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INFLUENCE OF TRIPLE JUNCTION STRUCTURE ON CU SEGREGATION IN AL THIN FILMS †

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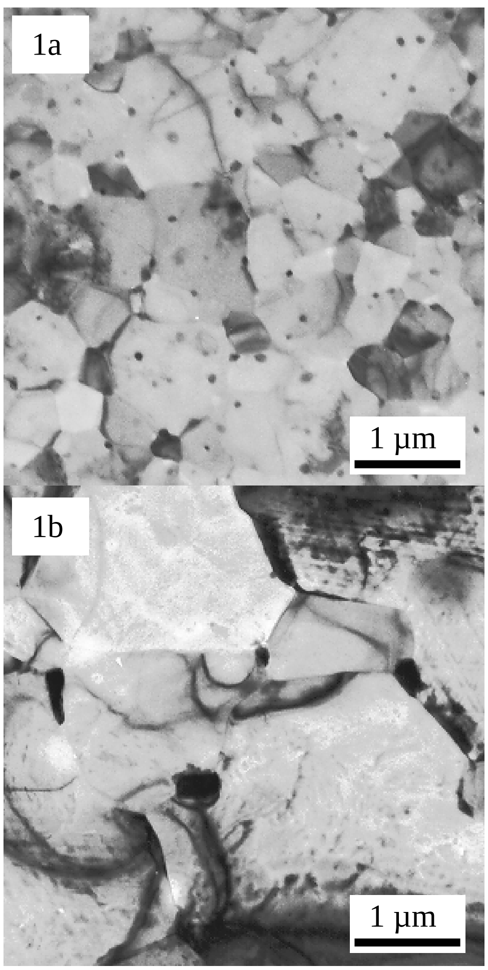
Al thin films, used as interconnects in integrated circuit devices, are subject to voiding failures due to electromigration and stress. Electromigration is a diffusion process and voids are known to form at points of flux divergence such as triple junctions. Void formation in Al-Cu films has also been associated with θ-phase (Al_2Cu) precipitates [1], which form preferentially at grain boundaries and triple junctions. Some triple junctions are favored as nucleation sites [2], presumably due to energetic differences arising from the crystallographic nature of the junctions. Their character can be calculated from the crystallographic orientations of the surrounding grains and the associated grain boundary dislocation networks [3]. Bollmann's method of analysis results in two categories of triple lines: I-lines - the special case where the grain boundary dislocations balance; and U-lines - the general case where the dislocation arrays do not balance. U-lines should have higher energies than I-lines and should therefore behave differently [3, 4]. This paper investigates the relationship between triple-line character and the location of Al_2Cu precipitates at certain triple junctions in Al-1Cu thin films.

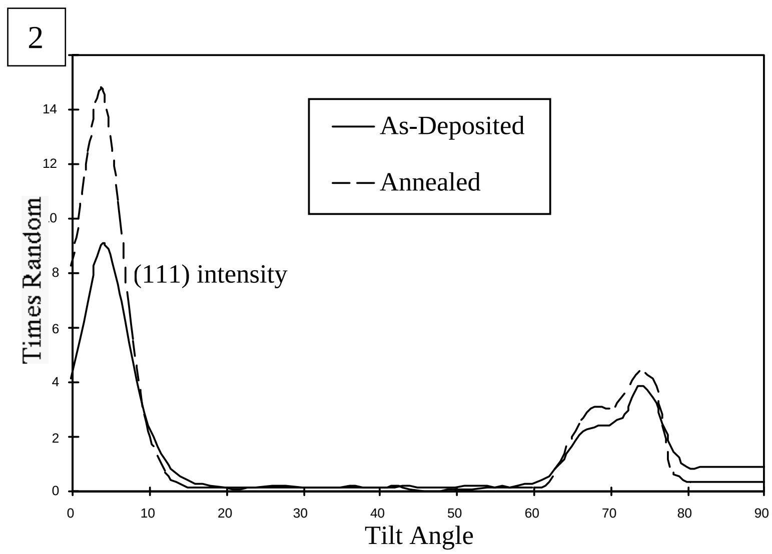
An Al-1Cu film was sputter deposited on oxidized Si wafers at room temperature at ~1μm/min to a thickness of 0.4μm. The film was annealed at 450°C for 30 minutes under 0.4 SLPM Ar flow to homogenize the Cu distribution, then cooled to 200°C and held for 11 days also under Ar flow to allow Cu segregation and precipitate growth. Plan-view specimens were examined by TEM at 200kV. The orientations of the grains around the triple junctions were determined from Kikuchi patterns obtained in convergent-beam mode. Overall crystallographic texture was measured using X-ray pole figure analysis.

