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Tungsten Plug Technology: Substituting Tungsten for Silicon Using Tungsten Hexaflouride

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W can be substituted for Si with a thickness of ~ 1 μm using Si reduction of WF_6 caused by chemical oxide formed on the Si surface. The substitution reaction strongly depends on the initial number of W nucleation sites(i.e., oxidation conditions) and W coalescence at the micro-channels in the growing W film(i.e. process temperature). The substitution process has been successfully applied to W plug technology together with Si filling by etchback.

1. Introduction

With increasing device integration into ULSI, the planarization of deep contact/via becomes more critical for reliable multilevel metallization. The selective W LPCVD(Low Pressure Chemical Vapor Deposition) [1),2),3)] has been most extensively studied as a most promising process to meet this demand. However, further study is needed to establish the selective W process for practical use; i.e. how to control the initial stage of W nucleation in terms of good selectivity and the W deposition rate on the contacts and vias with different depths and surfaces(e.g. n^+/p^+ contacts).

Another approach for contact/via planarization is based on the etchback process. Non selective W [4)] and poly Si [5)] have been investigated mainly as stuffing materials. In the poly Si filling process, a complex n^+/p^+ doping procedure in poly Si and high electrical resistivity of doped Si compared with W, are serious problems. Substitution of W for Si using WF_6 has been investigated to overcome the problems.

It is well known that W growth by Si reduction of WF_6($Si + 2/3WF_6 = 2/3W + SiF_4$) is generally self-limiting in thickness(≤ 10 nm) [6)]. Recently, it has been discovered that the self-limiting thickness can reach up to 100-200 nm depending on the thickness of native oxide on the Si surface[7),8)]. However, thicker W formation is needed to substitute Si stuffing in deep contacts and vias. In this work, substituting W for Si has been investigated using chemical oxide instead of native oxide on the Si surface at a suitable deposition temperature. And the W plug technology, substituting W for Si, has been applied to vias on W (or WSi_2) interconnections.

2. Experimental

2.1 Substitution of W for Si Using WF_6.

The W CVD was conducted in a hot-wall LPCVD reactor under the following conditions; WF_6/N_2= 20/2000 sccm, total pressure = 98 Pa, and process temperature = 300-500°C. Chemical oxides 1.5 nm thick were formed on non-doped (100) p-type Si wafers by the RCA cleaning method [8]. The samples with an HF dip were also prepared as a reference. In HF dip samples, less than 0.5 nm thick native oxide was grown on the Si surface before W CVD.

In Fig. 1, the resulting W film thickness is plotted against the temperature. The process time was 30 min. In the chemical oxide substrate, the W thickness is a maximum of 700 nm at 300°C and it reduces as the temperature increases. On the other hand, in the samples with HF dip, the W thickness is a maximum of 200 nm at 350°C.

In Fig.2, the resulting W film thickness was plotted against the time. In the chemical oxide substrates, the W thickness increased linearly and then became self-limiting with the time. In the chemical oxide substrate, isolated W clusters were formed at the Si surface at the beginning of the reaction(3 min). A continuous W film with "micro channels (small holes)" was gradually formed(12-30 min). Note that the micro channels were filled with the W (30-60 min). These results show that the self-limiting W film thickness can reach up to ~ 1μm by the presence of chemical oxide at a suitable temperature.

The Auger sputtering analysis of the W film show that the main impurities are oxygen(1-4 atm%) and silicon(≤ 1 atm%). The resisitivity of the film was 70 - 100 $\mu\Omega$.cm, which is almost ten times larger than that of selective W. The density of the film was 14-17 g/cm^3, which was 70-90% of the bulk density.

2.2 Plug applications to vias

Vias of 0.6-1.7 um diameter were formed through a 1 um thick layered insulator film on W and WSi_2 interconnections using triple layer resist lithography and the reactive ion etching. A Si film was deposited by LPCVD using Si_2H_6 because low temperature(≤500°C) deposition is preferable to a via filling process. After a Si etchback of the vias by RIE using SF_6, chemical oxide was formed on the Si surface. Substitution of W plugs for etchback Si plugs was done sequentially in a hot-wall LPCVD reactor. A W plug was successfully substituted for an etchback Si plug. The substituted W plug had a smooth surface, similar to that of the etchback Si plug. Cleaved cross sectional SEM pictures of the samples are shown in Fig. 3. Al metallization and H_2 post-anneal followed before contact resistance measurement.

