High Tensile Strength of Drawn Gold

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Abstract This paper studies the microstructure of drawn gold wires to equivalent strain of 10 and to equivalent strain of 8.5 then heat-treated. The texture of gold wire drawn to strain of 10 is mainly composed of <100> and <111> fibers. Tensile strength of the gold wire increases with <111> fiber fraction, while the grain size does not appear to affect the tensile property. With an exception at heat treatment at 600\degree C, the texture of gold wire drawn the strain of 8.5 is replaced with <100> fiber component by heat treatment process at 400–700\degree C. Heat treatment at 600\degree C produces <110> fiber or <112> fiber, depending upon annealing time.

Introduction

Gold wire is widely applied in electronic packaging process to interconnect micro-electronic components. It basically provides conducting path for electronic signal transfer, while it experiences thermal-mechanical load during service. The mechanical stability of gold wire is a matter of practical concern in the reliable functioning of electronic devices.

This study has investigated the effect of thermo-mechanical processing on the microstructure of gold wire. It examines the texture distribution and grain distribution and correlates them with tensile property on this extensively applied material in microelectronics.

Experiments

Specimens we have investigated are 25\mu m diameter gold wires that have been drawn to equivalent strain of ~10 and that drawn to strain of ~8.5 then heat-treated. Post heat-treatment were carried out at different temperatures between 400–700\degree C. Two different modes were chosen for the anneal process. One is a continuous heating condition, and the other is isothermal annealing at a given temperature. In a continuous heating condition, samples were placed in Lyndberg furnace with 3\degree C/min heating rate, which then removed from the furnace at each of the desired temperatures of 400\degree C, 500\degree C, 600\degree C, and 700\degree C. At an isothermal condition, samples were isothermally annealed for 30min to 1 hour. The microstructure of gold wire was evaluated at cross-section
perpendicular to drawing direction. For this observation EBSD system (Oxford, Inca) installed in high resolution FE-SEM (JEOL 6500F) was used. Raw data from EBSD was reprocessed by post-processing program, REDS (Reprocessing of EBSD Data in SNU), developed at Seoul National University, for the quantitative characterization of texture distribution and grain boundary misorientation.

Results and Discussion

25µm diameter gold wires

(1) Relationship between texture component and tensile strength

It is reported that <111> and <100> fibers are usually developed in drawn FCC metal and their volume fractions are varied by the stacking fault energy difference. Gold has the medium low stacking fault energy and final fraction of <111> drawing texture is about four times much more than <100> [1-3]. In this study, texture components of three different 25µm diameter gold wires are given in Fig. 1. Each wires have been made from three different thermo-mechanical processes, however, all of them are controlled to exhibit similar elongation property at failure (~4.5%). The microstructural characteristics commonly observed at these wires are <112> fiber at outer rim, <100> fiber at center region and <111> fiber between center and outer rim. However, the amount of each texture components becomes distinct by varying drawing process. Fig. 2 presents the relationship between texture and tensile strength. It suggests that the tensile strength of gold wire is proportional to <111> fiber fraction, and inversely proportional to <112> fiber or <100> fiber. Fig. 3 shows the grain size vs. the tensile strength. Grain size the tensile strength of gold wire.

![Fig. 1 Texture components in gold wire cross-section](image)

Fig. 1 Texture components in gold wire cross-section; 1st column is the overall texture distribution, and 2nd~4th column is the dividing of wire cross-section into the area with respect to each texture component of <100>, <111> and <112> fiber texture.
Fig. 2 Relationship between tensile strength and texture. The tensile strength is in proportion to the <111> fiber fraction, inverse proportion to <100>, <112> fibers.

Fig. 3 Relationship between tensile strength and mean-grain diameter of gold wire.

(2) CSL boundary and grain size distribution

Fig. 4 provides CSL boundary distribution at the cross-section of sample #1, #2 and #3 in Fig. 1. The texture contour of gold wire shown in Fig. 1 also can be distinguished by CSL distribution. When considering CSL boundaries up to Σ45, large amount of CSL is concentrated at <111> texture predominant region, whereas center area in which the primary texture is <100> shows rare CSL developments.

