X-ray Microdiffraction Studies of Strain and Texture in Al Interconnects

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Introduction

Stress induced by differential thermal expansion and electromigration is a major factor that influences metal interconnect voiding and failure in integrated circuits. Detailed information on interconnect microstructure, such as intergrain and intragrain crystallographic orientation, plastic deformation and strain, is essential to form a quantitative understanding of such failures and to improve the long-term reliability of electronic devices. In particular, high spatial resolution orientation and residual strain/stress *tensor* measurements are needed for modeling void formation and for predicting interconnect evolution under realistic operating conditions. Yet, detailed information of this sort has not been available because actual interconnects are buried beneath an amorphous glass layer that makes it virtually impossible to use electron probes. Strain and stress measurements reported using the bent beam technique [1] provide average values for interconnect stress, and strain measured using ~10 µm resolution x-ray microbeams [2,3] have provided single strain components for individual grains. Micro-Raman measurements [4] provide hydrostatic stress with a resolution of ~1 micron; however, they do not provide information on local triaxial stress in individual grains.

X-ray microbeams represent a powerful new technique for investigating texture and strain at the sub-micron level. X-ray microbeams are particularly well suited for grain to grain analysis in metal interconnect wires. The ability to combine white and monochromatic measurements allows the measurement of both dilatational and deviatoric strain [5], in addition to obtaining detailed measurements of local grain orientation and texturing. We have initiated measurements that characterize grain-to-grain orientation and triaxial strain measurements in individual grains of Al interconnect lines.

Methods and Materials

X-ray microbeam measurements were carried out on the MHATT-CAT beamline 7-ID microprobe at the Advanced Photon Source, Argonne National Laboratory. Focused x-ray microbeams were produced using elliptically-figured Kirkpatrick-Baez (KB) mirrors [6]. The results discussed here were obtained using a submicron beam size of 0.7 by 0.7 μm^2. The measurements were performed on a commercially fabricated microchip containing areas with 2 µm wide Al wires and 100 µm wide Al pads on a (100) silicon substrate. The sample was mounted on a 0.05 µm resolution x-y-z translation stage, and x-ray microbeam measurements were made by translating along interconnect lines or pad areas. At each location, white-beam Laue patterns were taken using a CCD x-ray detector in order to determine the orientation of individual grains and to extract the triaxial strain. In addition, energy scans were performed on selected Bragg reflections using the monochromatic beam mode with ~2 eV energy resolution. Details of the orientation, indexing, the extraction of deviatoric strain from Laue patterns, and of the determination of dilatational strain from energy measurement are described elsewhere [5,7].

Results

The grain structure of the interconnects is detected readily in the x-ray microbeam experiments. As shown in Fig. 1, the 100µm-wide Al pad was composed of grains with sizes ranging from sub-microns to tens of microns. In addition to the rather large (~5-10°) tilts between the individual grains, the measurements detect systematic rotations of the grains with a range of about 1°. These intra-granular rotations have not been discussed previously to our knowledge.

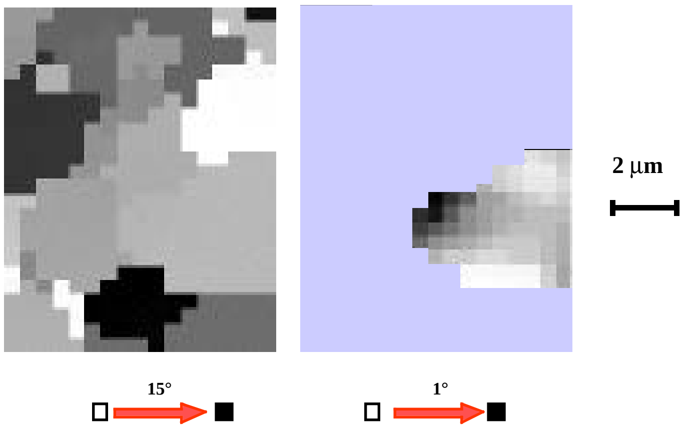

Fig. 1 The inter-granular tilts are clearly seen in wide angle (0-15°) map of the 100µm-wide Al interconnect. A small angle (0-1°) map to the right highlights the intra-granular bending of the largest individual grain in the left map.

