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A structural characterization method using polarized light microscopy and its applications

This application note introduces a defect delineation technique called PLM which is developed based on the principle of polarized light microscopy. It is a rapid, wafer-scale, nondestructive crystallographic defect identification and mapping technology which can be widely used for semiconductor material and device development such as defect study, wafer evaluation/screening, quality control, device/defect correlation and fundamental defect study. Though the discussion in this note is mainly related to silicon carbide (SiC), the method is not limited in application to this exemplary material.

Polarized light microscopy (PLM), also called birefringence topography or photoelastic stress method, is one of the oldest methods for experimental stress analysis, which can be further developed to delineate the various defects in SiC wafers through direct visualization of the stress associated with corresponding defects. PLM is based on the principle of the stressed region of an optically isotropic material becoming anisotropic and showing double refraction. This phenomenon can be easily detected using two crossed polarizers. Usually a defect in the crystal will induce lattice deformation around its location, and the resulting distortion produces a strain field in the crystal around the defect. Hence, the defect can be indirectly visualized by the strain distribution pattern around the defect using PLM. The sensitivity of the technique for detecting individual dislocations increases with the hardness, the photoelastic constant of the material and the magnitude of the Burgers vector of the dislocation. The very high hardness and the transparent or semitransparent properties of SiC material makes it well suited for PLM, especially for revealing micropipes and screw dislocations in most common *c*-axis cut SiC wafers.

Most defects in SiC wafers can be delineated by PLM, which include micropipes, closed-core screw dislocations, stress striations, grain boundaries or dislocation walls, and highly-stressed zones [reference 1, 2]. As shown in Figure 1, micropipes are usually highlighted as a butterfly shape (Fig. 1a), larger than the wave-shaped dislocations (Figs. 1b and c). Dark and bright regions demarcated along a straight line are observed at different locations even in good quality wafers. Such brightness-striated regions are called stress striations (Fig. 1e). The difference between a dislocation wall or grain boundary (Fig. 1d) and a stress striation (Fig. 1e) is that, in the former, the dislocations lie on a straight line with the individual dislocation stress features approximately perpendicular to the line, while in Fig. 1e, the individual dislocation features are not delineated by PLM. A highly stressed zone (Fig. 1f) usually indicates high residual strain, but not necessarily a high density of micropipes or screw dislocations.

The validation of dislocation delineation by the PLM can be verified by comparison of images obtained from the same regions of given substrates using both PLM and X-ray topography provided by synchrotron white beam X-ray topography (SWBXT) [reference

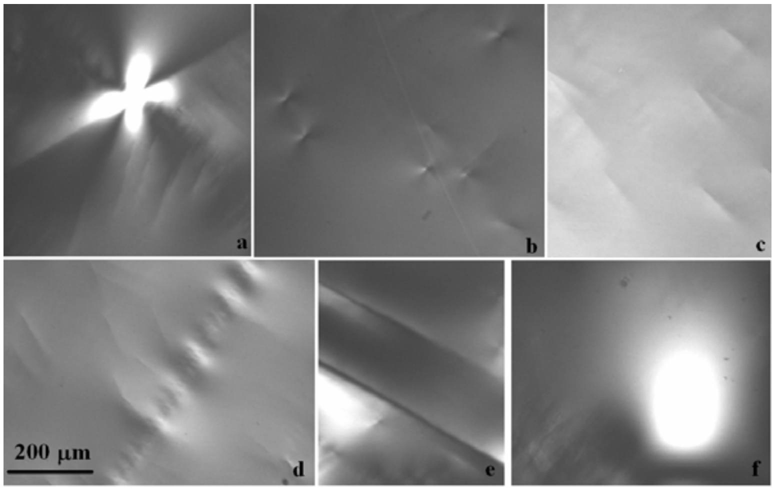
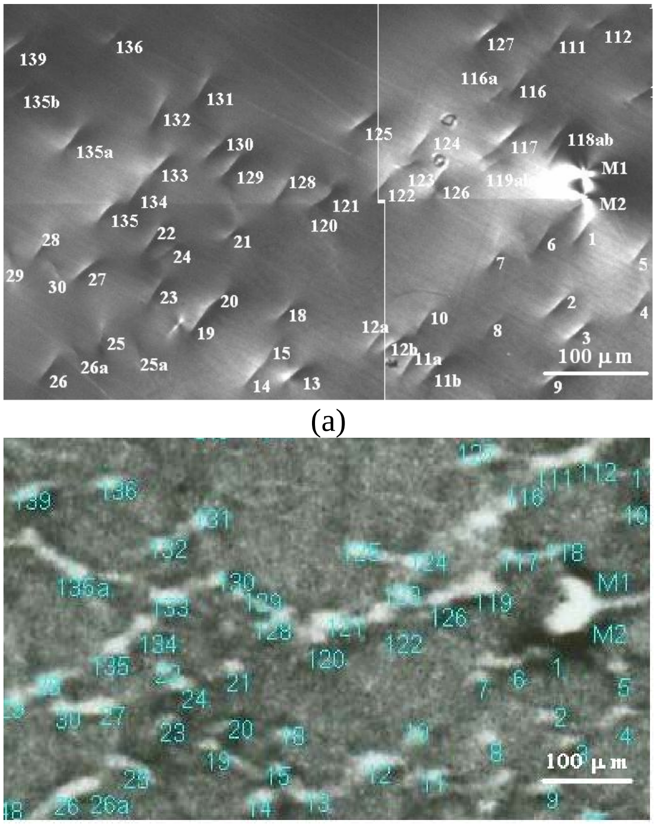


