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The effect of the HfN_x barrier thickness on the Cu grain orientation control

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Abstract

We demonstrate that the 5-nm-thick HfN_x films which showed excellent barrier properties in our previous study are applicable to the underlayer for the Cu grain orientation control. The strong (111) orientation of Cu is obtained by using the HfN_x barrier with 5 nm thickness instead of 10 nm thickness.

In this study, we clarify the reason of the preferential orientation of Cu(111) on the HfN_x barrier which has large lattice mismatch. Also, we examine the effect of the barrier thickness on the Cu grain orientation control.

1. Introduction

The preferential orientation of Cu(111) plane is strongly desired from point of view of the improvement of the electromigration (EM) reliability.[1] Recently, many studies related to the orientation and/or grain structure of Cu have been performed.[1,2] Especially, the Nb layer is thought to be a superior underlayer for the orientation of Cu(111).[3-5] This is because the interface of Cu(111)/Nb(110) is expected to show the epitaxial growth with a NW relationship.[6,7] On the other hand, it is known that the TiN layer may not be an appropriate underlayer for Cu. However, we realize the preferential orientation of Cu(111) on the HfN_x layer. Hf is same family element of Ti in a periodic table. Moreover, in the previous study, we demonstrated that the HfN_x films with nanocrystalline grains showed good barrier properties such as the structurally stable and chemically inert.[8]

In this study, we first investigate the correlation between the preferential orientation of Cu(111) and the thickness of HfN_x barrier. Also, we examine the factor obtained the preferential orientation of Cu(111) on the HfN_x layer.

2. Experimental Procedure

Specimens of $Cu/HfN_x/SiO_2/Si$ were prepared using a tetrode dc sputtering system with a base pressure of less than 5 x 10^{-7} Torr. On a 100-nm-thick SiO_2 layer thermally grown on a p-Si(100) wafer, a HfN_x layer (5~20 nm) and a subsequent Cu layer (100 nm) were deposited at 350 °C and room temperature, respectively, without breaking a vacuum. The target voltage and current of the HfN_x layer and Cu layer were 1 kV and 80 mA, and 500 V and 80 mA, respectively. Total gas pressure was 2 x 10^{-3} Torr. Some specimens were annealed at 500 °C for 1 h in a vacuum of 10^{-7} Torr. X-ray diffraction (XRD), XRD pole figure, and TEM were used to evaluate the crystallographic structure and/or texture of the obtained samples.

3. Results and Discussion

Figures 1 and 2 show the XRD patterns from the $Cu/HfN_x(5\ nm)/SiO_2/Si$ and $Cu/HfN_x(10\ nm)/SiO_2/Si$ systems before and after annealing at 500 °C for 1 h, respectively. In both figures, the obtained Cu films exhibited a (111)-preferred orientation even before annealing, and also an increase in intensity of the Cu(111) reflection line is observed after annealing at 500 °C for 1 h. This preference is stronger in the case of Cu/HfN_x(5 nm) than that of Cu/HfN_x(10 nm).

Here, the EM mean time to failure (MTF) for interconnects is empirically found to be expressed as

$$\text{EM MTF} \propto (S/\sigma^2)\log(I_{(111)}/I_{(200)})^3,$$

where S, σ, $I_{(111)}$, and $I_{(200)}$ are the median grain size, its standard deviation for a long normal distribution, and the x-ray-diffraction intensity for the (111) plane and for the (200) plane, respectively.[9] We well know that the term of the log $(I_{(111)}/I_{(200)})^3$ factor is guideline of the (111)-preferred orientation of Cu. The values of the log $(I_{(111)}/I_{(200)})^3$ obtained from the specimens before and after annealing at 500 °C are summarized in Table I. In the case of the Cu/HfN_x(5 nm), the values obtained from specimens before and after annealing at 500 °C were 5.46 and 7.29, respectively. On the other hand, the values from the Cu/HfN_x(10 nm) were 4.18 and 5.41, respectively, which are lower than that of Cu/HfN_x(5 nm). This imply that the Cu exhibited strong (111) orientation preference on the 5-nm-thick HfN_x barrier. It is also reported by Nakasaki *et al.* about the term of the log $(I_{(111)}/I_{(200)})^3$ factor that Cu(200 nm)/TiN(90 nm) before annealing had value of 4.16.[3] This value is nearly equal to that of Cu/HfN_x(10 nm), and is rather lower than that of Cu/HfN_x(5 nm). This indicates the HfN_x barrier is one of the barrier materials which is made to grow grains with (111) orientation of Cu interconnects.

