C-1-04
Extended Abstracts of the 2020 International Conference on Solid State Devices and Materials, VIRTUAL conference, 2020, pp123-124

Barrier properties of thin TaWN films in Cu(111)/TaWN/Si systems

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Abstract

Highly oriented Cu(111) growth is a much-needed issue for Si-LSI metallization and/or 3D-LSI technology as it can improve the reliability of Cu interconnects. We previously reported that TaWN thin film can be an important underlying material for controlling Cu(111) orientation.

In this study, we examined barrier properties of thin TaWN films, which is an underlying material that can realize Cu(111) orientation while being a diffusion barrier material. Also, we investigated the Cu(111) orientation from the viewpoint of TaWN barrier properties. One of the reasons for the high orientation was that large Cu crystal grains had already grown just above the barrier, and no interfacial reaction layer or interdiffusion layer was found at the interface. In addition, the formation of Cu silicide, which causes the collapse of the system, was not observed in the annealing up to 700 ºC, so it was known that the TaWN film of 5 nm is useful as a barrier.

1. Introduction

The orientation control of Cu interconnects has been very demanded in various fields such as in Si-LSI and 3D-LSI technologies,[1,2] because a Cu(111) plane with a densely packed face has high electromigration resistance, but until now it has been extremely difficult. In our previous study, we have succeeded in highly oriented growth of Cu(111) on a thin diffusion barrier film without an underlying material.[3-5] This means that we can choose new solutions to the issue of Cu(111) orientation control.

Meanwhile, we have been developing the TaWN ternary alloy barrier. The TaWN alloy can behave like a single metal nitride by replacing the positions of the Ta and W lattice points. As a result, the TaWN film was confirmed that the structurally stable TaN is the basic structure and that it behaves like a single metal nitride even though it is a ternary alloy.[4] In particular, it has extremely low resistivity among ternary alloys, and thus has promising fundamental properties as a diffusion barrier.

In this study, we focus on verification of the mechanism of Cu(111) orientation on the TaWN film and barrier properties of TaWN film.

2. Experimental Procedure

A TaWN films (5~100 nm) were deposited on a p-type Si(100) substrate by DC tetrode reactive sputtering using a Ta-W composite target with an Ar + N_2 gas mixture. The 150-nm-thick Cu film is deposited on the TaWN film with Ar gas without breaking vacuum. Some specimens were annealed at various temperatures up to 700 ºC for 1 h in vacuum on the order of 10^{-7} Torr. X-ray diffraction (XRD), pole figure, SEM-EBSD, TEM, energy dispersive X-ray analysis (EDX), and automated crystal orientation mapping in transmission electron microscopy (ACOM-TEM) were used to evaluate the crystallographic structure, orientation of film, grain size of the film, the stack structure, and/or the thermal and structural stability of the obtained specimens.

3. Results and Discussion

First, we will give an overview of our previous study.[3-5] We have formed a Cu film on a 5-nm-thick TaWN barrier and investigated the orientation of the Cu film. As a result, we confirmed that Cu film with highly oriented (111) growth was obtained. Up to now, the Cu(111) orientation has been limited to bcc metal with 100 nm thickness such as Nb having an epitaxial relationship.[6, 7] Our results bring a new finding for Cu(111) orientation control. Because, it was suggested that an extremely thin diffusion barrier material could achieve Cu(111) orientation.

The thermal stability of Cu/TaWN/Si structure was examined. Figure 1 shows XTEM images of the Cu/TaWN/Si structure before and after annealing at 500 °C for 1 h. In Fig. 1, the TaWN film does not show the detailed structure and texture due to the difference in etching characteristics from the Cu film, and there is no interfacial layer or interdiffusion layer at the interface, so the desired film thickness of 5 nm is obtained. Regarding the structure of the Cu film, some columnar crystal grains are seen in the as-deposited state specimen, but generally they appear to be one crystal grain just above the TaWN barrier. After annealing at 500 ºC, the size of the Cu crystal grains further increases, and one crystal grain having a size of about 100 nm or more can be seen. This indicates that the Cu crystal grains in the lateral direction are larger due to annealing. Fig. 2 shows a grain size distribution diagram of the Cu film in the Cu/TaWN(5 nm)/Si structure before and after annealing at 500 °C for 1 h. In the as-deposited specimen, the average grain size is about 88 nm and there is little variation. On the other hand, after annealing at 500 °C, as shown in the figure, the variation becomes large, and the average size is 116 nm. On the other hand, figure 3 shows XRD patterns of the Cu/TaWN(5nm)/Si structure before and after annealing at various temperatures up to 700 °C. In this figure, since Cu silicide is not seen, it is presumed that the reaction between Cu film and Si substrate does not occur. In Fig. 3, a very broad peak corresponding to fcc-TaN is obtained from the as-deposited specimen. It can be seen that, as the annealing temperature increases, the reflection line of TaWN slightly shifts to the larger 2θ value, but significant structural change hardly occurs. This implies that the obtained TaWN film has good thermal and structural stability without the grain re-crystallization owing to annealing. We will further discuss the usefulness of the TaWN barrier.

