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Submicron SiO_2 Hole Filling Characteristics Employing ECR Al Sputtering with High Magnetic Field

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Submicron SiO_2 hole filling was investigated by employing ECR Al sputtering with twice higher magnetic field than the usual condition of 875 gauss. 3000A diameter SiO_2 contact holes without any adhesive layer were satisfactory filled at 350℃, which was much lower than conventional methods. Lateral trenches with 1 μ m depth were also completely filled at 300℃. Al islands which were initially formed densely at both a side wall and a bottom play an essential role in the filling process by acting as the adhesive layer between Al and SiO_2.

1.Introduction

Reliable and low resistant filling technology for deep submicron contact and via holes is a key issue for the development of gigascale ULSI. Recently, Al flowage filling technology near melting temperature by DC magnetron sputtering has been actively researched [1,2] for its simplicity as compared with CVD methods using W [3],Al [4],or poly-Si. Our recent works revealed that ECR (electron cyclotron resonance) plasma was highly ionized and intensified by two times higher magnetic field than usual ECR condition of 875 gauss, and an excellent Al deposition characteristics were obtained [5]. The aim of this work is to examine a capability of this newly developed sputtering method for contact and via holes filling technology.

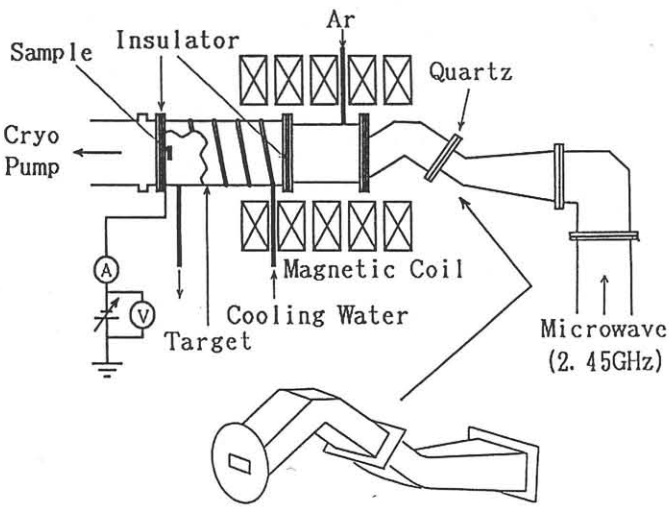

Fig.1 Schematic illustration of the experimental apparatus.

2.Experimental

It has been a serious problem for ECR sputtering that a deposition occurs at a quartz window where a microwave is introduced into a vacuum chamber. We succeeded in overcoming this problem by setting a quartz window behind a bent microwave guide from a cylindrical pure Al target as shown in Fig.1. Al deposition rate of 2000 A/min. was obtained at a very low Ar pressure of $8x10^{-5}$ Torr, and a target bias -600 V. For filling experiments, holes and trenches engraved in a 7000 A thick thermal SiO_2 and lateral trenches with SiN upper wall were used.

3.Results and Discussions

Filling of SiO_2 trenches and holes were investigated at various substrate temperatures. At 300℃, lower submicron holes were filled , while rather wide holes were sometimes not filled as shown in Fig.2. The observation of the initial stage (Fig.3) revealed that the failure was due to a stripping-off of deposited film. A satisfactory filling of holes whose diameter larger than

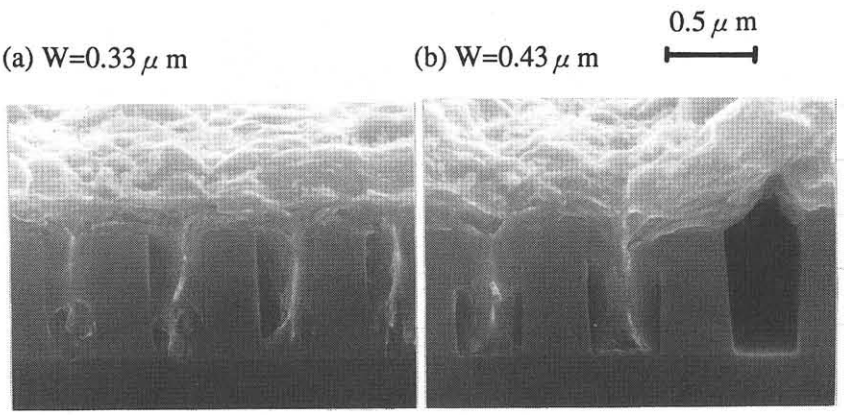

Fig.2 Cross-sectional profiles of SiO_2 trench filling at 300℃.

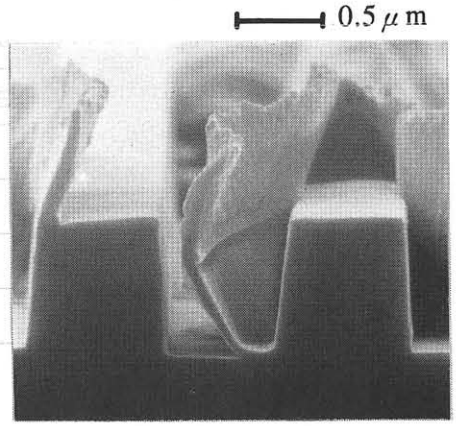

Fig.3 Stripping-off of the Al film after 30 seconds deposition at 20℃.

