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Influence of Interface Structure between Overlayer TiN and Al on Multilayered Interconnects

Makiko Kageyama, Yasuyuki Tatara and Hiroshi Onoda
VLSI R&D Center, Oki Electric Industry Co.,Ltd.
550-1, Higashiasakawa, Hachioji, Tokyo 193
Tel.426-63-1111, Fax.426-66-7213

Aluminum film with overlayer TiN, which was formed as anti-reflective material(ARM), have been examined. The effect of TiN film depends on its deposition process. TiN, which was deposited on air exposed aluminum, enlarges aluminum grain sizes because of its compressive stress. However, successive deposited TiN does not enlarge aluminum grains, it has been found to have epitaxial continuity to underlayer aluminum, and this crystal continuity suppresses Al atom mobility. Electromigration resistance of TiN/Al/TiN layered line was improved by this interface crystal continuity.

1.INTRODUCTION

With the trend of increasing packing density of VLSI, multilayered metallization came to be indispensable technique for high reliable interconnects. For Al-alloy lines with TiN barrier metal, relation between aluminum texture and underlayer TiN has been clarified by our group[1]. Aluminum was found to have the same texture as underlayer TiN texture which can be controlled by changing deposition condition, and electro-migration resistance of Al/TiN layered line was shown to be improved by promoting Al<111> preferred orientation.

This time, the effect of TiN overlayer on Al-alloy was examined. Some investigation on electromigration of aluminum with W, TiW,TiN or $MoSi_x$ overlayer were reported[2],[3]. However, the effect of overlayer metal was not clear. TiN is one of the most effective anti-reflective material for patterning deep submicron lines, and TiN/Al/TiN layered interconnects is the most prevailing structure. In addition, TiN, which has very close lattice constant as aluminum, is expected to improve the metal reliability.

In this point of view, we investigated the Al-alloy lines with TiN overlayer, and found that the effect of TiN is different if TiN was deposited successively in vacuum or not. Though aluminum grain enlargement is easy to occur for air exposed sample, the successive deposited sample is more reliable for electromigration because of continuous crystal structure at TiN and Al interface.

2.EXPERIMENTAL

Al-Si-Cu film of 500nm thickness was deposited on CVD SiO_2, and TiN film of 10nm thickness was deposited on Al-alloy by reactive sputtering. TiN deposition was carried out (a)after aluminum was exposed to air about an hour, or (b)successively without breaking vacuum. TiN films with various stress were formed on Al-alloy, and aluminum film properties were examined after annealing at 400°C. Stress of TiN film can be changed by changing its deposition power and total gas pressure. Aluminum grains were observed by SEM and FIB, and TiN/Al interdiffusion was evaluated by RBS.

In order to understand the effect of deposition process, TiN/Al interface structure was observed by TEM and electron diffraction. Its effect on electromigration resistance was also examined. For electromigration test sample, TiN/Al-Si-Cu/TiN three layered metal was prepared in order to avoid effects of film properties, as the reason will be described later. The thickness of both top and bottom TiN films is 100nm and Al-Si-Cu film is 500nm. These three layered metal was patterned to the lines with 2um in width and 22mm in length and passivated with SiN/SiO2 bilayer. The test structure was mounted onto Dual Inline Package and electromigration resistance was tested under the stress of 200°C in temperature and 1.78E6 A/cm^2 in current density.

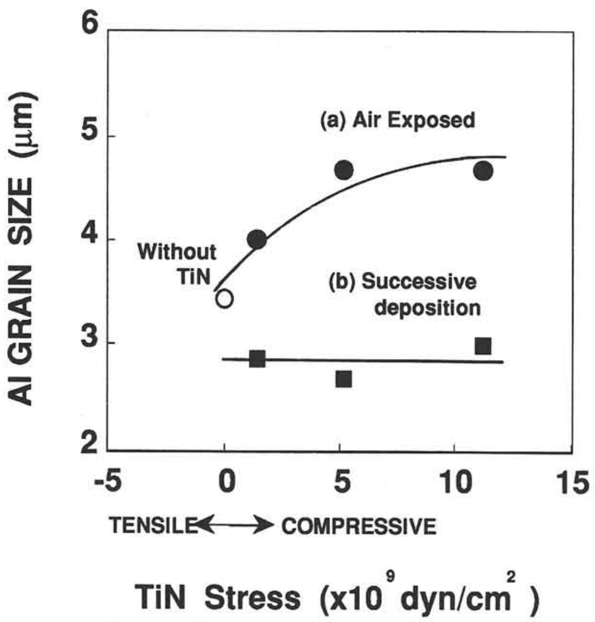

Figure 1. Dependence of aluminum grain size on TiN film stress. (after 400℃ annealing.)

