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Low stress C doped WN diffusion barrier for Cu interconnection

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Abstract

Carbon doped WN thin films have been deposited by atomic layer deposition method and the diffusion barrier performance for Cu interconnect has been investigated. As a result, the C-WN prepared with WF_6-CH_4-B_2H_6-NH_3 gas system has very low resistivity of 100 μΩ-cm, 95% step coverage in high aspect ratio via hole without plasma assistant process. Thermal stability and electrical measurements of Cu/C-WN interconnect structure show excellent performance.

1. Introduction

Typically, diffusion barrier for 3-dimensional through via requires tough thermal stability, lower resistivity, enhanced resistance against electromigration and stressmigration, reliable time dependent failure, etc [1]. Among diffusion barrier materials such as TaSiN, TaN, TiN, WN, RuO,[2-3] We have investigated a carbon doped tungsten nitride (C-WN) thin film and compared its barrier performance with WN and TiN. As a result, it is found that the C-WN barrier shows higher thermal stability, lowest resistivity, and better electromigration resistance. We have discussed the origin of excellent barrier performance with the film stress that is very important for subsequent process such as chemical mechanical polishing (CMP). And, for good step coverage and conformal deposition, atomic layer deposition (ALD) has been intensively studied.

2. General Instructions

First of all, we used a patterned Si substrates with native oxide on top were cleaned thoroughly. The WN and C-WN thin films were deposited by using ALD system with two different W sources WF_6 and $W_2(NMe_2)_6$. The other reactant gases were ammonia gas (NH_3) and diborane (B_2H_6) and methane (CH_4) without plasma. WF_6 has a problem such as encroachment on the Si surface, therefore, we used B_2H_6 as a sacrificial layer for preventing the encroachment. In order to investigate thermal stability, a 30-nm-thick Cu layer was electro-plated and the Cu interconnection lines were prepared with three different barriers, TiN, WN, and C-WN on inter-dielectric layer/Si structures. Thermal stability of Cu interconnect was tested by annealing at 500, 600, and 700℃ for 30 min in Ar ambient, Electromigration test was done with width 1 ㎛ × 1000 ㎛ length test pattern. Whether the diffusion barrier prevenst the Cu diffusion successfully or not was determined with Rutherford backscattering (RBS) and transmission electron microscopy (TEM) and X-ray photon spectroscopy (XPS) was used to determine the atomic concentrations of C and N.

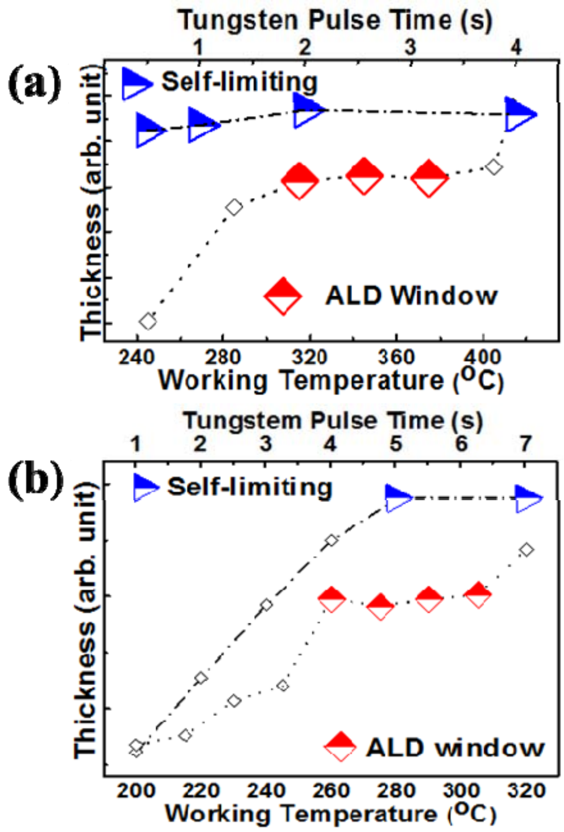

Fig. 1 Linear relationships between deposition rate and ALD cycles using (a) WF_6-B_2H_6-NH_3 and (b) WF_6-CH_4-B_2H_6-NH_3 gas systems

3. Results and Discussion

Self limiting and window of ALD is investigated with different combinations of reactive gases. Typically, Fig. 1 (a) and (b) show relationships between ALD deposition rate and cycle using WF_6-B_2H_6-NH_3 and WF_6-CH_4-B_2H_6-NH_3 gas systems, respectively. In case of (a), self limiting process is delayed after 5s, WF_6 expose time and the ALD window is in the temperature range of 260-300℃. In contrast, using CH_4, ALD is controlled by self limiting mechanism at the beginning and the ALD window is 320-360℃, which is slightly higher than the case (a). Specific resistivity is 100 μΩ-cm, which is the lowest. The resistivity of WN prepared with WF_6-B_2H_6-NH_3 is 432.2 μΩ-cm, the case prepared with $W_2(NM_2)_6$ precursor is 24,280 μΩ-cm due to high impurity.