3000 A was achieved at temperature higher than 350 ℃. A sequence of 3000 A diameter hole filling was shown in Fig.4-a,b,and c. At first small islands of Al were densely formed at both the side wall and the bottom (Fig.4-a), then the upper region of the hole was filled at 2 minutes (Fig.4-b). The region filled with Al further went down to the bottom and the hole was filled completely when 6 minutes passed (Fig.4-c). The same filling sequence was observed in the case of Si holes.

In order to understand the filling mechanisms, Al deposition profiles through a narrow SiN window and filling characteristics into a lateral trench were investigated. Al deposition profile at temperatures lower than 200 ℃ was Gaussian type (Fig.5-a). However, a sweepout of Al particles occurred just under the window at 300 ℃ (Fig.5-b), which indicated an enhancement of surface diffusion by ion bombardment. With further increase in temperature (400 ℃), an aggregation into Al particles became dominant and the sweep-out was suppressed (Fig.5-c). A filling depth L into lateral trenches at 300 ℃ is shown in Fig.6 as a function of time. The filling depth increased initially, however, it saturated at 1.2 μ m after 12 min. The SEM photograph of lateral trench filling is shown in Fig.7. The saturation indicates that the filling can never exceeds the area where Al islands were initially formed. It is considered that the densely formed Al islands played as an adhesive layer when the Al front proceeded to deep in the hole. Assuming that the filling proceeded by some diffusion mechanism, then L is proportional to $(D\tau)^{0.5}$, where

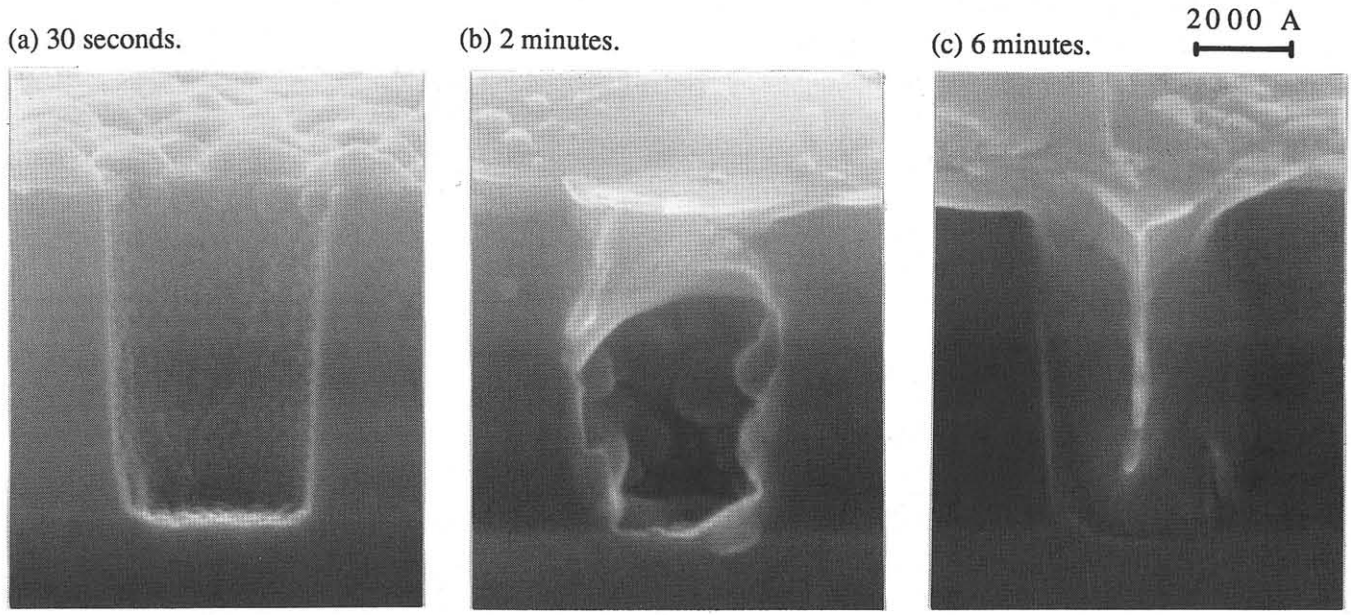

Fig.4 Sequence of deep submicron SiO_2 contact hole filling process at substrate temperature 400 ℃.