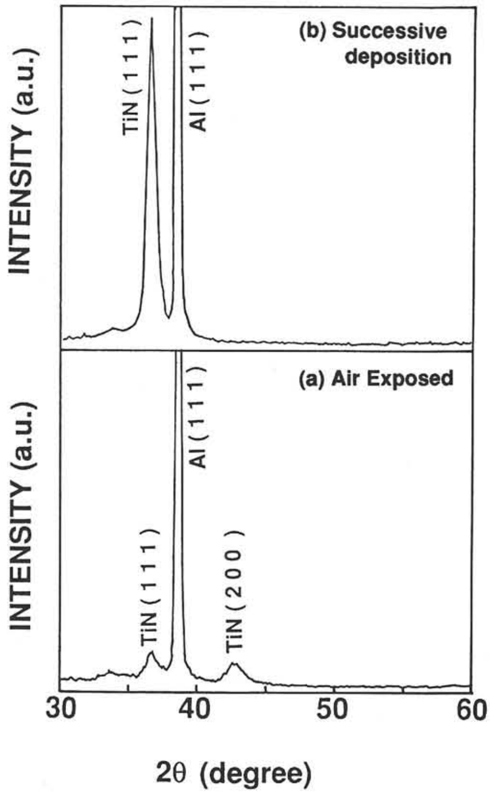

Figure 2. X-ray diffraction patterns from TiN/Al layered structure.

3.RESULTS AND DISCUSSIONS

Figure 1 shows the dependence of Al grain size on TiN stress. Grain size was observed by FIB after 400°C annealing. The deposition condition of aluminum was the same for all samples and grain sizes were almost the same before annealing process; however, grain growth behavior is largely affected by overlayer TiN stress and its deposition process. For air exposed samples(a), TiN overlayer clearly enlarges aluminum grains. Dependence of aluminum grain size on TiN stress indicates that compressive stress promotes Al atom movement and enlarges grains. Aluminum grain enlargement phenomenon by overlayer metal has been reported by Hinode et al[3], and in this work, it came to be clear that it was caused by compressive stress of overlayer metal. On the other hand, grain enlargement was suppressed for successive deposited samples(b). The grain sizes were smaller than monolayer Al, and dependence on TiN stress was not observed. Though thermal diffusion of Ti into Al-alloy was evaluated by RBS and XRD, no interdiffusion and no compounds were observed for both sample (a) and (b) even after 500°C anneal. It means that grain growth suppression is not due to Ti diffusion for successive deposited sample.

X-ray diffraction patterns shown in fig.2 show there is another difference on both (a) and (b) sample. Strong TiN peak of successive deposited sample(b) predicts that there is some crystallographic effect in TiN/Al interface structure.

Figure 3 shows the photographs of TEM observation and electron diffraction patterns of TiN/Al interface of (a)air exposed and (b)successive deposited sample. As for air exposed sample(a), about 2nm thickness of amorphous layer that seems to be oxide was formed at interface. TiN has columnar structure with random crystal direction. Electron diffraction of upper TiN shows ring patterns which designate random poly-crystal and no relation to underlayer Al crystal was observed. On the other hand, successive deposited TiN(b) shows the same continuous lattice as aluminum in most parts of the interface, and columnar grain boundaries of TiN were not observed clearly. The electron diffraction patterns of this sample show that aluminum and TiN have the same crystal plane. It indicates that the TiN film has an epitaxial continuity to underlayer Al-alloy, because TiN and aluminum have the same f.c.c. structure and very close lattice constant.

If crystal continuity between TiN and underlayer Al-alloy suppress interface and grain boundary diffusion of Al atom, it should suppress Al atom movement caused by electromigration.

The result of electromigration failure was shown in fig.4. Electromigration resistance is known to be affected by aluminum grain size and texture largely[4]. Table I shows aluminum grain size after full process. The samples with TiN barrier metal has much smaller grain size than TiN/Al two layered structure.