Figure 1, Typical PLM defect patterns observed in a 6H SiC (0001) wafer (a) micropipe, (b) closed-core screw dislocations, perpendicular to wafer, (c) closed-core screw dislocations, slightly off *c*-axis, (d) dislocation wall, (e) stress striations, (f) highly stressed zone.



(a)

(B)

Figure 2, Defect delineation comparison between SWBXT and PLM, (a) PLM image, (b) SWBXT image

2, 3]. Figure 2a shows a birefringence image recorded from a 6H-SiC sample, representing an area of 0.6mm×0.4 mm with 2 micropipes (M1, M2) and approximately 60 closed-core screw dislocations (each marked with a number). Fig. 2b shows the back-reflection SWBXT image recorded from the same region. In Fig. 2b, the black rings with white centers of varying diameters show the contrast from 1*c* to n*c* Burgers vector screw dislocations. The white line is the corresponding residual contrast from basal plane dislocations, while the large irregular shape corresponds to a group of screw dislocations with Burgers vector of >2c, i.e. micropipes. The micropipes and screw dislocations in Fig. 2b, corresponding to those in Fig. 2a, are marked with the same number. By comparing the defect pattern distribution, there is an approximate one-to-one correspondence in super screw delineation between the images obtained by PLM and SWBXT. The above results indicate that the micropipes and elementary screw dislocations delineated by PLM are comparable with that by back-reflection topography provided by SWBXT.

PLM is powerful in defect delineation (1c screw dislocation delineation) and nondestructive in nature. It enables fast response in material and device development and provides an excellent balance between quality control and cost-effectiveness. This technique can be used at multiple stages of semiconductor material and device development, which include:

- Bulk wafer evaluation for material growth and commercialization: rapid, non-destructive, high resolution, wafer-scale, defect identification & mapping
- Wafer selection prior to epi-growth
- Investigation of defect generation in the epitaxial layer
- Optimization of epi-growth process (GaN & SiC)
- Epi-wafer selection prior to device fabrication
- Device/defect correlation investigations
- Fundamental defect study

PLM has been patented (pending) by University of South Carolina. For commercial availability of this technology, please contact USC IP Office. For detailed applications of PLM, please visit http://www.maxmiletech.com/applicationnotes.htm.

Reference:

[1]. "Nondestructive defect delineation in SiC wafers based on an optical stress technique, " *Applied Physics Letters*, vol. 80(18), 2002: 3298-3300.
[2]. "Nondestructive defect characterization of SiC substrates and epilayers", *Journal of Electronic Material*, Vol. 33, 2004: 450-455.
[3]. "Extended SiC Defects: Polarized Light Microscopy Delineation and SWBXT Ratification", *Japanese Journal of Applied Physics Letters*, Vol. 42, 2003: L1077-L1079.