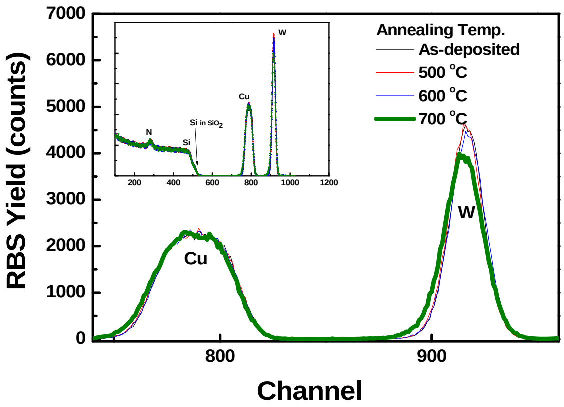

Fig. 2 RBS spectra of Cu/C-WN/SiO_2/Si structures annealed at 500, 600 and 700 ℃ for 30 min.

Thermal stability of the Cu interconnect using the C-WN barrier shows excellent performance to prevent the Cu diffusion even at 700℃ as shown in Fig. 2. The inserted figure is the full spectrum of RBS and the details show that the tail end of Cu peak is not overlapped with the head end of WN peak, and the Si peak is also not overlapped with the Cu peak.

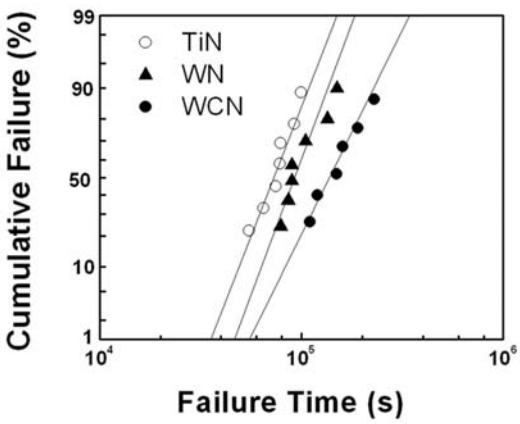

Fig. 3. Cumulation electromigration failure of Cu/TiN, Cu/WN and Cu/C-WN interconnections

Electromigration failure of the Cu interconnects is as shown in Fig. 3. This mean time to electromigration failure analysis is obtained with the acceleration conditions: high current density is 10^2 A/cm^2 and the measurement temperatures are fixed at 215 and 225℃. The electromigration test obviously suggests that the Cu/C-WN interconnect is the best since life time is the longest. Almost 90 % of the Cu/TiN line is failed comparing with only 20 % of the Cu/C-WN is failed.

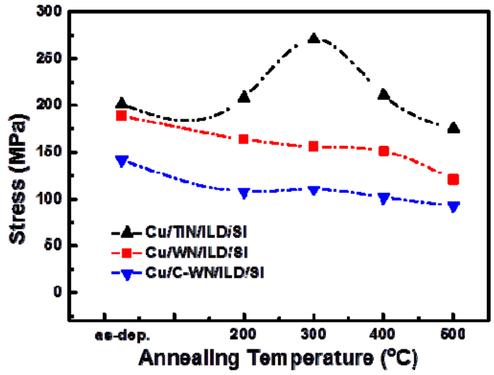

Fig. 4 Film stress of 3 different Cu interconnects according to annealing temperature

The origin of excellent performance against the electromigration is explained by the film stress of Cu interconnect. Fig. 4 shows that the Cu/C-WN/ILD/Si interconnect has the lowest film stress even at the higher annealing temperature. While high current density flows through the Cu interconnect, it is associated with the drift of metal atoms in the direction of the electron flow. The net atomic flux causes voiding and eventually open circuit. Then, high tensile film stress causes voiding in the interconnect line because voids predominately nucleate at the Cu to ILD interface due to relative poor adhesion [4]. Consequently, stress induced voidings lead to finally, the open circuit failure. Therefore, it is plausible that the nucleation of void may be suppressed by reducing the film stress and the Cu/C-WN/ILD/Si interconnects have the most reliable electromigration resistance because of the lowest film stress [5]. We will discuss influences of film stress and mechanical hardness in detail.

3. Conclusions

C-WN thin film shows very reliable performance as a diffusion barrier for Cu interconnects comparing with the WN and the TiN diffusion barriers.

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