Blanket CVD-W Formed by SiH₄ Reduction of WF₆ on TiN for Planar Interconnection

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A deposition mechanism of CVD-W on TiN by SiH₄ reduction of WF₆ was studied, especially for initial nucleation, and key points for uniform nucleation were clarified, i.e. first, the chemical activation of TiN surface by WF₆ exposure, second, promotion of SiH₄ decomposition on the activated TiN, resulting in an enhancement of W nucleation by trace amounts of Si on TiN surface. In application to the planar interconnection, low junction leakage current and low contact resistance were realized by the deposition sequence developed.

1. Introduction

One of the key issues to realize the blanket CVD-W interconnection which has an excellent step coverage is to develop the glue or adhesion layer on inter-insulating layer such as SiO₂ because blanket CVD-W shows extremely poor adhesion on the insulating films. It is also required that the glue layer has good contact to both type of diffusion layer. Titanium nitride (TiN), which has been developed as the effective barrier layer in aluminum wiring, [1] was shown to satisfy the above-mentioned requirements. [2]-[4] In view of the film formation aspect, however, TiN has a serious problem in initiating the deposition of W on it.

In order to overcome the difficulty, the blanket CVD-W process that is applicable to the formation of W onto TiN glue layer has been developed using a novel SiH₄ reduction of WF₆. In this paper, deposition characteristics of the newly developed SiH₄ reduction process will be shown in conjunction with the initial nucleation features. Also will be given some of the electrical performance of the blanket CVD-W film in CVD-W/TiN/TiSi₂/Si contact structure.

2. Experimental

Depositions were done in a cold-wall batch type LPCVD reactor. WF₆, SiH₄ and H₂ gas were used as the reactant gases and Ar gas as the carrier gas.

In the case of W deposition onto TiN, the gas sequence or the order of the introduction of reactant gases into the reaction chamber plays an essential role for improving the deposition characteristics. We investigated the effect of "WF₆-pretreatment" of TiN surface on the deposition characteristics of SiH₄ reduction of WF₆.

TiN was deposited onto thermally grown silicon dioxide or Si substrate by reactive sputtering followed by rapid thermal annealing in a nitrogen ambient.

3. Results and Discussions

-Deposition Characteristics-

Figure 1 shows the thickness of W films formed by SiH₄ reduction or H₂ reduction onto TiN with and without the WF₆ pretreatment as a function of the deposition time. The
thickness of \( W \) films was measured by cross-sectional SEM observation at the center of 6-inch diam. substrate. Figure 2 shows the sheet resistance maps. As clearly seen in Fig.1, an incubation period of about 90 sec is observed in the case of the \( \text{SiH}_4 \) reduction process without the WF\(_6\)-pretreatment, resulting in poor thickness uniformity as shown in Fig.2. However, newly developed process, in which the WF\(_6\)-pretreatment followed by \( \text{SiH}_4 \) reduction of WF\(_6\) shows linear relation between film thickness and the deposition time without incubation period, resulting in good thickness uniformity. On the other hand, \( \text{H}_2 \) reduction process with and without the WF\(_6\)-pretreatment has an incubation period, resulting in poor uniformity of the film thickness. The WF\(_6\)-pretreatment of TiN has no effects on W nucleation in \( \text{H}_2 \) reduction process.

In order to investigate the effect of the WF\(_6\)-pretreatment on TiN, TiN surface after pretreatment was analyzed by the fluorescent X-ray analysis and ESCA.

Figure 3 shows the fluorescent X-ray signal intensities of Ti and W from TiN with the WF\(_6\)-pretreatment as a function of the pretreatment temperature. Decrease of Ti signal and increase of W signal are observed at high temperature region typically used for the blanket CVD-W process (higher than 400°C), implying WF\(_6\) reacts with TiN and modification of TiN surface occurs during the WF\(_6\) pretreatment.

Figure 4 is the ESCA spectrum from the TiN surface to show the effect of the WF\(_6\) pretreatment for \( \text{SiH}_4 \) and \( \text{H}_2 \) reduction process. In Fig.4, (a) is the spectrum only with the WF\(_6\)-pretreatment, (b) is that exposed
with H₂ for 60 sec after the WF₆-pretreatment and (c) is that exposed with SiH₄ for 60 sec after the WF₆-pretreatment, respectively. In the sample (c), Si signals clearly appear in addition to W signal on the TiN surface by the exposure of SiH₄ after the WF₆-pretreatment. This result shows that decomposition of SiH₄ is promoted only on the TiN surface pretreated with WF₆. It was confirmed that the trace amounts of Si on the WF₆- and SiH₄-exposed TiN surface enhanced the initial nucleation of W deposition.

Figure 5 shows the SEM observations at the initial stage of W deposition with and without the WF₆-pretreatment. With the WF₆-pretreatment dense nucleation of W was observed on TiN. While without the WF₆-pretreatment, it was sparse.

-Electrical Characterizations-

In order to investigate electrical characteristics of the newly developed SiH₄ reduction process for W deposition on TiN, a junction leakage current and a contact resistance for an N⁺ diffusion layer were measured. As shown in Fig.6, for a junction leakage current measurement two types of test pattern were used to clarify the effect of W film stress on a junction leakage current. One is a wide pattern (1125 µm x 1875 µm) covering 130200 contacts of 1.0 µm², the other is a stripe wiring pattern (2.2 µm x 800 µm x 600 wires) contained 120000 contacts of 1.0 µm² which is very similar to actual devices. For a contact resistance measurement the 4-terminal Kelvin pattern was used. The results of junction leakage current and contact resistance were compared with those of AlSi/TiN/TiSi₂/N⁺Si.

![Fig.5 SEM observations at the initial stage of W deposition. (a) is with WF₆ pretreatment and (b) is without WF₆ pretreatment.](image)

![Fig.4 Results of ESCA analysis. (a) is the spectrum only with WF₆ pretreatment, (b) is that exposed with H₂ for 60 sec after WF₆ pretreatment and (c) is that exposed with SiH₄ for 60 sec after WF₆ pretreatment, respectively.](image)

![Fig.6 Test device for junction leakage current measurement.](image)
Figure 7 shows the histograms of junction leakage current at \( V_R = 5V \) for both patterns. In the wide pattern, the leakage current of W films is about six times larger than that of AlSi films. While in the stripe pattern, the leakage current of W films are almost the same as that of AlSi. The higher leakage current in the wide pattern is due to its high tensile stress, while in the stripe pattern the W film stress is reduced by chopping the film and has no visible effects on a junction leakage.

Figure 8 shows the histograms of contact resistance. The contact resistance is almost the same as that of AlSi, and sufficiently low due to the TiN/TiSi\(_2\) structure.

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### Reference