Analysis of electrodeposited nano-scale copper wire microstructure by EBSD method

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Abstract

The high-resolution electron backscatter diffraction (EBSD) technique was applied to study electrodeposited and subsequently annealed nano-scale copper wires. The mean grain size was found to be coarser than the mean free path of electrons (~ 40 nm). The wires were shown to contain a notable fraction of low-angle boundaries as well as annealing twins. The material was found have a strong {111}<110> texture.

1. Introduction

Copper has been used as an interconnect material for high performance ultra large scale integrations (ULSIs) due to its low electrical resistivity and high reliability. Recent results have also shown that microstructure plays an important role in Cu wire resistivity due to grain boundary scattering because grain or subgrain sizes may become comparable to the mean electron free path (40nm) when wire width is decreased to less than 100 nm. Thus microstructural control becomes an important issue in advanced microelectronic devices. Up to now many important microstructural aspects remain unclear and obviously more research is needed for reliable microstructural control in the nano-scale copper electrodeposits.

2. Experimental

The structure of electrodeposited copper wire (Fig. 1) after annealing at 0.1 deg per second and maximum temperature of 300°C for 10 min in vacuum ($5x10^{-5}$ Torr) was investigated through EBSD technique preceded by chemical mechanical polishing (CMP). To evaluate the possible variations of microstructure and texture in the thickness direction, the observations were made at the trench heights of 50, 100 and 200 nm, which correspond to bottom, mid-thickness and upper parts of the deposits, respectively.

3. Results and discussion

Ignoring twins, the copper wires were only one grain in width and the HABs typically had transverse orientation (Fig. 2). The grain structure of the wires was like bamboo. Taking into account that the wire width was 80 nm, the underlying grain structure was nanocrystalline in nature at least in one (i.e. the width) dimension. The grains contained a developed LAB substructure which was more pronounced in the bottom part of the trench. Another important feature of the deposited grain structure was significant fraction of twin boundaries.

The typical grain and sub-grain lengths were close to 100 nm (Fig. 3, a); the shortest was in the bottom part of the trench. The number fraction of the sub-grains shorter than the mean electron free path (40-50 nm) was ~ 4% (Fig. 3, b).

The misorientation angle distributions featured a pronounced low-angle maximum as well as a sharp peak near 60° (Fig. 4, a). The twin boundaries have primarily originated from the annealing twinning (Fig. 4, b).

The material was found have a strong {111}<110> texture, being ~15 times more random (Fig. 5).

4. Conclusion

The mean grain and sub-grain sizes were measured and found to be much coarser that the mean free path of electrons (i.e. 40 nm).

The microstructure featured a large fraction of annealing twins as well as a significant proportion of highly mobile 40°<111> boundaries.

The <110> direction was always parallel to the wire axis whereas the {111} plane was aligned either with the side walls or the bottom surface depending on the trench height.

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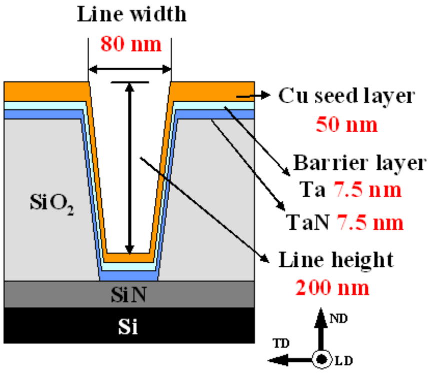

Fig. 1 Schematic representation with a superimposed reference frame of a trench cross section before electroplating.

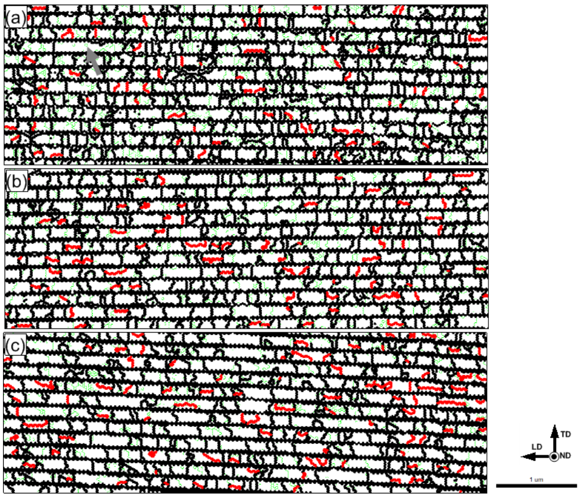

Fig. 2 Grain boundary EBSD maps illustrating microstructure at different heights of the trenches: (a) 50 nm; (b) 100 nm; and (c) 200 nm. In the maps, LABs, HABs and Σ3 twin boundaries are depicted as green, black and red lines, respectively. The inter-trench spaces appear as black.

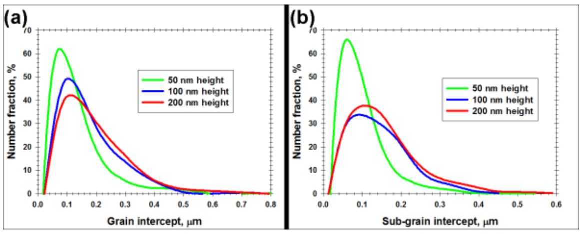

Fig. 3 Distributions of (a) grain size and (b) sub-grain size measured at different heights of trenches using the linear intercept method.

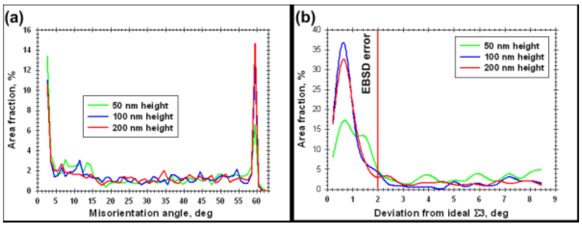

Fig. 4 (a) Misorientation angle distributions and (b) deviation of measured twin misorientations from the ideal Σ3 relationship.

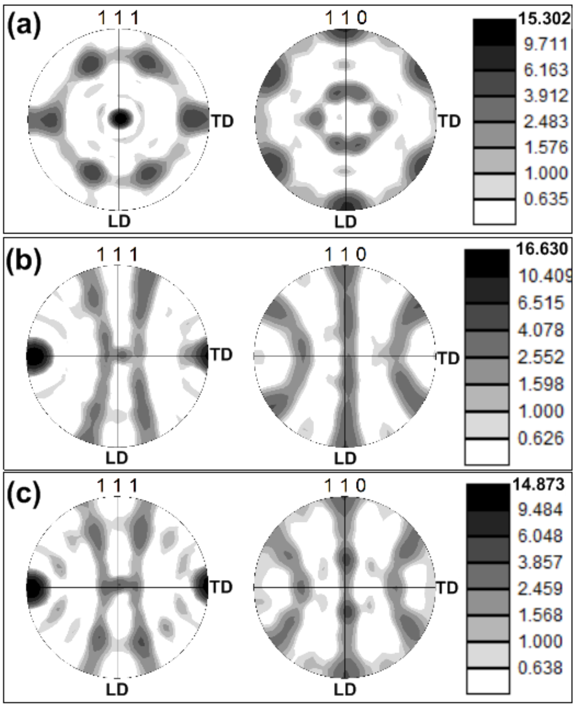

Fig. 5 111 and 110 pole figures illustrating texture at three trench heights: (a) 50 nm; (b) 100 nm; and (c) 200 nm.