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Surface Displacement in Indented Thin Films: Comparison Study of TEM Microstructure and Triangular Dislocation Loop Model

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Abstract – Surface displacement in indentation is important factor for derivation of Young's modulus and Hardness, which is influenced by residual stress owing to material plasticity. In present study, triangular dislocation loops are constructed from L-shape angular dislocations in semi-infinite half space [1], and elastic displacement is calculated (Fig.1). The cross-section view of Al film on Si substrate (Fig.2) shows continues surface pile-up, whereas intensive local shear displacement in Al_2Cu film (Fig.3). Surface displacement of the films is two times larger than that derived from theoretical one, which might be responsible for that repulsive force is operated on dislocation motion toward substrate.

Indentation method is conventionally utilized to determine the Young's modulus and hardness, however there exists great difficulties in evaluation for thin-film material, since load-displacement curve includes the elasticity from the substrate, moreover, the different plasticity in film and substrate yields the pile-up effect in the vicinity of loading area, hence derivation of contact area would be failed.

Present study focuses on the estimation of pile-up displacement in thin films, then direct observation has been conducted to indented films with different ductility of Al and Al_2Cu on Si substrate. Derivation of theoretical displacement owes to the triangular dislocation loop model (Fig1), where plastic portion of the displacement is demonstrated by total sum of burgers vector whereas elastic portion is by embedded loops in half space. Loops are arranged so that the segment of triangular loop contacts with a hemisphere (Fig1.b).

Sample preparation for TEM owes to FIB method, and cross-section of x_2 surface (see, fig1a) is milled and observed by TEM. Total depth in indentation is almost consistent with the film thickness of 400[nm].

Al film (Fig.2) shows continuous pile-up on the edge of contact area, and columns of Al suffer significant shear displacement beneath the indenter tip. On the other hand, morphology of pile-up displacement in Al_2Cu yields discontinuous steps on the free surface, where shear displacement is localized and each column are subdivided. However, Si substrate is still elastic since no evidence of induced dislocation is observed beneath the indentation tip.

The pile-up displacements observed in Al and Al_2Cu films yield twice as large as dislocation model, which might be responsible for that imaginary force on interface causes repulsive force on the dislocations.

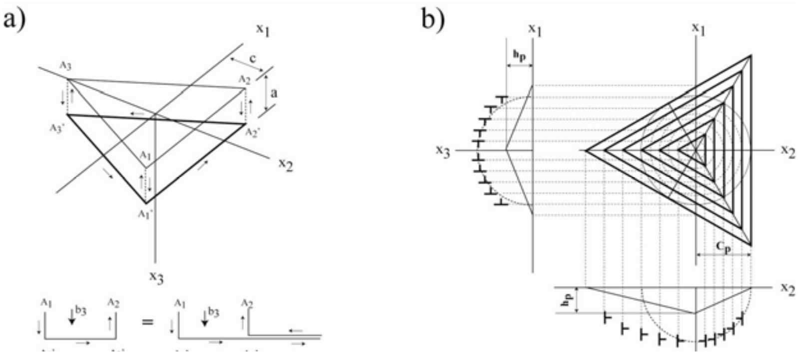

Figure 1: a) Configuration of a triangular dislocation loop, b) distribution of five dislocation loops as an example

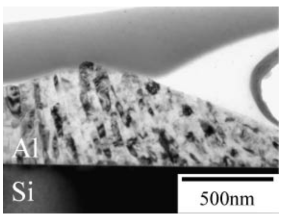

Figure 2: Cross-section TEM image of Al film.

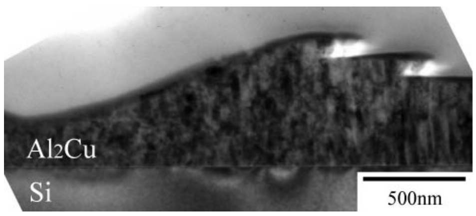

Figure 3: Cross-section TEM image of Al_2Cu film.

[1] T.Mura, N. Yamashita, T.Mishima and Y. Hirose, Int. J. Engng Sci. 27, (1989), 1-9