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THE EFFECT OF STRESS DISTRIBUTION ON TEXTURE EVOLUTION OF Cu DAMASCENE INTERCONNECTS DURING ANNEALING

WPŁYW NAPRĘŻEŃ NA TRANSFORMACJĘ TEKSTURY DAMASCEŃSKICH POŁĄCZEŃ MIEDZIANYCH W OBWODACH ELEKTRONICZNYCH PODCZAS WYŻARZANIA

Textural changes of Cu interconnect having different line width was investigated after annealing. Texture was measured using XRD (x-ray diffraction) and the surface texture was investigated using EBSD (electron backscattered diffraction) techniques. To analyze a relationship between the stress distribution and textural evolution observed in the samples, the stresses were calculated for the different line width at 200°C using FEM (finite element modeling) along the width and depth of the line. In this investigation, it was found that the inhomogeneity of stress distribution in Cu interconnects is an important factor necessary for understanding textural transformation during annealing. Textural evolution in damascene interconnects lines after annealing is discussed, based on the state of stress in Cu electrodeposits.

Keywords: Cu damascene interconnects, Texture, Stress, EBSD, OIM, FEM

Zmiana tekstury w elektronicznych połączeniach miedzianych o różnej szerokości była badana po wyżarzaniu. Textura była mierzona przy użyciu dyfrakcji rentgenowskiej, a tekstura na powierzchni metodą EBSD. Związek pomiędzy rozkładem naprężeń a obserwowaną ewolucją tekstury w próbkach był analizowany metodą elementów skończonych na drodze obliczeń naprężeń w połączeniach o różnej szerokości, w temperaturze 200°C. Obliczenia wykazały, że niejednorodność rozkładu naprężeń w miedzianych połączeniach elektronicznych jest niezbędnym czynnikiem do zrozumienia transformacji tekstury podczas wyżarzania. Ewolucja tekstury w damasceńskich połączeniach miedzianych obwodów elektrycznych po wyżarzaniu jest rozważana w odniesieniu do stanu naprężeń w elektrolitycznie osadzonej miedzi.

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1. Introduction

As the features of the integrated circuitry (IC) chips are scaled down to submicron dimensions, the manufacturer demands new technology to meet performance and reliability requirements for the electronic interconnects. According to these demands, the copper damascene process became an important issue in the integrated circuitry chips industry since it allows a decrease in RC (resistance and capacitance) delay losses, reduces the number of processing operations and increases the lifetime of the interconnect lines [1]. Since the Cu damascene process has been introduced in the IC chips industry, significant research on the relationship between texture and reliability of copper interconnects has been undertaken. It is found that strong {111} texture increases the resistance of electromigration failure in aluminum thin films [2]. However, such a relationship for the Cu hasn't been firmly established and the driving forces which can affect the textural evolution during annealing were not clearly identified until now [3-5]. In this study, the details of textural evolution will be examined using XRD and EBSD technique, and the stress contribution to the evolution of texture during annealing will be discussed.

2. Experimental Procedure

Two different types of samples, one as-deposited and another annealed having a different cross- sectional profile and line widths, as shown in Figure 1, were used for

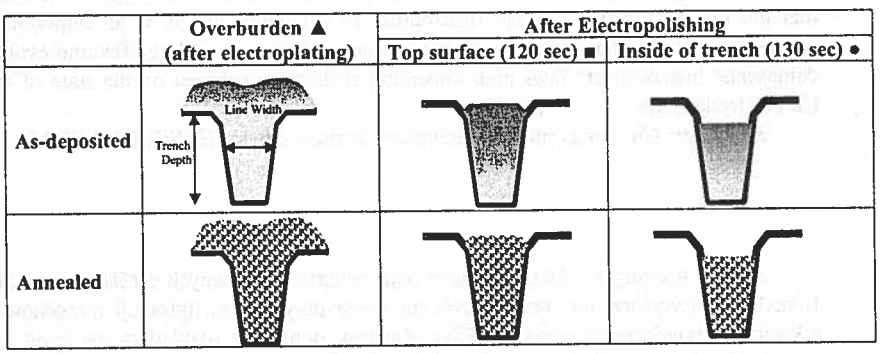

Fig. 1. Schematic diagram of the cross-sectional profile of Cu interconnects

this investigation. All samples were fabricated using the same conditions and were kept at room temperature for 6 months. TaN, 400Å thick, was deposited on the surface of the Si (100) wafer as the barrier layer, and then a copper seedlayer was deposited on the barrier layer. The trenches were filled with copper by electroplating in a sulfuric acid bath using 24mA/cm^2 current density. Then, the samples were annealed at 200°C for 10 minutes in the vacuum furnace to avoid oxide formation on top of Cu interconnects. The samples with different line widths have the same trench depth of 0.7 μm.