In Fig. 4, series resistance of 1000 vias(Rc) is plotted against via size(d). The contact resistivity was found to be less than 1 x 10^{-8} Ω.cm^2 from the slope of the linear relationship between Rc and d^{-2}. A large part of this contact resistivity is thought to come from the bulk resistance of the W plugs.

3. Discussion

A model of substitution of W for Si, based on our experimental results, is shown in Fig. 5. The number of nucleation sites on the surface is reduced by the presence of the oxide, with nucleation possibly occuring at weak points(pin hole etc.)[6),8)]. Micro channels are thought to be formed because the volume of Si consumption is almost twice that of the W formed in the reaction [8]. A continuing reaction of WF_6 with Si substrate through micro channels allows thick W film growth.

A W film thickness will continue to increase until micro channels are filled with W. A small amount of Si was detected by AES in the film, suggesting that surface migration of some reducing species(Si etc.) of WF_6 on the W surface is related to the coalescence at the micro channels.

Therefore the resulting W film will be thicker with fewer nucleation sites and with a slower W coalescence process(i.e. forming chemical oxide in stead of native oxide and decreasing the deposition temperature in so far as the Si reduction reaction will not stop).

The resulting W film has higher resisitivity and porosity than the selective W process. Densification of the W film is required to improve W film quality. This can be achieved by adding H_2 or SiH_4 reduction processes in so far as selectivity will not be lost. This technology is easily applicable to Si contact together with barrier metals or silicided junctions.

4. Conclusion

Novel W plug technology substituting W for Si has been developed for submicron via filling. In the substitution process, key process parameters are oxidation conditions at the Si surface and the process temperature. Low contact resistivity of less than $1x10^{-8}\Omega.cm^2$ was sucessfully obtained between W plugs and W (or WSi_2) interconnections, thus showing the feasibility for submicron contact/via plug applications.

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6. References

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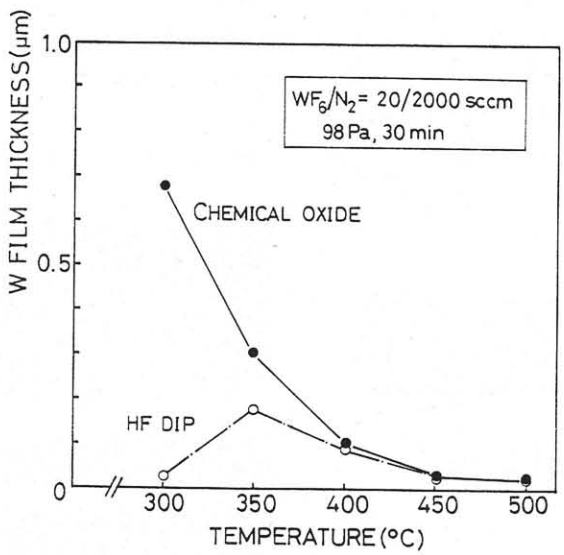

Fig.1 Temperature dependence of W film thickness.

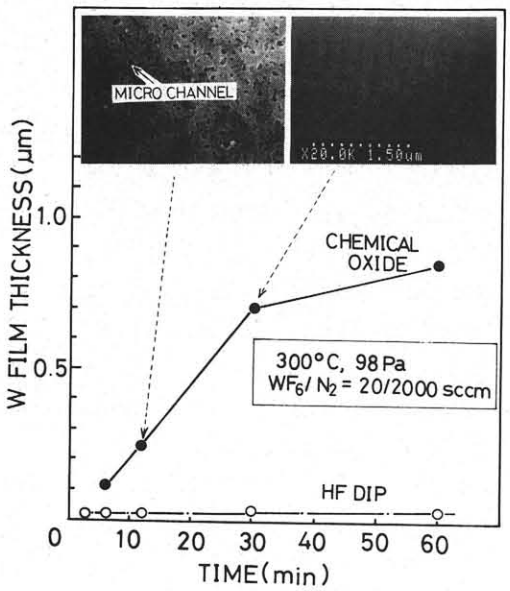

Fig.2 Time dependence of W film thickness.

