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Control of Cu(111) orientation on TaWN alloy barrier

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Abstract

This paper describes the Cu grain orientation control on the thin barrier film with the good barrier properties. We demonstrate a highly oriented Cu(111) interconnects on 5-nm-thick TaWN barrier even in the as-deposited Cu/TaWN/Si specimen. Moreover, this structure can maintain a stable system without Cu-silicide formation even after annealing at 700 °C for 1 h. We can also obtain the high performance barrier properties in Cu/TaWN/Si system. We demonstrated that high thermal stability and highly (111) oriented Cu interconnects can be realized at the same time using a thin TaWN barrier which we could not be obtained so far.

In this study, we examine the relation between the structure of the barrier and the Cu(111) orientation, and clarify the mechanism of controlling Cu(111) orientation on the thin barrier.

1. Introduction

The growth of (111)-oriented Cu interconnects is strongly desired for the improvement of the electromigration (EM) reliability in LSI/3D-LSI metallization.[1] It has been studied so far, but the selectivity of underlying materials for highly oriented Cu(111) is poor. For example, an Nb film is known as an underlying material capable of orienting Cu (111) from the relation of epitaxial growth of Cu (111) // Nb (110),[2-4] but it is insufficient as a barrier material for suppressing the Cu diffusion. On the other hand, TiN and TaN films are well known as diffusion barriers for Cu interconnects, but it was reported that the Cu/TiN and Cu/TaN bilayer cannot achieve sufficient Cu(111) orientation.[5-7]

In our previous study,[8] we examine the growth of a (111)-oriented Cu layer on a thin TaWN ternary alloy barrier for good electromigration reliability. It was revealed that the preferentially oriented Cu(111) layer is observed on a thin TaWN film even in the as-deposited Cu/TaWN(5 nm)/Si system, but the mechanism of the Cu(111) orientation on the TaWN barrier was unknown.

In this study, we examine the control mechanism of Cu(111) orientation on the thin barrier film by examining the details of the degree of Cu(111) orientation and the structure/texture of the TaWN barrier.

2. Experimental Procedure

A HF-solution- and distilled-water rinsed p-Si(100) wafer was used as the substrate. The TaWN film (5-10 nm) was reactive-sputter-deposited using a DC tetrode sputtering system with a Ta-W composite target at a substrate temperature of 400 ºC with an Ar+ N_2 gas mixture. Without breaking vacuum, the Cu film (150 nm) was deposited on the TaWN film at room temperature with Ar gas. The sputtering gas pressure was fixed at 2 x 10^{-3} Torr in any case. The prepared Cu/TaWN/Si specimens were then annealed at various temperatures up to 700℃ for 1 h in vacuum on the order of 10^{-7} Torr. The obtained specimens were characterized using AES, XRD, pole figures, ω-rocking curves, and EBSD.

3. Results and Discussion

First, we describe a characterization of a TaWN barrier film in this study. The composition of the TaWN barrier film determined by AES was $Ta_{30}W_{36}N_{34}$. The resistivity of this film was ~290 μΩcm. This value is extremely lower than those of the other ternary alloy films (Ta-Si-N: 600-2200 μΩcm,[9] Ti-W-N: ~7150 μΩcm[10]).

Figure 1 shows the XRD pattern from the obtained TaWN film (100 nm). The symmetric reflection lines are obtained between the fcc-TaN and W_2N peak positions, particularly close the TaN peak. This suggests that the TaWN alloy basically takes only a TaN structure with random orientation. The details on these have been described elsewhere.[8]

We examine the orientation of the Cu layer on the TaWN film. From the XRD patterns of the Cu/TaWN/Si system, the sharp and strong peak of Cu(111) is observed even before and after annealing (not shown). We evaluate the full width at half maximum (FWHM) of the Cu(111) peak obtained in ω-rocking curve measurement. Table I is the value of FWHM of the Cu(111) peak. The FWHMs in our study show higher crystallinity than that in the case of Cu/TiN, and its value is close to that in the case of Cu/Nb.[5]

To analyze microstructural evolution, the orientation of grains on the top area of the Cu interconnects before annealing were measured by the EBSD technique, as shown in Fig. 2. In the orientation image map in Fig. 2(a), the colors of Cu grains were almost blue or blue purple. This indicates that most of they have approximately the (111) orientations. Also, the {111} pole figure in Fig. 2(b) proves that the pole at the normal direction of surface is almost parallel to <111>. The image map and the {111} pole figure in Cu/TaWN/Si specimens after annealing at 500℃ for 1 h show that the grain size of Cu increases and the pole figure becomes sharp. However, the Cu(111) orientation is basically kept unchanged from the as-deposited specimen. We considered that the good Cu (111) orientation is closely related to the structure and texture of the thin TaWN barrier, then examine the structure of the TaWN barrier. We are analyzing the structure of the 5-nm-thick barrier film, and it is becoming clear that the TaWN barrier also shows (111) orientation.

4. Conclusions

By using TaWN barrier, we succeeded in obtaining highly reliable Cu interconnects and Cu (111) orientation superior in EM resistance at the same time. In particular, the Cu(111) orientation was realized on the TaWN barrier in as-deposited specimen, which was presumed to be due to the fact that the underlying TaWN barrier was mainly (111) oriented.

Acknowledgements

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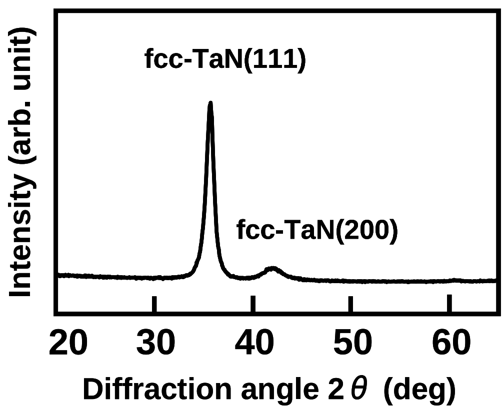

Fig. 1. XRD pattern of the as-deposited TaWN film (100 nm).

Table I. The value of FWHM of the Cu(111) peak obtained in ω-rocking curve measurement.

	TaWN	TiN5)	Nb5)
As-deposited	5.86°	12.6°	3.81°
500 °C	4.68°	-	-
700 °C	4.73°	-	-

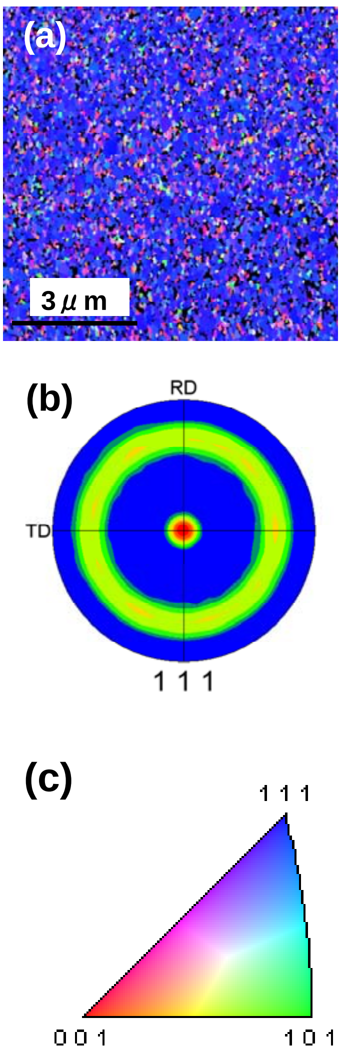

Fig. 2. (a) The inverse pole figure map (ND) of Cu, (b) the {111} pole figure, and (c) the reference figure (color cording).