The crystallographic texture of copper interconnects was measured using a Siemens D500 x-ray goniometer with a copper tube. To remove the overburden of Cu damascene interconnects, the samples were electro-polished for 120 seconds in a H_3PO_4 solution using 17mA/cm^2 current density. After electropolishing, the top surface area of the trench was analyzed using the orientation imaging microscope (OIM) mounted on a Philips XL30 FEG-SEM to identify the orientation of each grain in the copper interconnects. The stress distribution in interconnects was calculated by FEM using FEMLAB, commercial software.

3. Results

The quantitative texture information of Cu interconnects was collected using XRD and the EBSD technique. At first, three pole figures were measured by XRD and ODF (orientation distribution functions) were calculated, and then the plots of {111} fiber at each cross-sectional profile are constructed to describe through thickness intensity changes, as shown in Figure. 2. The texture of the as-deposited sample shows weak {111} fiber, however, after removing the overburden layer of copper by electropolishing, the fiber intensity increased (Figure 2a). After annealing, the texture of the overburden layer doesn't change much, however, textures of the trench under this layer are transformed. At first, after electropolishing for 120 seconds, specific directions on the {111} texture are developed as indicated by arrows (Figure. 2b). After electropolishing for 130 seconds which means a half depth of the trench, the strength of {111} fiber texture is decreased and a weak {111}< 110 > texture is developed. This can be explained that the constraints generated by the sidewall increase at layers closer to the trench bottom and may affect the texture development of copper in the trench. The obtained results demonstrate the strong through thickness inhomogeneity of texture in the trench after annealing. The possible effect of the stress related to the sidewall constraint on the directional texture development of Cu interconnects will be discussed later.

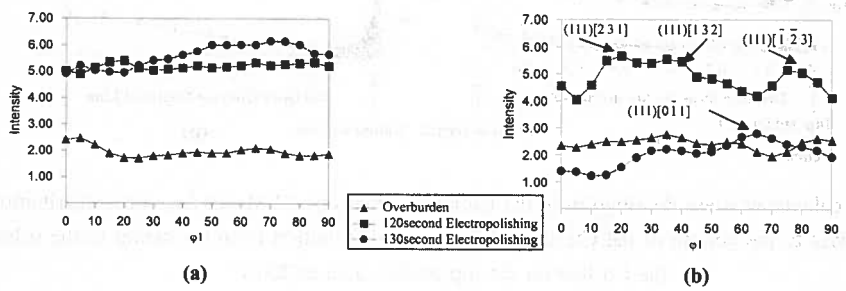

Fig. 2. {111} fiber plots at different cross-sectional profiles of Cu interconnects (XRD): (a) as-deposited, (b) after 200°C annealing

The EBSD results on the top surface of Cu interconnect (Figure 3), indicate that {111}< 110 > textures exist in all samples, however it becomes fiber-like textures as the line width increases. Compared to the "as-deposited" sample, the texture of the "annealed" sample becomes stronger. The maximum intensity is the strongest in the narrowest line and it decreases as the line width increases. The difference of texture's strength between the "as-deposited" and "annealed" is the highest for the narrow lines. In addition, a weak {111} sidewall component was found in the narrow lines, such as 0.14, 0.24 and 0.5 μm line width. It seems that the annealing process minimizes the sidewall contribution to overall texture in the Cu interconnects.

