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Contact Plug Formed with Chemical-Vapour-Deposited TiN

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A conformal titanium nitride film was deposited in a thermal LPCVD system, using $TiCl_4$ and NH_3. Due to its superior step coverage, it is possible to form a CVD-TiN plug by a subsequent etchback process. Taking account of the film stress and the Cl content, TiN was deposited at 700 °C with $NH_3/TiCl_4 = 1$ for filling a contact hole, having the stress of 3.9×10^9 dyn/cm^2 and the Cl content of ~2 %. In order to form an ohmic contact, titanium silicide ($TiSi_x$) was also deposited in the same system prior to TiN deposition, using $TiCl_4$ and SiH_4. A typical deposition rate and a resistivity of CVD-$TiSi_x$ were 400 Å/min and 27 μΩcm, respectively.

Introduction

For ULSIs, a contact plug formation is a key technology to fill submicron or smaller contact holes with a high aspect ratio. Chemical-vapour-deposited tungsten (CVD-W) is currently used for such a contact plug. Titanium nitride (TiN), which is used as an adhesion and barrier layer for the CVD-W plug process, will be no longer applicable for contact holes with higher aspect ratio in the future ULSIs, due to the poor step covering of the sputtering method. For this reason, chemical-vapour-deposited TiN (CVD-TiN) with an excellent step coverage has recently attracted a lot of attention.

There are several reactions to form a TiN film, depending upon the source materials. A reaction using $TiCl_4$ and NH_3 as reactants is widely used to form a TiN film applicable to LSI fabrication. In this system, a complete filling of contact holes is easily realized due to its excellent step coverage, leading to a possibility of plug formation with TiN by an etchback process.

In forming a TiN plug, optimization of the film characteristics such as resistivity and mechanical film stress is required. It is also important to lower the contact resistance of TiN plug. With only CVD-TiN , however, it is very difficult to obtain a sufficiently low contact resistance. Therefore a contact layer such as $TiSi_x$ or Ti is indispensable to reduce the contact resistance.

In this work, we propose a simple plug process with CVD-TiN, optimizing its resistivity, Cl content and film stress. In order to obtain a good ohmic contact with the CVD-TiN plug, the deposition of $TiSi_x$ prior to TiN deposition by using $TiCl_4$ and SiH_4 is also investigated.

Experimental

Titanium nitride was deposited onto a 6 inch-diameter substrate in a resistively heated quartz reactor, using $TiCl_4$ and NH_3 as reactants, and N_2 as a diluent. To avoid the formation of so-called yellow adducts, each source gas was introduced into the reactor separately. The $TiCl_4$ delivery line was heated to ~80 °C in order to prevent any condensations of $TiCl_4$ vapourized at 75 °C. An additional SiH_4 gas line is available for an *in-situ* formation of $TiSi_x$ prior to the deposition of TiN. The deposition temperature ranged from 450 °C to 700 °C for TiN and from 700 °C to 800 °C for $TiSi_x$. The $TiCl_4$ flow rate was fixed at 25 sccm for both depositions. The flow rates of NH_3 and SiH_4 were from 25 sccm to 150 sccm and from 25 sccm to 200 sccm, respectively. The N_2 flow rate was controlled to maintain the total pressure equal to 50 Pa.

After the filling of contact holes with a blanket CVD-TiN, an etchback process using a Cl_2 plasma is applied to form a TiN plug.

Results and Discussion

CVD-TiN characteristics

If thick conducting films are used for an etchback plug formation, it is very important to keep the resistivity and the mechanical stress as low as possible in order to avoid a film cracking or an unacceptable

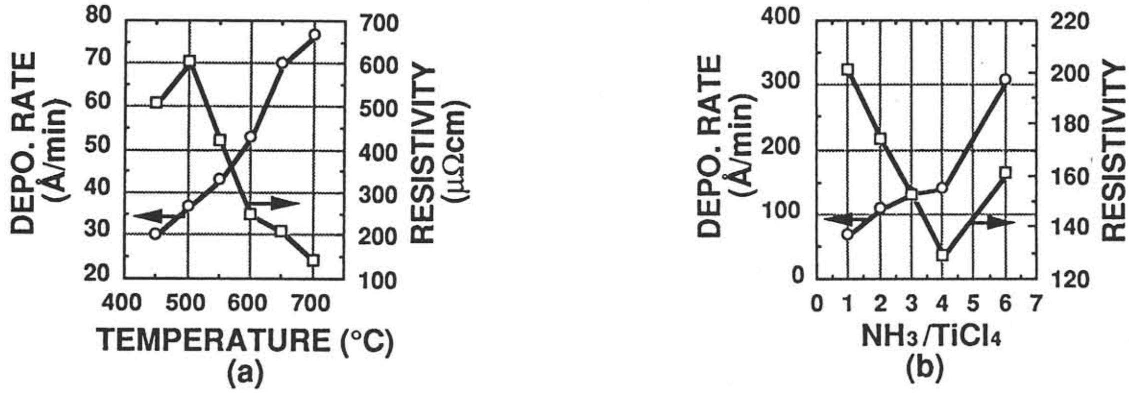

Fig.1. Dependence of the deposition rate and the film resistivity of CVD-TiN on (a) the deposition temperature (NH_3 = 25 sccm) and (b) the flow rate ratio of $NH_3/TiCl_4$ (650 °C).

