

Al(111)/CVD-TiN(111) Stacked Film Formation Technique with High Aspect-Ratio Contact Hole Filling for Highly Reliable Interconnects

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CVD-TiN film having (111) preferred orientation and good step coverage was prepared, for the first time, by predepositing 10nm thick Ti layer and optimizing the flow rate of source gases, TiCl_4 and NH_3 . The role of thin Ti underlayer is discussed from the point of lattice matching of crystal plane. It was also demonstrated that both sputtered and chemical-vapor-deposited Al on the CVD-TiN showed strong (111) orientation required for achieving high electromigration resistance, being affected by the orientation of the underlayer. Our new method to prepare the TiN film is very attractive for highly reliable Al interconnects with contact hole filling, in coming next generation ULSI.

1. Introduction

Shrinking dimensions of devices beyond quarter-micron makes sizes of contact hole smaller and aspect-ratio of contact hole extremely higher. Thus, it becomes difficult to obtain sufficient conformal step coverage of barrier metal in such a contact hole by conventional sputtering. Recently, excellent step coverage of (200) oriented titanium nitride (TiN(200)) film was formed by low pressure chemical-vapor-deposition (LPCVD) ^{1,2}.

If we apply CVD-TiN as lower barrier metal for Al interconnects, preferred crystal orientation of the TiN film is to be (111) orientation. It is because that Al film formed on (111) oriented TiN film have remarkable (111) preferred crystal orientation, resulting in excellent electromigration resistance³. However, formation of CVD-TiN(111) film having conformal step coverage has not been reported yet.

In this study, a new method to prepare (111) oriented CVD-TiN film showing good conformal step coverage is reported. Furthermore, fabrication of CVD-Al(111)/CVD-TiN(111) stacked structure with contact hole filling is also demonstrated.

2. Experimental

TiN films were chemically deposited from TiCl_4 , NH_3 and H_2 at 650°C. TiCl_4 was introduced with Ar carrier gas. Flow rate of TiCl_4 and H_2 were kept constant at 0.5 and 10sccm, respectively. Total pressure during

deposition was fixed at 0.1Torr. Dependence of crystal orientation and step coverage on NH_3 flow rate which was varied from 10 to 50sccm was investigated. Two types of substrates, on which contact holes were formed, were used. In type(a), contact windows were opened in 0.8 μm -thick BPSG layer for making contacts to Si(100) substrate. In type(b), 10nm-thick titanium(Ti) film was deposited by sputtering on the type(a) substrate. Al film was deposited on CVD-TiN film by sputtering or CVD. After TiN film was deposited, the substrates were transported in vacuum to other reactors for CVD-Al or sputter-Al. And then, Al film was deposited on the TiN film. The CVD-Al film was deposited by using DMAH(dimethyl-aluminum-hydride) and H_2 as source gases at 210°C at 2Torr.

3. Results and Discussion

Figure 1 shows XRD peak intensity ratio of TiN(111)/TiN(200) and the bottom coverage of CVD-TiN as a function of NH_3 flow rate. The bottom coverage of TiN is defined as a ratio of thickness of TiN film deposited on the bottom of contact hole, having 0.5 μm diameter(aspect-ratio is 1.6), to that on BPSG, as shown in an inset of Fig. 1. On type(a) substrate, (111) oriented CVD-TiN films were obtained by using higher NH_3 flow rate than 25sccm and (200) oriented films were obtained by using NH_3 flow rate below 20sccm. It is noted that those (111) oriented films showed nonconformal step coverage and that, however, conformal step