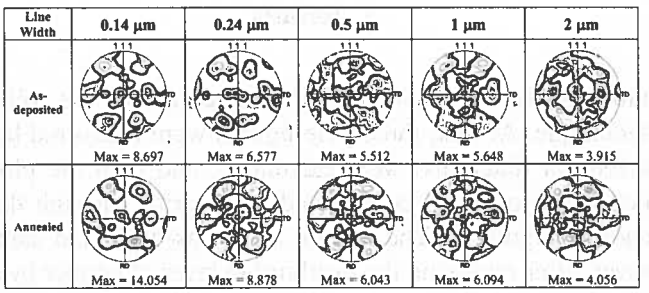

Fig. 3. (111) pole figures of copper interconnects having a different line width (EBSD): as-deposited and annealed samples

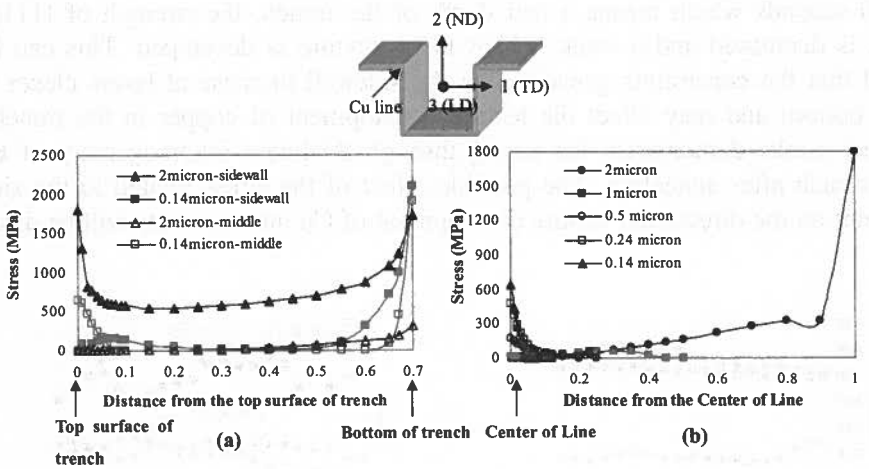

Fig. 4. The calculated stress distribution in the Cu interconnects by FEM: (a) S_{11} stress distribution from the top surface to the bottom of the Cu line (b) S_{11} stress distribution from the center to the sidewall of the Cu line on the top surface area at 200°C

A possible contribution of the stress to the textural evolution during annealing was investigated (Figure 4). In order to examine the stress distribution in the trench,

the FEM was used. In this calculation, it is assumed that the finite element mesh can expand freely along the ND (normal direction) when Cu interconnect with overburden is annealed at 200°C. Since the mirror symmetry is applied along the ND and the LD (line direction), only the half of Cu interconnect line was modeled in this investigation. It was also assumed that the copper interconnect has the isotropic mechanical properties and the expansion coefficients of surrounding silicon oxide is compared to that of copper. Therefore, the data obtained from this modeling should be considered only as a qualitative representation of the stress changes at high temperature. Figure 4a shows that S_{11} stress component distribution at the side and the middle of the trench changes from the top surface to the bottom of the trench. This is shown only for 0.14 and 2μm line width. In the 2μm line width, S_{11} stress component is high at the top and bottom layer of the trench in the near sidewall, however, it is very low in the middle of the line. In the 0.14μm line width, S_{11} stress component is high at the top and bottom of the trench in the middle of the line, however, it is very low at the top in the near sidewall. Also, inhomogeneous stress distribution was found across the line width for each line and the location of the maximum value of S_{11} moves from the sidewall of the trench to the middle as the line width decreases (Figure 4b). From these results, it can be concluded that the stress distribution across the line depth and width is important in each Cu interconnects line. Therefore, the stress state can be a reason for textural evolution.

4. Discussion and summary

The importance of stress on the texture evolution in Cu damascene interconnects have been emphasized by several researchers since differences in the thermal expansion coefficients of copper and dielectric (silicon dioxide) generate stress in the interface area between different layers [4-5]. Lee et al. [6] suggested that the strain energy can be minimized when the absolute maximum principal stress direction is parallel to the minimum Young's modulus direction. The minimum Young's modulus direction of copper is the < 100 > direction. However, the < 100 > orientations are not on the {111} plane. Therefore, it is most probable that grains having < 112 > direction, which is on the {111} plane, and is at the smallest angle with the < 100 > direction, will grow favorably. Therefore, the texture is likely to approach the texture of {111}< 112 > // trench width direction which is {111}< 110 > // trench length direction. In addition, this stress distribution along the trench depth and width is inhomogeneous, as shown in Figure 4. From these results, texture evolution of Cu interconnects after annealing can be explained that S_{11} stress component generated from the constraint of sidewalls along the depth of line and the difference in thermal expansion coefficients between layers along the width of line affects the texture development during annealing. Therefore, the stress distribution along both trench width and depth is im-

portant in the textural evolution since it can produce a different texture inside the trench.

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