Fig. 5 provides <100> texture at different drawing speeds. As drawing speed becomes faster the amount of <100> component at the center region of cross-section increases. This may be due to the deformation inhomogeneity at faster deformation rate. For a given drawing magnitude, faster deformation rate causes more intensive shear deformation at the surface area directly contacting with drawing die. Deformation at center becomes smaller at faster drawing rate with the consequence of more <100> fiber fraction with less CSL boundaries.

Fig. 4 CSL boundary distribution at the cross-section of wire. CSL boundaries are mainly Σ3, Σ7, Σ13, and Σ21 components indicated by black segments.
Fig. 5 <100> texture distribution of gold wire at different drawing speeds, (Black dots are <100> components).

Fig. 6 Grain size distribution of three different wires.

Fig. 6 is the relationship between grain size and distance from the center of drawn gold wire (25µm). Grain size becomes smaller at outer side. The reason for this may be associated with different deformation magnitude along the radial direction. While the outer rim goes through the extensive shear deformation by direct friction with drawing die during drawing process, midpoint of wire may experience less shear deformation than that at outer side. The driving force for (dynamic) recrystallization is minimal at center region with the result of larger grain size. This discussion appears to be reinforced by CSL distribution in Fig. 4. The center of cross-section is almost free from CSL boundaries which are usually resulted from plastic deformation, more extensive at outer side.

It is not entirely clear that <100> texture at the center area of drawn gold wires appears to be associated with initial as-cast texture <100>. CSL boundaries that indicate plastic deformation and dislocation rearrangement are hardly observable at this area (Fig. 4). Moreover, larger grain size at center region also suggests the least amount of deformed-recrystallized processing. The High possibility is that center area does not experience extensive plastic deformation during drawing process with the consequence of the remaining of initial microstructure.

Heat-treated gold wire with 80% reduction in area

The textures of gold wires, which have been annealed at continuous heating condition, are presented by inverse pole figures in Fig. 7. Gold wire with equivalent strain of 8.5 is selected as base material, it shows initial <100> and <111> mixed textures. However, <100> component becomes predominant when specimens are heated to wide range of the temperature of 400°C~700°C, with the exception at heating to 600°C by which <110> texture is extensive. The predominant <100> recrystallized-texture at low annealing temperature is due to the faster growth rate of pre-existing or newly-nucleated <100> fibers growing into <111> region [4].
Fig. 7 Texture variation by heat treatment. Temperature was raised from 25°C to (a) 400°C, (b) 500°C, (c) 600°C, (d) 700°C. Temperature increasing rate was 3°C/min.

Fig. 8 provides the texture change of drawn wire under isothermal annealing condition. Previous studies suggested that the deformed-recrystallized texture of FCC metals, such as aluminum, copper, etc., are <111> at relatively high temperature annealing [5] and <100> at low temperature annealing, respectively. However, the result of current study shows deformed-recrystallized texture of gold wire is different from those at usual FCC metals. Fig. 8 suggests initial <100> and <110> fibers converting to the <112> components at the annealing condition of 500°C and 600°C, while the initially formed recrystallized texture <100> remains stably at the annealing condition of 700°C for an hour.

Fig. 8 Texture change of drawn and heat-treated gold wire. (a) 500°C (b) 600°C (c) 700°C
Conclusion

The followings are conclusion we have drawn at current study.

1. <111>, <100> and <112> are the major texture components of 25µm drawn gold wire with equivalent strain greater than 10. It was found that tensile strength of wire was proportional to the <111> fraction.

2. Large amount of CSL boundaries was found in the <111> predominant region, whereas center region with predominant <100> was almost free from CSL boundaries.

3. By continuous heating of drawn gold wire (80% RA) at heating rate 3°C/min, <100> component became predominant when samples were heated to 400°C, 500°C and 700°C. However, a specimen heated to 600°C exhibited predominant <110>.

4. By isothermal annealing condition, <110> component which had been initially developed at 600°C converted to <112>. At 700°C annealing condition, <100> is predominant notwithstanding the long annealing time.

References

[2]. F. Haessner, Z Metallk, 54, 98 (1963)