Figure 3 shows the cross-sectional TEM views of the $Cu/HfN_x(5\ nm)/SiO_2/Si$ system before annealing. In Fig. 3(a), the obtained HfN_x layer consisting of nanocrystalline grains with random orientation in lateral direction and sizes ranging from 2 to 5 nm is uniform and continuous. As seen in Fig. 3(b), the Cu layer with large grain size is observed. As confirmed by XRD and TEM, the Cu layer with the (111) preferential orientation in normal direction is formed, although the Cu layer shows the random orientation in lateral direction.

It is reported by Nakasaki *et al*. that the ratio parameter of the nearest-neighbor distances of each plane of Cu(111)/HfN(111) is 1.253 which is larger than 1.175 of Cu(111)/TiN(111).[3] This implies that TiN(111) plane is structurally suitable for the Cu(111) plane, compared with the HfN(111). However, the Cu layer exhibits a (111)-preferred orientation on the HfN_x barrier in this study. These experimental results are extremely interest. We elucidate the mechanism of this phenomenon, and will report the details in conference.

Acknowledgements

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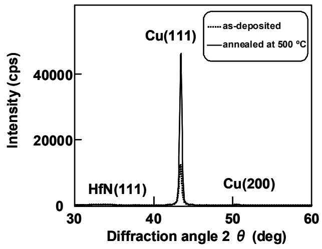


Fig. 1 XRD patterns of Cu(100 nm)/HfN_x(5 nm)/SiO_2/Si system before and after annealing at 500 °C 1h..

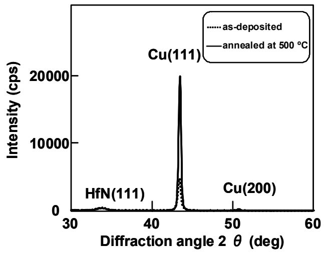
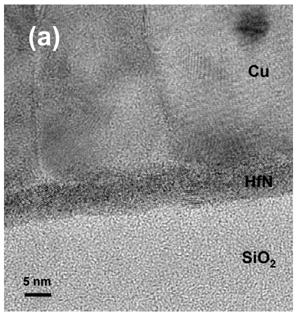


Fig. 2 XRD patterns of Cu(100 nm)/HfN_x(10 nm)/SiO_2/Si system before and after annealing at 500 °C 1h..



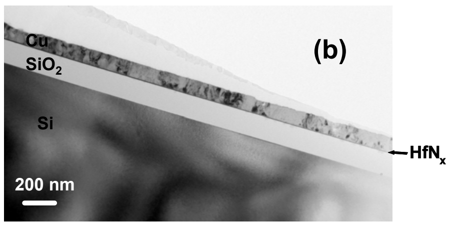


Fig. 3 Cross-sectional TEM images of Cu(100 nm)/HfN_x(5 nm)/SiO_2/Si system before annealing: (a) local view, and (b) entire view.

Table. I The values of $\log(I_{(111)}/I_{(200)})^3$ obtained from the specimens before and after annealing at 500 °C for 1h.

Barrier thickness (nm)	$\log\left\{\frac{I(111)}{I(200)}\right\}^3$	
	as-deposited	annealed at 500 °C
5	5.46	7.29
10	4.18	5.41