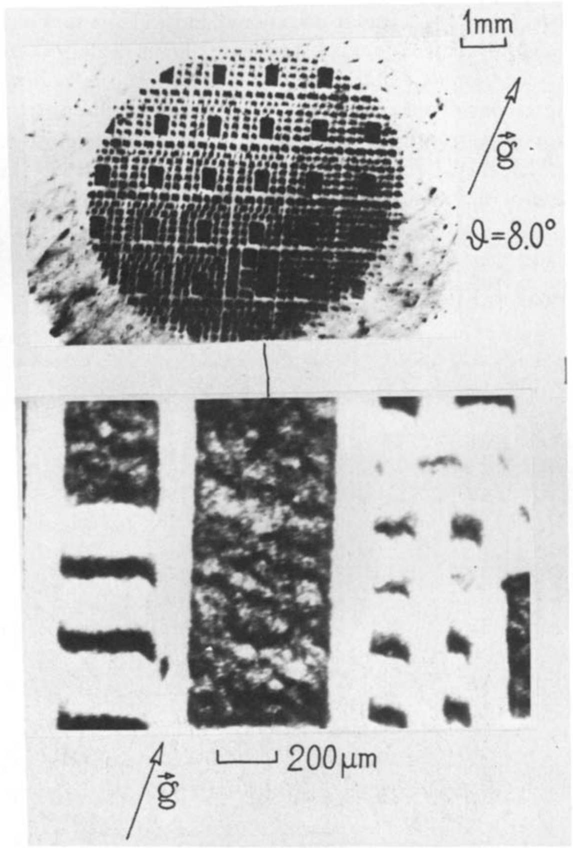


Fig. 5. Topographic image of a silicon structure with a dielectric insulation on the polysilicon matrix.

This angle is indeed equal to $\pi/2$ if the marks are along [112] and is roughly equal to 60° if they are directed along $\langle 110 \rangle$. The contrast of the images of the marks is reversed (fig. 4). The size D of the image of the deformation region, which embraces the image of the mark, increases, of course, with increasing the load on the cutter. At 120 g (the largest value of the load), the deformation regions of two adjacent marks overlap, and it is possible that this results in a certain underestimating of the size D when measuring (see the table 1). A decrease of the anisotropy factor, given in table 1, as the load on the scriber increases, should be considered as natural. At low load and, consequently, at small deformations localized in the narrow zone along the mark, there is no energy possibility for relieving the stresses: the load leads principally to an inculcation of the lattice sites into the interstitial sites. As the load increases, the phenomenon of nonuniform shear manifests itself: there appear numerous dislocations going onto the walls of the mark. Further increase in the load ensures energetically a means of relieving the stresses by cracking and shear.

Here it is also shown that there is a possibility in principle to obtain topographic images of rather complex silicon structures if these contain polysilicon matrices generating a powerful texture background (fig. 5). The object of exposure was a silicon structure with dielectric insulation (SSDI) containing merely small cells of single-crystal silicon (the (111) plane was parallel to the surface of the wafer) in active regions of the device: pockets with a depth ranging from 10 to 30 μm (transistors with diffused atoms of boron, phosphorus (under the base and the emitter respectively) and gold). The pockets were "sunk" into a polysilicon matrix which was insulated from them by the silicon-dioxide film. For the exposure the wafer was placed perpendicularly to the SR beam; the pockets were on the back of the wafer.

References

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