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 WF₆-CH₄-B₂H₆-NH₃ 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 stressmigra- tion, 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 WF₆ and W₂(NMe₂)₆. The other reactant gases were ammonia gas (NH₃) and diborane (B₂H₆) and methane (CH₄) without plasma. WF₆ has a problem such as encroachment on the Si surface, therefore, we used B₂H₆ 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 μm × 1000 μm length test pattern. Whether the diffusion barrier prevent 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) WF₆-B₂H₆-NH₃ and (b) WF₆-CH₄-B₂H₆-NH₃ 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 ALD cycles using (a) WF₆-B₂H₆-NH₃ and (b) WF₆-CH₄-B₂H₆-NH₃ gas systems.

ty is 100 μΩ-cm, which is the lowest. The resistivity of WN prepared with WF\textsubscript{6}-B\textsubscript{2}H\textsubscript{6}-NH\textsubscript{3} is 432.2 μΩ-cm, the case prepared with W\textsubscript{2}(NM\textsubscript{2})\textsubscript{6} precursor is 24,280 μΩ-cm due to high impurity.

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Fig. 2 RBS spectra of Cu/C-WN/SiO\textsubscript{2}/Si structures annealed at 500, 600 and 700 °C 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 °C 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\textsuperscript{2} A/cm\textsuperscript{2} and the measurement temperatures are fixed at 215 and 225 °C. 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.

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.

References