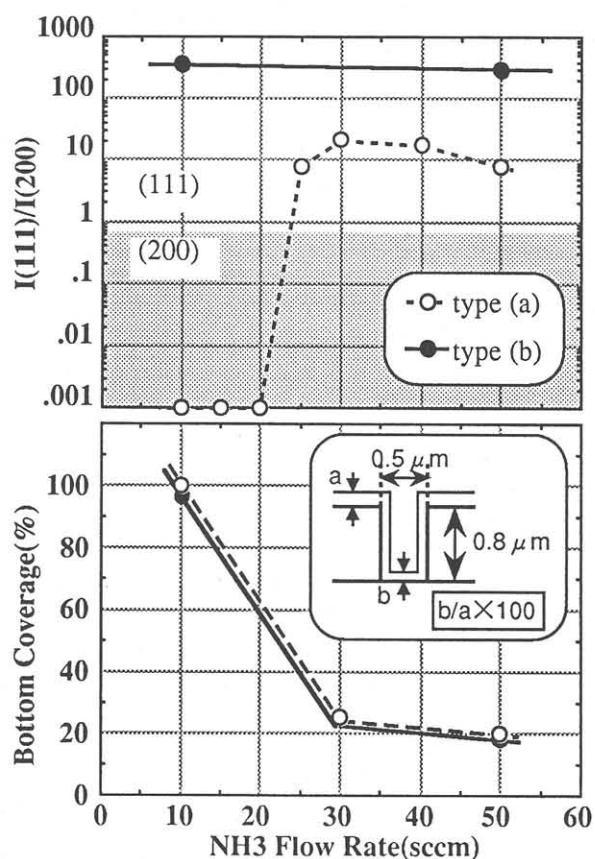


Figure 1 : Plot of XRD peak intensity ratio of TiN(111)/TiN(200) and bottom coverage of CVD-TiN as a function of NH_3 flow rate. Definition of bottom coverage is shown in inset of this figure.

coverage was obtained in the (200) oriented films.

The difference of preferential orientation of TiN films caused by the difference of NH_3 flow rate can be explained by considering growing plane. Fig. 2(a) illustrates a NaCl type lattice structure of crystalline TiN film. (200) plane of TiN consists of the same number of Ti atoms and nitrogen(N) atoms, as shown in Fig. 2(b). However, (111) oriented TiN film consists of stacking Ti atomic layer (Ti-layer) and N atomic layer (N-layer) alternately, as shown in Fig. 2(c). Considering these characteristics of TiN crystalline structure, we assume that larger partial pressure of NH_3 enhances preferential adsorption of NH_3 molecule to type(a) substrate, leading a first N-layer formation, and then, Ti-layer and N-layer are alternately stacked, resulting in (111) preferred oriented CVD-TiN film.

On the other hand, only (111) oriented TiN films were obtained on Ti-sputtered substrate

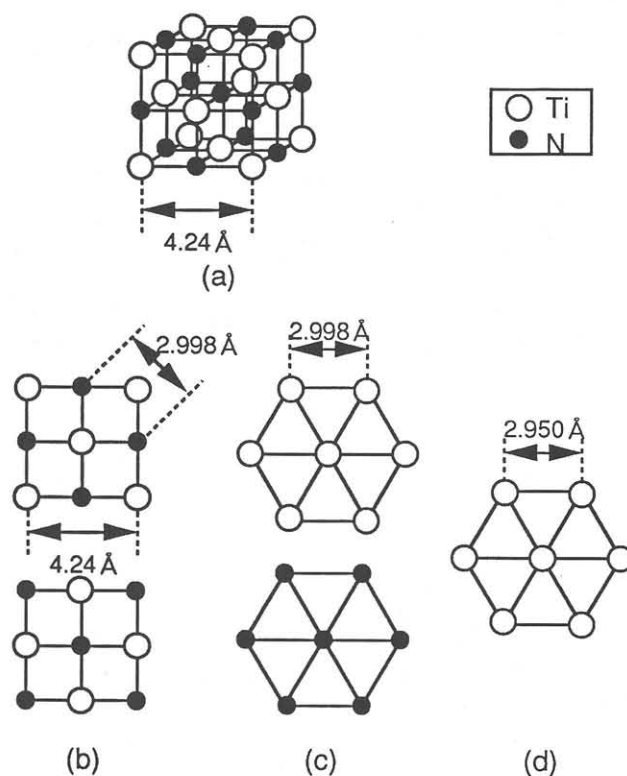


Figure 2 : Illustrations for modeling of lattice structures of TiN (as shown in (a)), atomic arrangement of (200) plane (in (b)), (111) plane of TiN (in (c)) and (002) plane of Ti (in (d)).