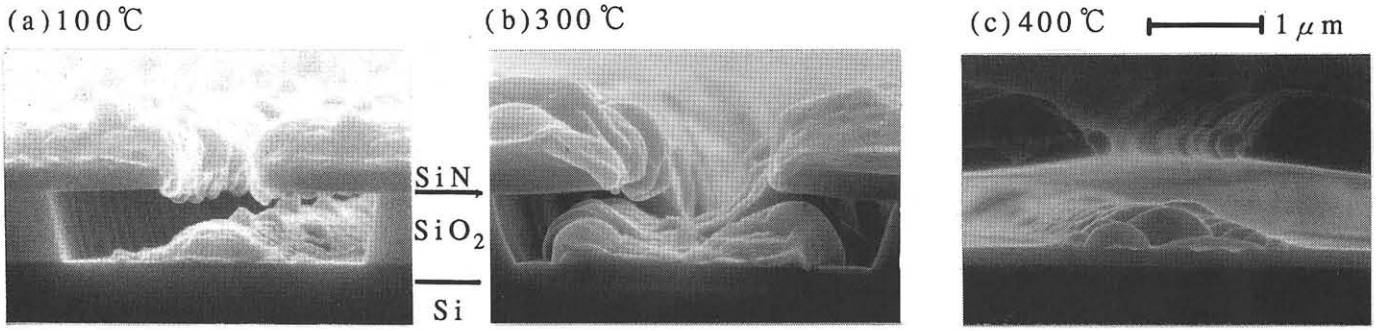

Fig.5 Al deposition profiles through a SiN window on SiO_2 substrate.

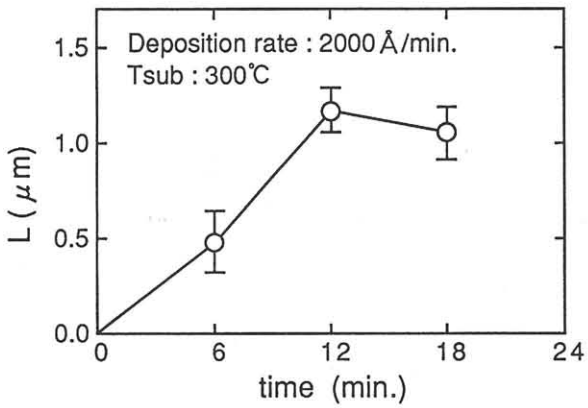

Fig.6 Lateral filling depth L as a function of deposition time at 300℃ .

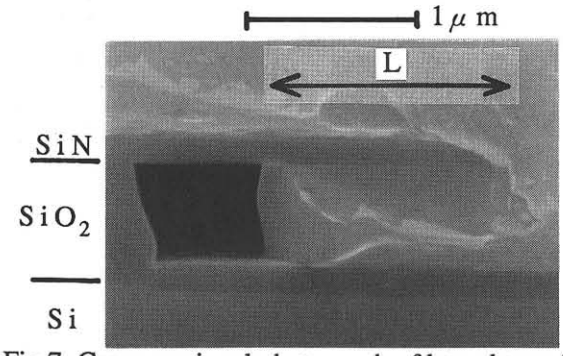

Fig.7 Cross-sectional photograph of lateral trench filling with L=1.2 μm at 400℃, 12 min..

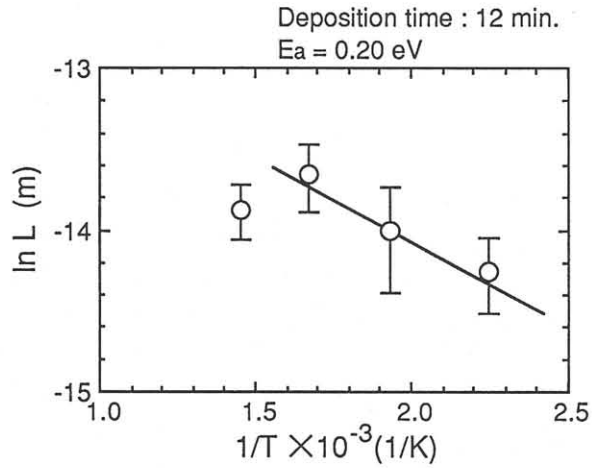

Fig.8 Lateral filling depth L as a function of temperature.

$D=D_0\exp(-Ea/kT)$, and τ is a deposition time. Figure 8 shows temperature dependence of a mean lateral filling length L at 12 minutes. More than 5 identical trenches were averaged over for measuring L at each temperature. In estimating the activation energy Ea, the data at 400℃ was omitted since there was the considerable difference in the initial deposition profiles as already shown in Fig.5. The activation energy 0.20 eV was obtained from the linear relationship between ln L and 1/T observed at temperature below 300℃. It is speculated that the excess vacancies introduced by ion bombardment at the surface reduced the activation energy at grain boundaries.

4.Conclusions

3000 A diameter SiO_2 contact holes with aspect ratio 2 were, for the first time, satisfactory filled at 350℃, which is lower than that used in the conventional DC magnetron sputtering. The initially formed dense Al islands played an essential role in the filling process by acting as the adhesive layer between Al and SiO_2. A large perpendicular component of incoming Al flux due to very low Ar pressure (8×10^{-5}Torr), and an enhancement of diffusion by ion bombardment effect further assisted the SiO_2 hole filling.

References

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