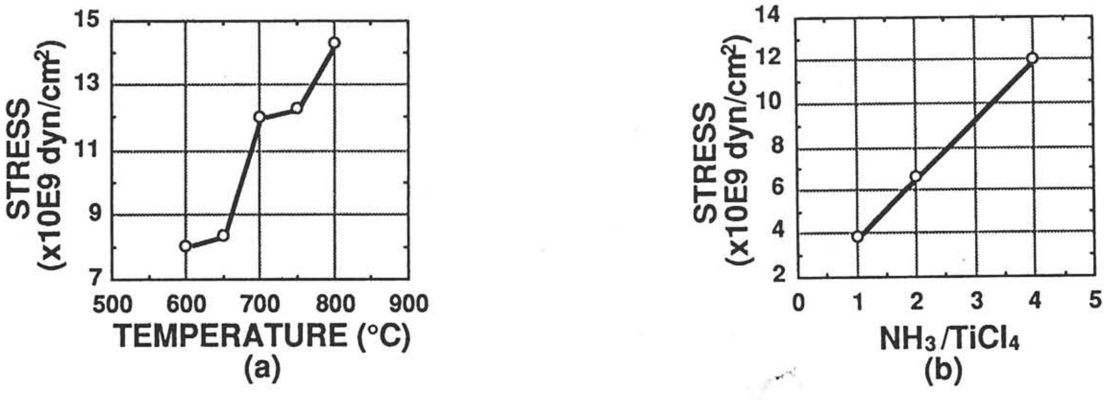

Fig.2. Dependence of CVD-TiN tensile film stress on (a) the deposition temperature (NH_3 = 100 sccm) and (b) the flow rate ratio of $NH_3/TiCl_4$ (700 °C).

increase of the wiring resistance. As shown in Fig.1, the resistivity of the TiN film decreases as the deposition temperature increases or as the flow rate ratio of $NH_3/TiCl_4$ increases. According to a SIMS analysis, the undesirable Cl content decreases from ~10% to ~2% with increasing the deposition temperature. These results indicate that a deposition at a higher temperature with a higher flow rate ratio of $NH_3/TiCl_4$ is preferable. However, it should be mentioned that an excessively high ratio of $NH_3/TiCl_4$ gives more amounts of yellow adducts and leads to the generation of particles.

Figure 2 shows the film stress as a function of the deposition temperature (a) and the flow rate ratio of $NH_3/TiCl_4$ (b). It is shown that the tensile stress can be reduced by decreasing the temperature or the flow rate ratio.

Considering the characteristics mentioned above, TiN was deposited at 700 °C with $NH_3/TiCl_4$ equal to 1 for the filling of contact holes.

TiN plug formation

The superior step coverage of this film makes it possible to fill a submicron contact hole completely with CVD-TiN. By a subsequent etchback process, a TiN plug can be formed. A TiN plug process has advantages over a W plug process. First, due to a good adhesion of CVD-TiN to SiO_2, no glue layer is required. Second, the etchback process is easier compared to that of a W plug with a TiN adhesion layer.

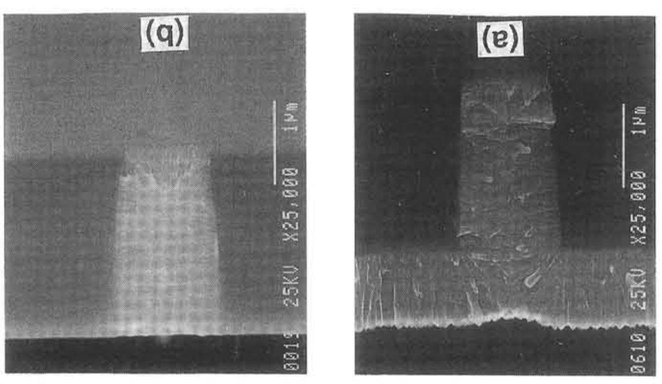

Fig.3. Cross-sectional SEM photographs of CVD-TiN (a) as-deposited (b) after etchback.

Figure 3 shows cross-sectional SEM photographs of an as-deposited (a) and an etchbacked CVD-TiN (b).

Based on typical film resistivities, the resistance of this plug (1.2 μm-diameter, 2.2 μm-depth) is estimated to be approximately 4 Ω. This value is significantly lower than a typical contact resistance. Because the growth of crystalline columns is parallel to the bottom of the contact hole, it is suggested that a TiN plug has good barrier characteristics. Besides, the increase of the effective thickness of the TiN barrier as a result of plug formation would also contribute to this barrier properties.