(type(b)), being independent of varied flow rate of NH_3 from 10 to 50 sccm. A reasonable explanation for this observation is as follows. The orientation of Ti film was (002). Atomic arrangement and interatomic distance of Ti(002) plane is very close to those of TiN(111) plane, as shown in Figs. 2(c) and (d). Thus, preferential crystal orientation of TiN film formed on Ti(002) film tends to be (111) orientation independent of NH_3 flow rate. It is noted that (111) oriented TiN film having approximately 100% bottom coverage was realized by setting NH_3 flow rate at 10 sccm. In the estimation of bottom coverage, lower bottom coverage of Ti film can be ignored due to extremely thin Ti film thickness of 10 nm.

These results suggest that crystal orientation of CVD-TiN film strongly depends on coherency with underlayer such as Ti layer, however, that degree of step coverage is determined by gas condition during deposition rather than by surface condition of underlayer.

Using TiN as underlayer, we examined orientation of sputter-Al. NH_3 flow rate was

fixed at 10sccm for these runs. Figures 3 show XRD (X-ray diffraction) patterns of sputter-Al/CVD-TiN stacked structures. On type(b) substrate, XRD pattern of the (111) oriented TiN and strong (111) oriented Al were observed (Fig. 3(b)). On the other hand, when Al film deposited on TiN(200) film formed on type(a) substrate, Al(111) peak intensity was drastically reduced (Fig. 3(a)). We have firstly demonstrated that Al(111) film formation was induced by (111) oriented CVD-TiN underlayer.

Then, we applied these method to fill contact hole and form interconnects, at one time, by using stacked structure of CVD-Al(111)/CVD-TiN films. Fabrication processes are described below. TiN film of 0.1μm thickness was deposited on type(b) substrate. Then, Al film was chemically deposited on the TiN film. Intensity of (111) orientation of Al film on TiN(111) film was enhanced by sequential deposition without air exposure. Cross-sectional SEM photograph of the stacked films formed at contact hole is shown in Figure 4.

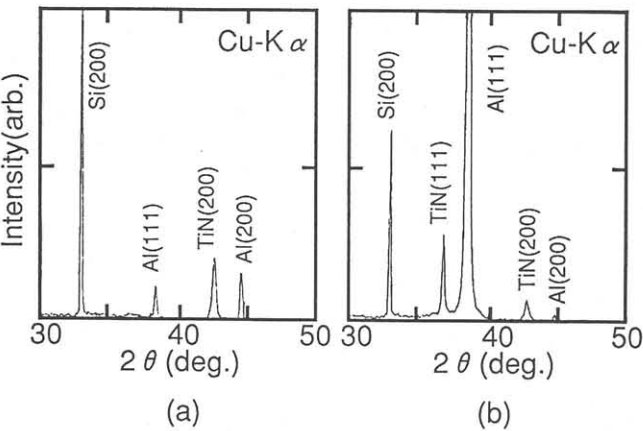


Figure 3 : XRD patterns from Al/TiN structures on type(a) substrate (as shown in (a)) and on type(b) substrate (as shown in (b)).

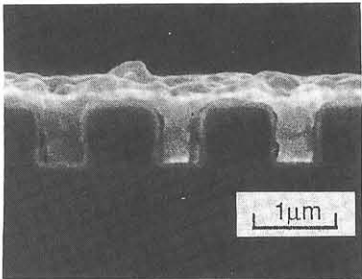


Figure 4 : Cross-sectional SEM photograph of CVD-Al/CVD-TiN stacked structure formed at contact hole.

Conformal step coverage of TiN was observed and contact hole was filled by CVD-Al/CVD-TiN stacked structure completely.

4. Conclusions

CVD-TiN(111) film was obtained by optimizing NH₃ flow rate, but step coverage was poor by conventional thermal-CVD. However, formation of TiN(111) films having excellent step coverage was realized by predepositing thin Ti(002) film on the substrate before CVD. To explain our finding, we propose an assumption that the step coverage of CVD-TiN is mainly dependent on gas condition during film deposition, but that the crystal orientation strongly depends on coherency with underlayer.

It is confirmed that Al films on the CVD-TiN(111) films show (111) preferred orientation required for achieving high electromigration resistance, as was observed in sputter-Al(111)/sputter-TiN(111). Furthermore, a simultaneous formation of complete contact hole filling and interconnects is successfully demonstrated by using the stacked structure of CVD-Al(111)/CVD-TiN(111) films. Therefore, our new developed method to prepare the TiN film is very attractive for highly reliable Al interconnects with contact hole filling, in coming next generation ULSI.

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