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The Effect of Underlayer Texture on Cu Film Orientation in Cu/Refractory-Metal Structure

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1. Introduction

The electromigration (EM) performance of Al-based interconnects depends on Al (111) preferred orientation[1-5), 7)]. Cu texture is also an essential factor that determines EM lifetime in the case of Al. C.Ryu et al. have reported that CVD Cu interconnects with stronger Cu (111) orientation have a longer EM lifetime[8)]. In this work, the effect of underlayer texture on Cu film orientation has been studied. It will be shown that Cu (111) crystallographic orientation is enhanced on TiN film having strong TiN (111) orientation.

2. Experimental

Various underlayers for Cu film, such as TiN (50 nm), TiN (40 nm)/Ti (10 nm), rapid thermal nitrided-TiN (50 nm) (RTN-TiN) and W (50 nm) films, were deposited on SiO_2/Si substrates by DC magnetron sputtering system. TiN film was deposited by reactive sputtering in N_2 ambient. In TiN/Ti layered structure, Ti film and reactive sputtered TiN film were sequentially deposited in a same vacuum. RTN-TiN film was formed by rapid thermal annealing of Ti film at 760 °C for 30 sec in N_2 ambient. Cu films with 390 nm thickness were sputter-deposited on the underlayers after breaking a vacuum. The samples were ex-situ annealed at 450 °C for 15 min in a vacuum. The crystallographic textures of the underlayers and the Cu films were evaluated by XRD analysis, and the Cu/RTN-TiN interface was observed by XTEM.

3. Results and Discussion

Figure 1 shows XRD spectra for (a) RTN-TiN, (b) TiN/Ti, (c) TiN and (d) W films deposited on SiO_2/Si substrates. TiN film exhibits random orientation (Fig.1 (c)). On the other hand, RTN-TiN and TiN/Ti films exhibit (111) texture (Fig.1 (a), (b)). The TiN (111) preferred orientation, however, is different largely by changing film formation method or film structure. TiN (111) peak intensity of TiN/Ti layered film is three times higher than that of TiN film. Furthermore, RTN-TiN film provides a remarkably strong TiN (111) peak intensity about 2 orders higher than that of TiN film. W film has (110) preferred orientation.

Figure 2 shows X-ray Cu (111) rocking curves of 390 nm thick Cu films on various underlayers deposited SiO_2/Si substrates after annealing at 450 °C for 15 min. The crystallographic texture of Cu film has a close correlation with underlayer texture as in the case of Al/TiN layered structure[6,7)]. The full width at half maximum (FWHM) value for the Cu film decreases with an increase in TiN (111) texture (RTN-TiN: 2.75°, TiN/Ti: 4.08°, TiN: 5.47°). FWHM value of Cu film deposited on W underlayer is the biggest (6.56°). The crystallographic orientation of Cu film can be controlled by choosing a suitable underlayer.

A cross-sectional TEM image obtained from Cu/RTN-TiN layered structure after annealing at 450 °C for 15 min is shown in Fig.3. Though TiN grains are much smaller than Cu grains, the continuity of crystal is clearly observed at the Cu/RTN-TiN interface. The lattice-fringe spacings of Cu and TiN layers in TEM image correspond to that of Cu (111) and TiN (111) (Cu: 2.008 Å, TiN: 2.44 Å). <111> oriented Cu film grows epitaxially on <111> oriented TiN film.

Cu and TiN have the same cubic crystal structure (Cu: fcc type, TiN: NaCl type), having the lattice constant of 3.615 Å and 4.24 Å. The lattice mismatch is 14.7%, and is considered to be too large to obtain epitaxial growth of Cu film on TiN film. On the hypothesis that the Cu film grows on TiN film with Cu (111) plane rotating 30° around <111> axis on TiN (111) plane, twice Cu atomic periods along <110> direction nearly corresponds with TiN atomic period along <221> direction: The third nearest atomic distance of 5.112 Å along <110> direction in Cu (111) plane matches to the second nearest atomic distance of 5.193 Å along <221> direction in TiN(111) plane. The effective mismatch becomes about 1.6%. It has a possibility that Cu (111) plane grows epitaxially on TiN (111) plane with a rotational angle of 30°.

In order to obtain a clear relation of atomic arrangement between Cu and TiN in (111) plane, TiN/Cu/RTN-TiN layered structure was evaluated. TiN film was deposited on Cu/RTN-TiN structure with strong Cu (111) orientation. By using this structure, the strong <111> oriented overlying TiN film can be obtained. By selected-area electron diffraction (SAED) observation, it is confirmed that the overlying TiN crystal has a rotational angle of within ±10° in (111) plane relative to Cu (111) plane. Thus, it is considered that the large lattice mismatch is relaxed by formation of strain or dislocation at the interface of Cu/RTN-TiN layered structure. A typical discontinuity between Cu and TiN lattices can be seen in the circle shown in Fig.3.

