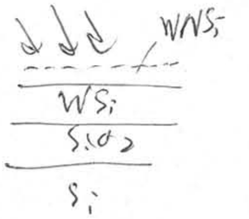
Extended Abstracts of the 1998 International Conference on Solid State Devices and Materials, Hiroshima, 1998, pp. 260-261 **A-6-2**

0.1μm 世代。
Cuは[illegible]バリア
メタルの抵抗が問題。
現在のスパッタでは厚くてこまる…
SEAでは[illegible]
6nmまで下げる。



WSiN Diffusion Barrier Formed by ECR Plasma Nitridation for Copper Damascene Interconnection

A. Hirata, K. Machida, N. Awaya[1], H. Kyuragi and M. Maeda

NTT System Electronics Laboratories
3-1 Morinosato Wakamiya, Atsugi-shi, Kanagawa, 243-0198 JAPAN
TEL +81 462 40 2514, FAX +81 462 40 4321, E-mail: ahirata@aecl.ntt.co.jp

1. Introduction

Copper(Cu) damascene interconnection has been intensively investigated because of its low resistivity[1,2] in order to reduce RC delay time and consumption power. As the interconnection sizes shrink, the volume fraction of barrier metal increases, which raises the copper interconnect resistivity. Below 0.1 μm generation, less than 20 nm thick barrier metal is required for low interconnect resistivity[3].

Our experiments have shown that a very thin (<6 nm) tungsten silicon nitride (WSiN) barrier layer formed by electron cyclotron resonance (ECR) plasma nitridation acts as a good barrier against dopant diffusion[4]. However, little is known about WSiN's barrier capability against Cu diffusion.

In this paper, we show that thin (<6 nm) WSiN formed by ECR plasma nitridation can prevent Cu diffusion and evaluate the leakage current characteristics of Cu damascene interconnection with this WSiN barrier.

2. Experimental Results and Discussion

WSiN Diffusion Barrier

The Cu damascene interconnection with the WSiN diffusion barrier is fabricated as shown in Fig. 1. $WSi_{2.6}$ film is formed by sputtering. Its thickness is 20 nm on the flat pattern, and its surface is nitridated by ECR nitrogen plasma. RF bias is applied to the substrate during nitridation. Sputtering and CVD are used to form Cu films.

Figure 2 shows the secondary ion mass spectroscopy (SIMS) depth profiles of Cu in SiO_2 after annealing at 500°C for 1 h. For this analysis, unpatterned samples were used. As the RF bias power increases, the amount of Cu in SiO_2 decreases. This implies that the barrier effectiveness of WSiN is improved as RF bias power is increased.

The Effect of Applying RF Bias

Figure 3 shows the correlation between WSiN film thickness and nitrogen concentration (C_N) in WSiN with RF bias power. These results were obtained by auger electron spectroscopy (AES). The WSiN thickness saturates, even though RF bias is raised. That is, the improvement in barrier capability can not be explained only by WSiN thickness because the barrier capability of WSiN is improved by increasing RF bias power. As the RF bias power increases, C_N becomes higher. Thus, it seems the increase in nitrogen affects the barrier capability.

Figure 4 shows x-ray photoelectron spectroscopy of Cu in WSiN. No peak shift is observed, which indicates that Cu-N bonds are not formed. The Cu concentration in WSiN was calculated from these spectra. With no RF bias, it is 2 %, and with RF bias, it is 0.8 %. This means that Cu does not react with N, and hardly any Cu enters the WSiN. These results indicate WSiN is not a compound-forming barrier but a stuffed barrier, which prevents diffusion by stuffing nitrogen atoms into diffusion paths, such as interstitial sites[5].