4. Conclusions

We can prepare the TaWN films as a diffusion barrier for Cu interconnects. The Cu/TaWN/Si structure shows a good thermal and structural stability. Also, a remarkable Cu diffusion is not observed even after annealing at 700 ºC for 1 h. These results indicate that the obtained TaWN film is promising candidate for the diffusion barrier applied to the reliable Cu interconnects.

Acknowledgements

Part of this study was supported by JSPS KAKENHI Grant Number 18K04223.

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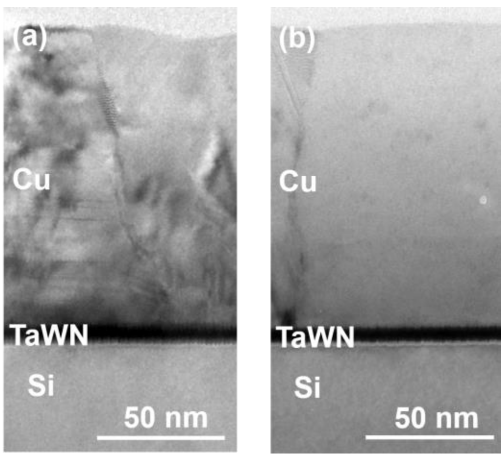

Fig. 1 XTEM images of the Cu/TaWN(5nm)/Si structure. (a)before annealing and (b)after annealing at 500 ºC for 1 h.

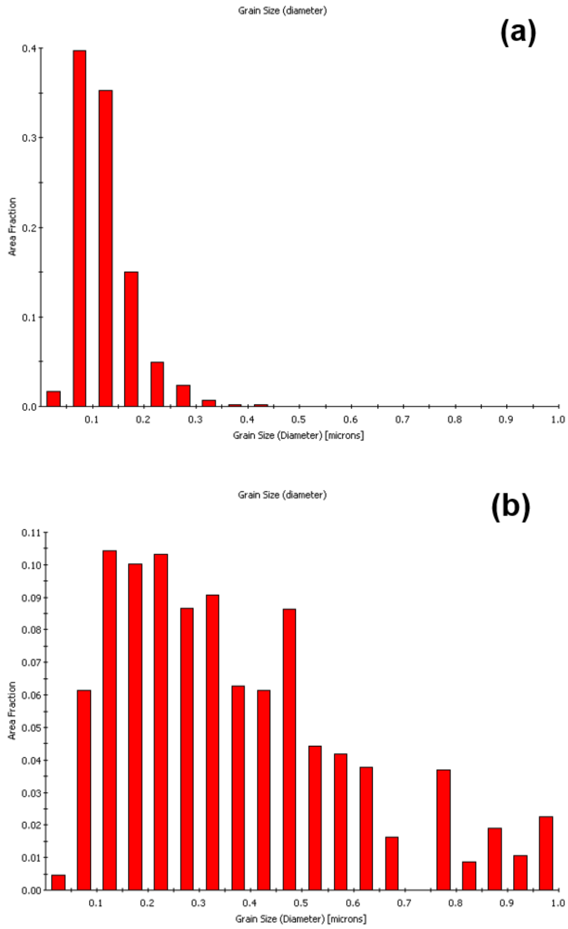

Fig. 2 Grain size distribution chart of Cu films in the Cu/TaWN(5nm)/Si structure: (a) before annealing and (b) after annealing at 500 ºC for 1 h.

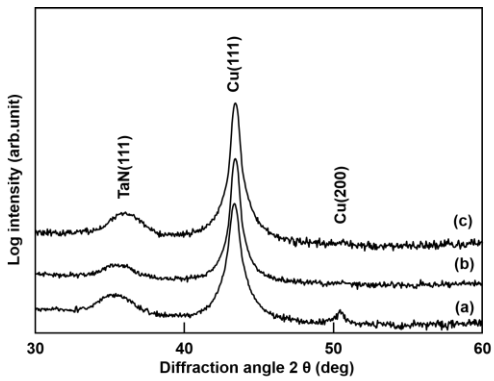

Fig. 3 XRD patterns of the Cu/TaWN(5nm)/Si structure. (a) before annealing (b) after annealing at 500 ºC, and (b) at 700 ºC for 1 h.