4. Conclusion

The effect of underlayer texture on Cu film orientation has been studied. It has been found for the first time that the crystallographic orientation of Cu film can be controlled successfully by using proper TiN underlayer. Cu (111) preferred orientation is enhanced on TiN film with strong (111) orientation. From a cross-sectional TEM observation, it was indicated that Cu (111) plane grows parallel to TiN (111) plane. It was also clarified that Cu (111) plane has a same atomic arrangement on TiN (111) plane in spite of a large lattice mismatching.

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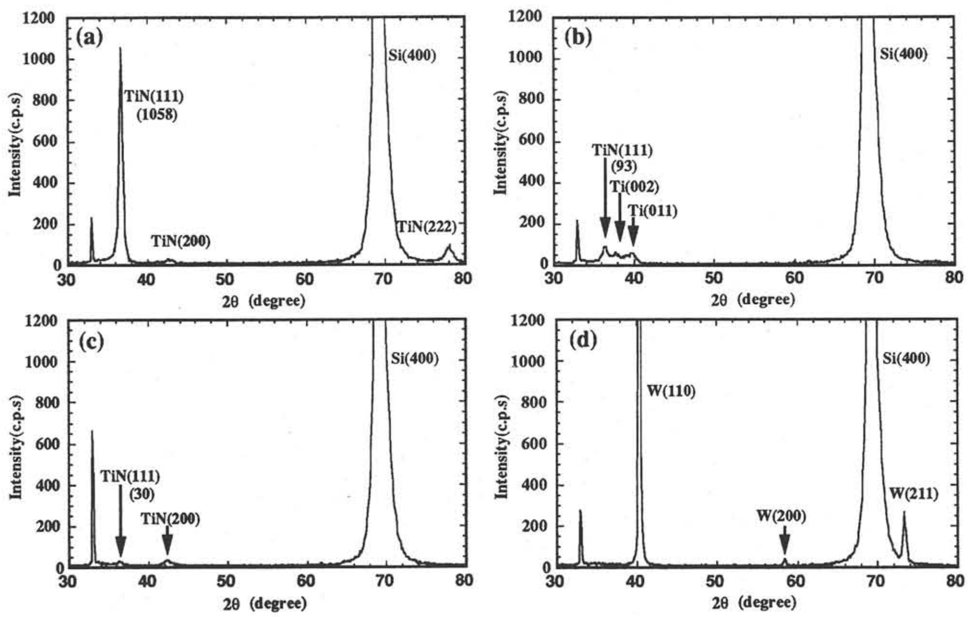

Fig.1 XRD spectra for (a) RTN-TiN(50 nm), (b) TiN(40 nm)/Ti(10 nm), (c) TiN(50 nm) and (d) W(50 nm) films deposited on SiO_2/Si substrates. The values in the parentheses under TiN (111) notation in the figures show TiN (111) peak intensites.

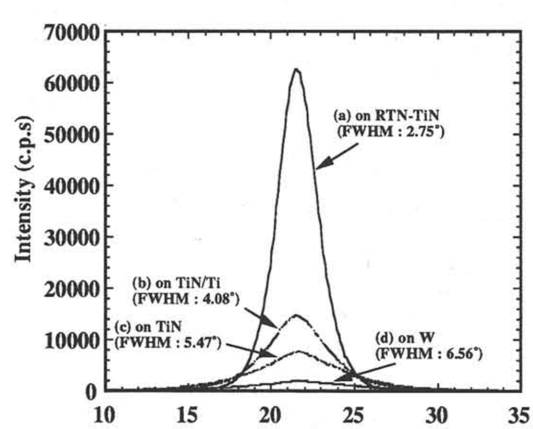

Fig.2 X-ray Cu(111) rocking curves of Cu films (390 nm) on (a) RTN-TiN(50 nm), (b) TiN(40 nm)/Ti(10 nm), (c)TiN(50 nm), (d)W(50 nm) films after annealing at 450 °C for 15 min.

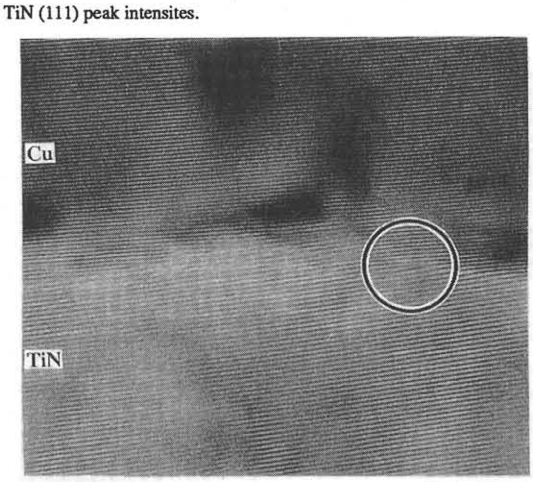

Fig.3 A cross-sectional TEM image obtained from Cu/RTN-TiN layered structure after annealing at 450 °C for 15 min.