Nitridation at the Trench Sidewalls

It has not been clarified whether trench sidewalls can be nitridated by ECR plasma because ECR plasma has high vertical directionality to the substrate[6]. C_N at the sidewalls was measured by μ-AES, and the results are shown in Fig. 5. It is over 30 % regardless of RF bias, and WSiN is formed on the sidewalls. The formation of WSiN at the bottom of trench is similarly observed. Applying RF bias raises C_N at the sidewall. Nitrogen is simultaneously reflected and resputtered during nitridation at the bottom of trench when RF bias is applied. It appears that the nitrogen from the bottom hits the sidewalls, which results in their nitridation.

Figure 6 shows the leakage current characteristics of Cu damascene interconnection using WSiN and TiN barrier metal. The leakage current level of WSiN is below 1 nA. This is the same level as that of 50-nm-thick TiN, which has been widely investigated as a barrier metal in Cu interconnection. These results mean WSiN formed on the trench sidewalls can suppress Cu diffusion. We can conclude, therefore, that WSiN formed by ECR plasma nitridation can be used as the barrier metal for Cu damascene interconnection.

3. Conclusion

Extremely thin (<6 nm) WSiN formed by ECR plasma nitridation acts as a good barrier against Cu diffusion. WSiN can be formed at trench sidewalls even though ECR plasma with RF bias has the vertical incident angle to the substrate, and Cu diffusion can be suppressed by this WSiN barrier metal. Using this method, we can form extremely thin barrier metal for Cu damascene interconnection.

Acknowledgment

The authors wish to thank J. Yamada for his advise and encouragement. They would also like to express their gratitude to M. Suzuki for AES analyses.

[1] Present affiliation : SHARP Co., 2613-1, Ichinomoto-Cho, Tenri, Nara 632-8567, Japan

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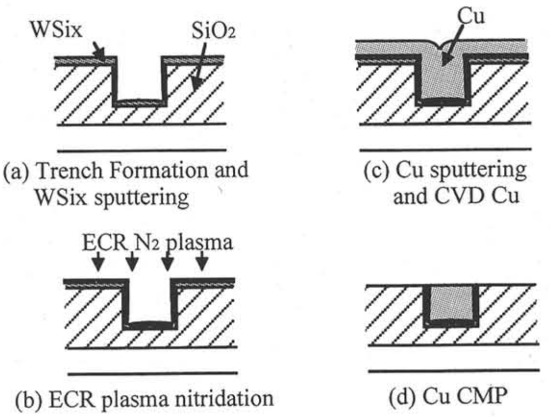

Fig. 1 Fabrication process for Cu interconnections using WSiN formed by ECR plasma nitridation

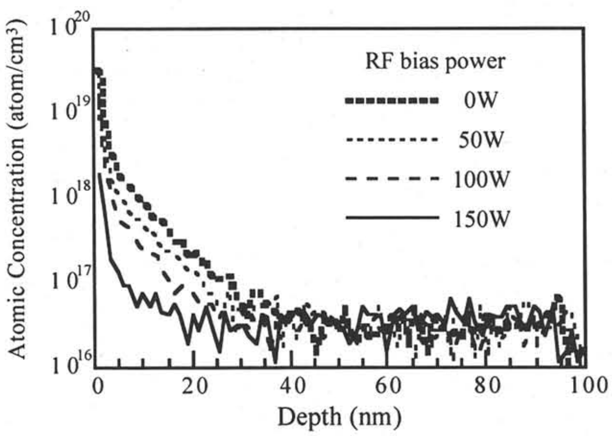

Fig. 2 SIMS depth profiles of Cu in SiO_2 after annealing at 500 °C for 1 h. Cu and WSiN were removed before the measurement.