Basic characteristics of CVD-TiSix

The deposition of titanium silicide is carried out on both Si and SiO_2 substrate, using SiH_4 and $TiCl_4$. A remarkable difference is observed in the dependence of the deposition rate upon the flow rate ratio of $SiH_4/TiCl_4$ for these substrates. The deposition rate and the film resistivity of TiSix on a Si substrate are shown in Fig.4, as a function of the flow rate ratio of $SiH_4/TiCl_4$. The resistivity mostly decreases as $SiH_4/TiCl_4$ increases and a value as low as ~25 μΩm is achieved under the condition of $SiH_4/TiCl_4$ = 8. The deposition rate changes oppositely.

Figure 5 shows the SEM photographs of the surface morphology of CVD-TiSix with $SiH_4/TiCl_4$ equal to 3 (a) and 8 (b). The surface morphology with $SiH_4/TiCl_4$ equal to 8 is slightly smoother than that with $SiH_4/TiCl_4$ equal to 3. This implies that a higher ratio of $SiH_4/TiCl_4$ results in a higher density of nucleation. With $SiH_4/TiCl_4$ equal to 1 or 0, substrate is damaged with some encroachments, as shown in Fig. 6. Hence the flow rate ratio of $SiH_4/TiCl_4$ and the gas introduction sequence are important factors for the application of CVD-TiSix as a contact layer.

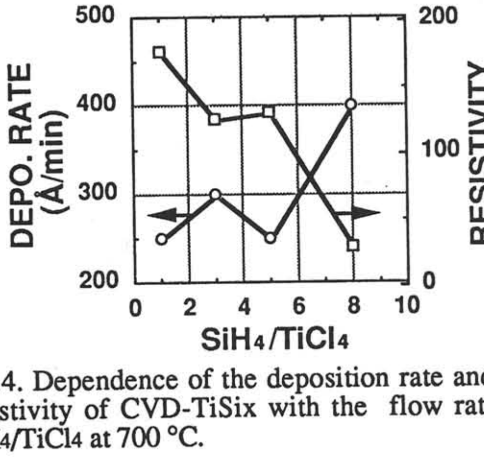

Fig.4. Dependence of the deposition rate and the film resistivity of CVD-TiSix with the flow rate ratio of $SiH_4/TiCl_4$ at 700 °C.

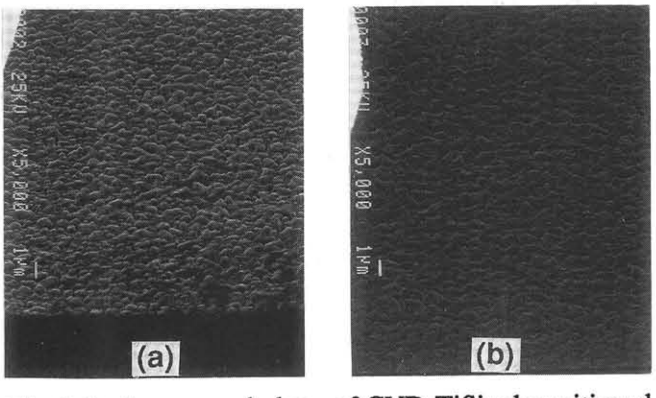

Fig.5. Surface morphology of CVD-TiSix depositioned with (a) $SiH_4/TiCl_4$ = 3 at 700 °C and (b) with $SiH_4/TiCl_4$ = 8 at 700 °C.

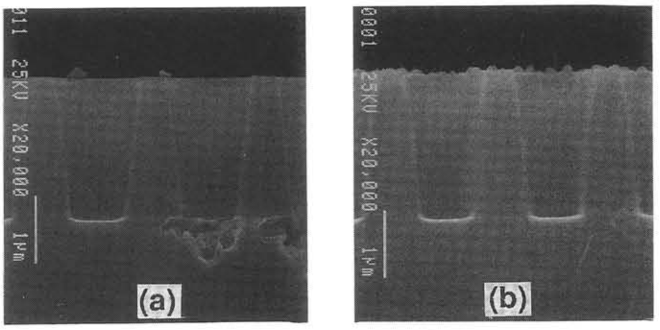

Fig.6 Cross-sectional SEM photographs at the bottom of a contact hole after TiSix deposition at 700 °C with $SiH_4/TiCl_4$ = 1 (a) and with $SiH_4/TiCl_4$ = 3 (b).

Conclusion

Chemical vapour deposition of TiN was carried out, using $TiCl_4$ and NH_3 as reactants, and N_2 as a diluent. Under following conditions: $TiCl_4$ = 25 sccm, NH_3 = 25 sccm, N_2 = 250 sccm, deposition at 700 °C, deposition rate of 76.6 Å/min was obtained. The resultant film resistivity and the tensile stress were equal to 142 μΩcm and 3.9×10^9 dyn/cm^2, respectively. A contact hole was filled completely with CVD-TiN and TiN plug could be formed by an etchback process.

Chemical vapour deposition of TiSix was carried out, using $TiCl_4$ and SiH_4 as reactants and N_2 as a diluent. A film resistivity of 26.8 μΩcm and a deposition rate of 400 Å/min were obtained.

Acknowledgment

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