Precipitates in the as-deposited state (fig.1a) seemed to be distributed throughout the film, although cross-section TEM showed that they were confined to the top surface and bottom interface rather than in the grain interiors. After heat treatment, precipitates were found almost exclusively at triple junctions (fig.1b). The mean grain size of the film increased from 0.4 μm to 1.0μm, and the as-deposited (111) fiber texture sharpened (fig.2). Fig. 3a shows three triple junctions, two with precipitates and one without; the Bollmann analysis revealed all junctions to be U-lines. Figure 3b shows a junction with no precipitate, characterized as an I-line. The proportion of I-lines was approximately 15%. This is in reasonable agreement with a computer simulation of triple-line character distribution [5] which predicted that the proportion of I-lines would be 12.5% for sharp (111) fiber texture (grains with (111) axes within 10° of the fiber axis). The predicted proportion of I-lines decreased with weaker texture. The films in this work had a sharp (111) texture, with most grains having (111) axes within 10° of the fiber axis (fig.2). However the 4° (111) peak offset, commonly observed in Al films deposited on SiO_2, may affect the predicted I-line proportion.

In summary, junctions with precipitates were always U-lines, and I-lines never contained precipitates. Presumably the disordered structure of the U-lines is energetically more favorable for precipitates than the more ordered structure of the I-lines. However, not all U-lines contained precipitates. This result is similar to Palumbo and Aust's [6] observation of corrosion at U-lines and not I-lines, but not at all U-line triple junctions. Obviously, not all U-lines are alike. This limitation of the Bollmann analysis is partly due to the “black and white” nature of the grading scale, and partly because the I/U-line model is based strictly on the geometry of the interpenetrating lattices of a triple junction. It does not consider the crystallography of the actual triple line direction. This is analogous to the limitations of the coincidence site lattice model for grain boundaries. Several suggestions have been made about how to introduce a “gray scale” in the characterization in order to differentiate between the general U-line cases [7, 8]. These will be addressed in further work.

1. L. Beranbaum and B. Patnaik, App. Phy. Lett., 18, (1971), 284.
2. D. Frear et al., Met. Trans. A, **21A,** (1990), 2449.
3. W. Bollmann, Philos. Mag. A, **49**, (1984), 73.
4. W. Bollmann, Philos. Mag. A, **57**, (1988), 637.
5. E. Doni et al., Scripta Metall., **24**, (1990), 2325.
6. G. Palumbo and K. Aust, Mat. Sci. Eng. A, **113**, (1989), 139.
7. W. Bollmann, Mat. Sci. Eng. A, **113**, (1989), 129.
8. G. Palumbo and K. Aust, Scripta Metall., **24**, (1990), 1771.
9. RK thanks the NIST Office of Microelectronics Programs





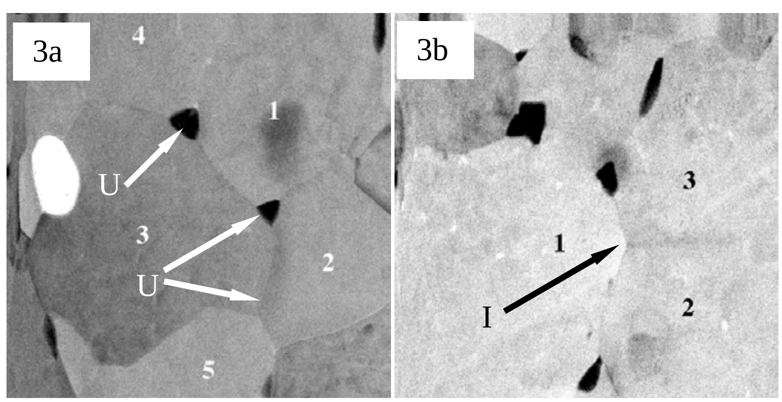


Fig.1. TEM**(a)** as-deposited film, **(b)** annealed film; **Fig.2**. X-ray pole figure, linear fiber plot: offset (111) fiber texture; **Fig.3.** STEM images **(a)** U-line triple junctions **(b)**. I-line triple junction.