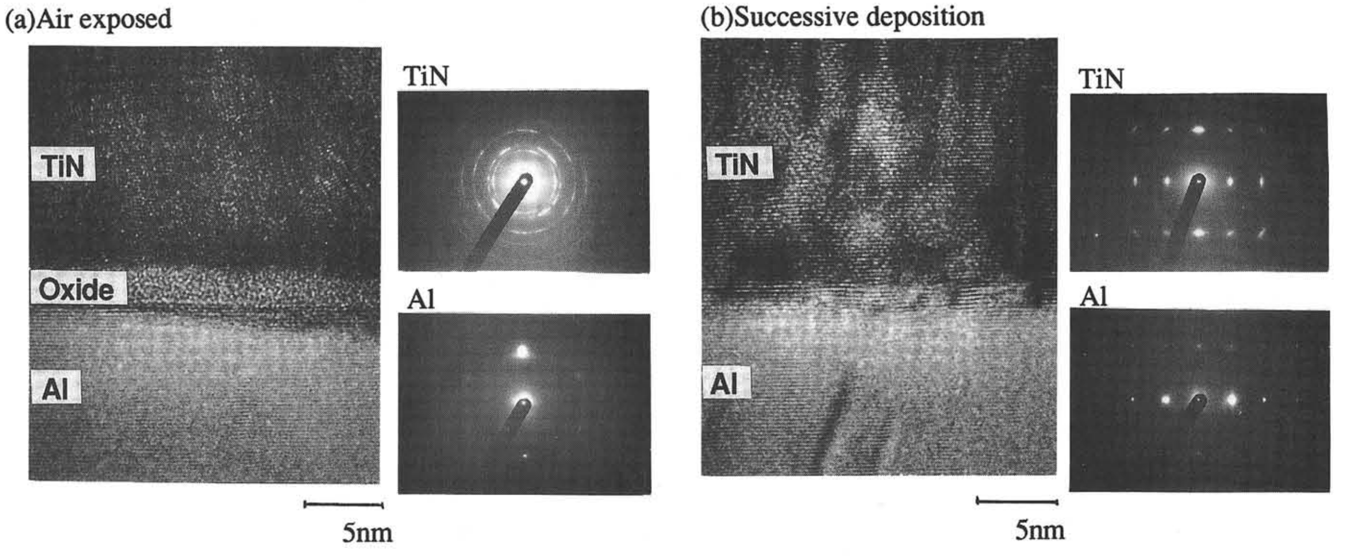

Figure 3. TEM micrographs and electron diffraction from TiN/Al Interface.

Since the grain size is defined by underlayer TiN, deposition condition of overlayer TiN causes little effect on aluminum grain size. For test sample, we used TiN/Al/TiN three layered structure in order to eliminate the difference in aluminum grain size. The resistance of test line was monitored and 5% increase was regarded as failure criteria.

The successive deposited sample(b) has about 2 times longer MTTF than air exposed sample(a). Since there is no difference in aluminum properties, it is concluded that TiN, which has crystal continuity to Al, suppress aluminum diffusion at TiN/Al interface, and promote more reliable interconnects.

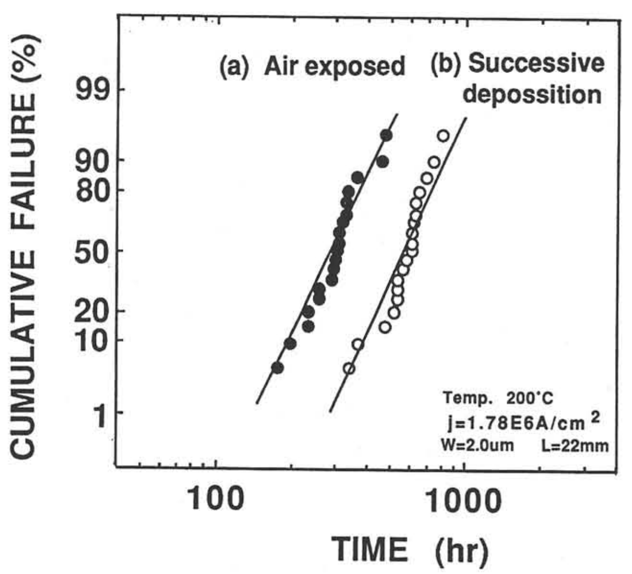

Figure 4. Cumulative failure of TiN/Al/TiN three layered lines.

4.CONCLUSIONS

Aluminum film with the TiN overlayer which was formed as anti reflective material have been investigated. The effects of TiN on aluminum filın properties and interconnects reliability are depend on its deposition process largely.

TiN, which was deposited on air exposed aluminum, enlarges aluminum grain sizes because of its compressive stress. However, successive deposited TiN does not enlarge aluminum grains, it was found to have epitaxial continuity to underlayer aluminum, and it is supposed to suppress aluminum atom movement. Electromigration resistance of TiN/Al/TiN layered interconnects was improved by this crystal continuity at successive deposited interface.

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