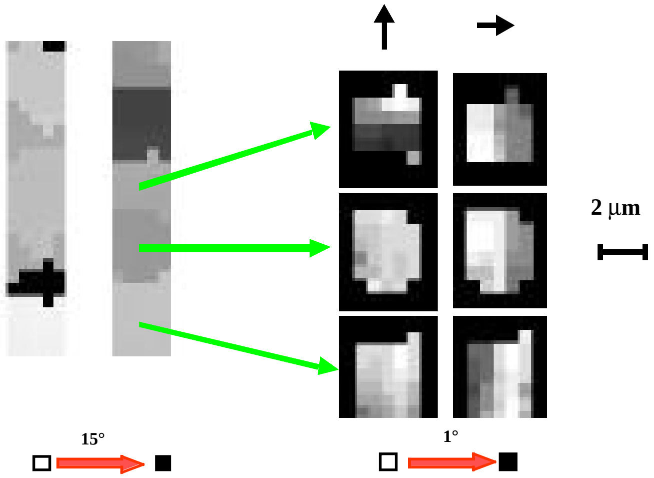

Fig. 2. The bamboo structure and rotations within individual grains in 2-µm-wide Al interconnect wires.

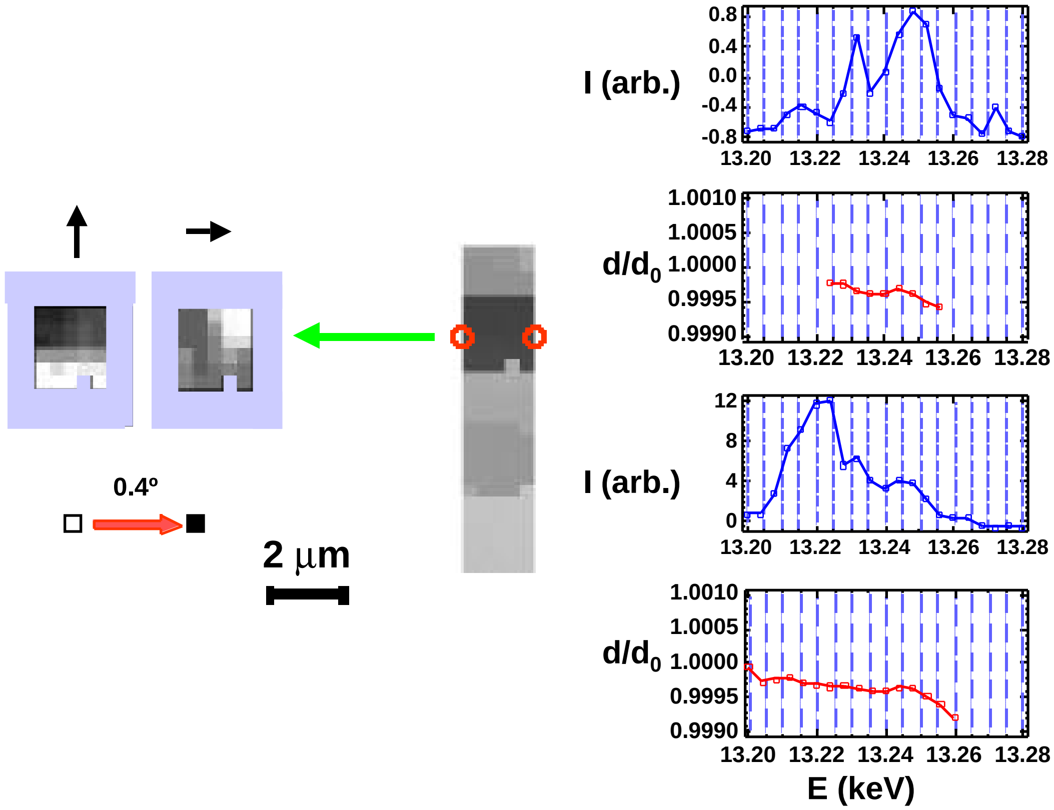

Fig. 3 Energy scan for the (3 3 3) reflection at two locations within a single grain in a thin wire. Intragranular orientation variations along, and perpendicular to, the direction of the wire are indicated by the 0.4° variation between the lightest and darkest regions. Energy scans at two locations and the corresponding d/d_0 are displayed. The average d/d_0 value for all subgrains and locations is about -4×10^{-4}.

The 2µm-wide interconnect wires are characterized by a bamboo structure. These wires also show intra-granular bending. The deviatoric strain tensor within a single grain can be determined from the Laue pattern alone[6]. However determination of the hydrostatic strain component requires measuring the energy of at least one reflection in addition to the Laue pattern.

As shown in Fig. 3, the position and energy dependence of a reflection can be mapped out to determine the local strain and orientation distributions. Although the results shown in Fig. 3 are preliminary, they indicate that the observed spread in the diffracted beam is primarily due to plastic bending of the grains. A correction due to the angular divergence (~0.5 mrad) of the incident beam must be included in a final data analysis.

Discussion

X-ray microdiffraction with the polychromatic microprobe station at beamline 7-ID will allow quantitative and nondestructive measurements of the evolution of grain morphology, strain and orientation. This new information is essential to formulating a fundamental understanding of the factors affecting the reliability of advanced metal interconnects.

Acknowledgments

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