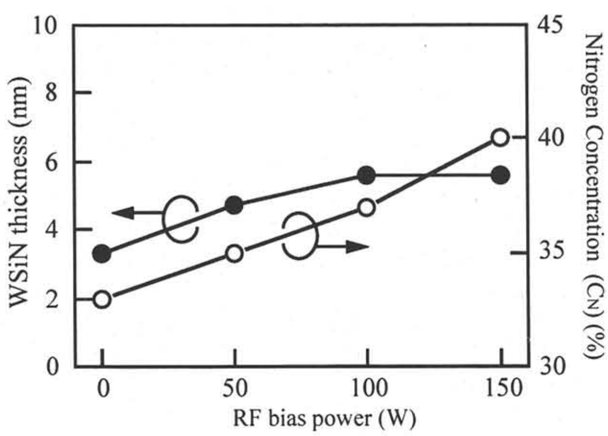

Fig. 3 WSiN film thickness and nitrogen concentration (C_N) in WSiN versus RF bias power during nitridation. These results were measured by AES.

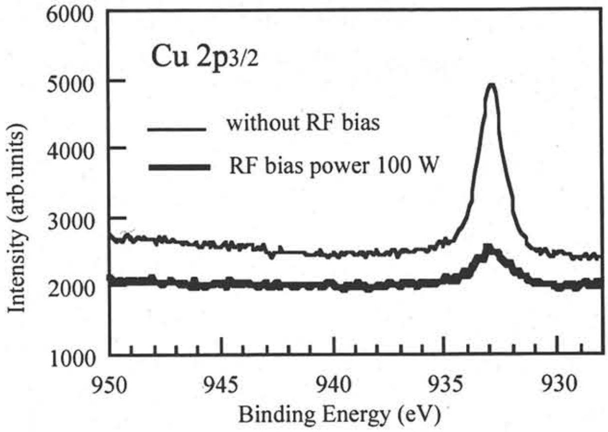

Fig. 4 XPS spectra of Cu in WSiN formed with (100 W) and without RF bias. Samples were annealed at 500 °C for 1 h, and Cu was removed before XPS analysis.

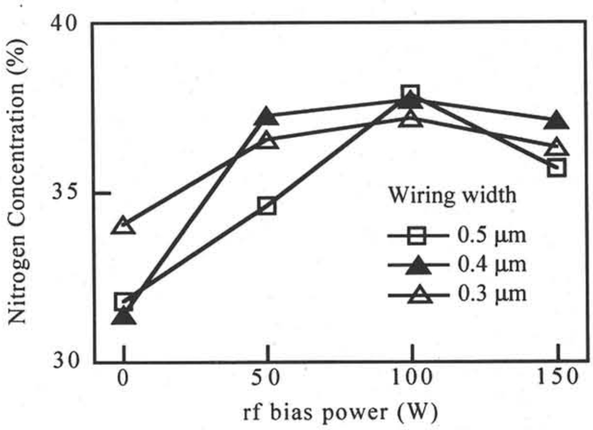

Fig. 5 The nitrogen concentration (C_N) in WSiN as a function of RF bias power with wiring width as a parameter. The nitridation time was 300 s, and the trench depth was 0.6 µm. C_N was measured by µ-AES.

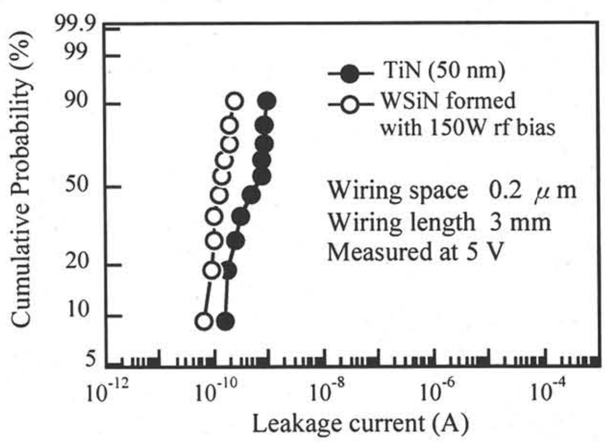

Fig. 6 Leakage current characteristics of Cu interconnection with WSiN and TiN barrier metal after annealing at 400 °C for 1 h. The WSiN nitridation condition was for 300 s with 150 W RF bias. TiN barrier metal was formed by sputtering, and its thickness was 50 nm.