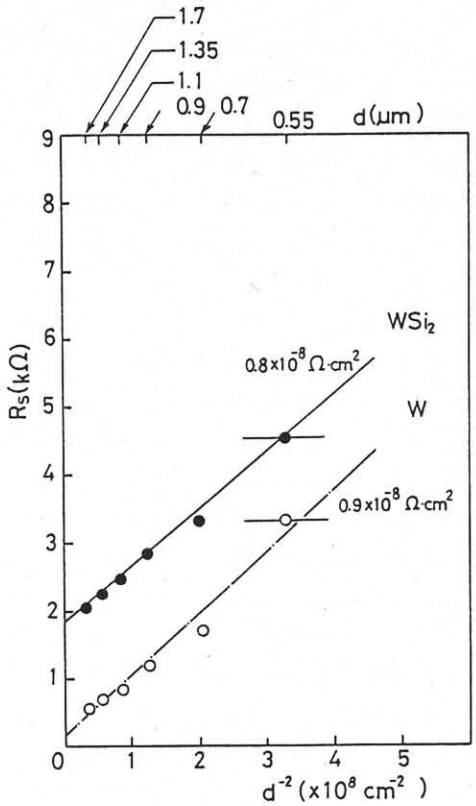

Fig.4 Via size dependence of series contact dependence.

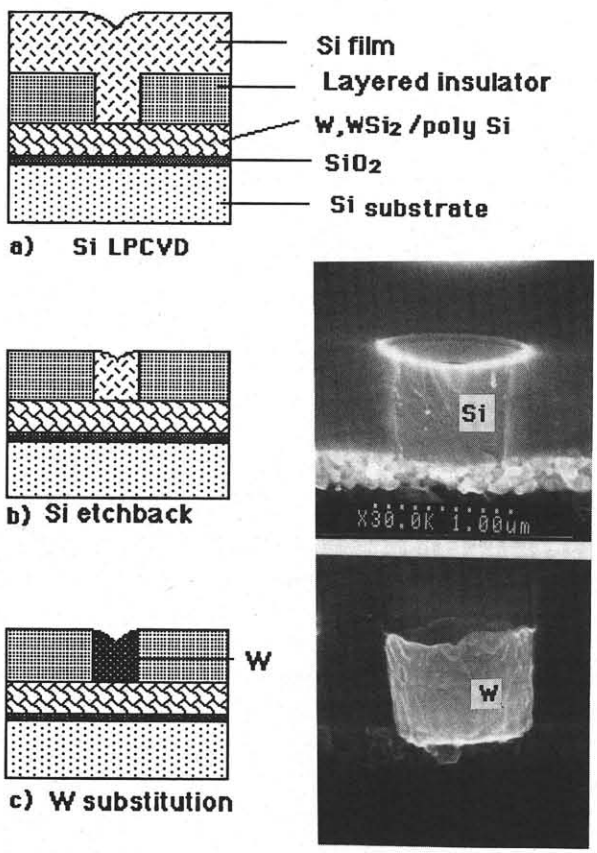

Fig.3 SEM photographs of etchback Si and a W plug(taken from side).

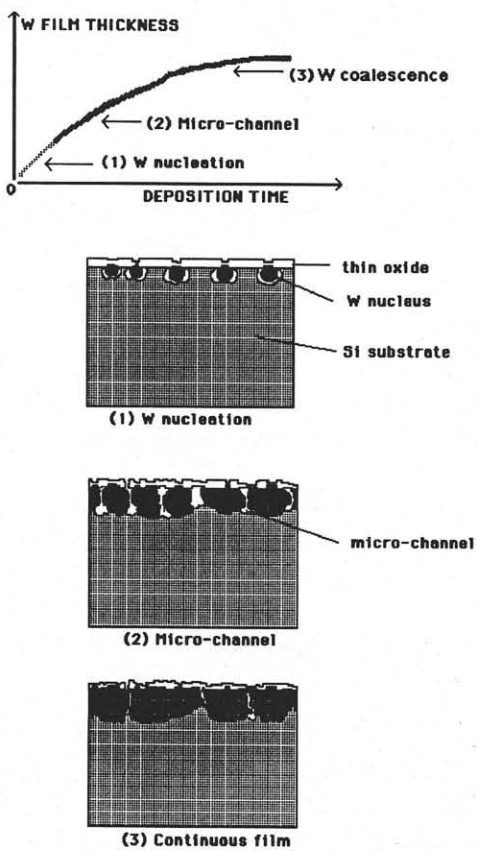

Fig.5 Model of Si substitution reaction in chemical oxide substrate.