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Ion-Assisted Low-Temperature Surface Reflow of BPSG for Highly-Reliable Contact Metallization

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A new low-temperature surface reflow process of borophosphosilicate glass (BPSG) induced by the assistance by low-energy ion bombardment in Ar plasma has been proposed. By using the ion-assisted surface reflow of BPSG we have succeeded in rounding the contact hole edges at a temperature as low as 450°C. The rounding of the contact hole edges accomplishes an excellent step coverage of sputter-deposited metal films, which has been confirmed by Ta film deposition on the rounded contact hole edges.

INTRODUCTION

As ULSI devices continue to shrink in size, the aspect ratio of contact holes increases. As a result, achieving good metal coverage at small contacts becomes a critical issue in metallization, because the sharp edge of contact window and the deep hole induce the formation of overhangs, voids or cracks in the deposited metal films[1)]. The purpose of this paper is to describe the technology to realize highly reliable contact metallization. By using precisely controlled low-energy ion bombardment process, we have succeeded in inducing surface reflow of BPSG films at a temperature as low as 450°C. We have observed that the rounding of the contact hole edges due to the surface reflow is very effective in achieving an excellent step coverage of sputter-deposited metal films.

EXPERIMENTAL

Borophosphosilicate glass films were deposited on bare Si (100) wafers by atmospheric pressure chemical vapor deposition (APCVD) at 300°C. BPSG film thickness was 1μm. The contact holes were formed by reactive ion etching (RIE) after the densification annealing of the BPSG films at 950°C for 20 minutes in N_2 ambient. The contact hole size was 1μm in diameter.

The procedure described above was used to study the effect of the BPSG film composition and that of the ion bombardment energy on the rounding of contact hole edges. The bombardment energy of ions incident on the substrate surface is precisely controlled by employing the dual-frequency-excitation plasma processing equipment[2-4)]. The edge rounding was made by Ar ion bombardment with the parameters indicated in Table I. To control the ion energy we have changed the substrate RF-power from 0 W to 50 W. The substrate RF-power of 0 W corresponds to an ion energy of 9 eV and the RF-power of 50 W, to 29 eV.

In order to evaluate the effect of contact edge rounding on the metal step coverage, Ta films were deposited on the samples with or without the ion assisted reflow and their features were compared by Scanning electron microscope (SEM) observation. Ta films were deposited by sputtering also using a dual-frequency-excitation plasma chamber at room temperature. We have carried out both the Ar plasma irradiation and the Ta film deposition without breaking the vacuum using a cluster chamber system.

Table.I: Parameters of Ar ion bombardment process.

Ar pressure	30mTorr
plasma irradiation time	1 hour
ion flux density	1.4×10^{16} ions cm^{-2} sec^{-1}
target RF	200W (100MHz)
substrate RF	0 ~ 50 W (14.76MHz)
substrate temperature	450°C

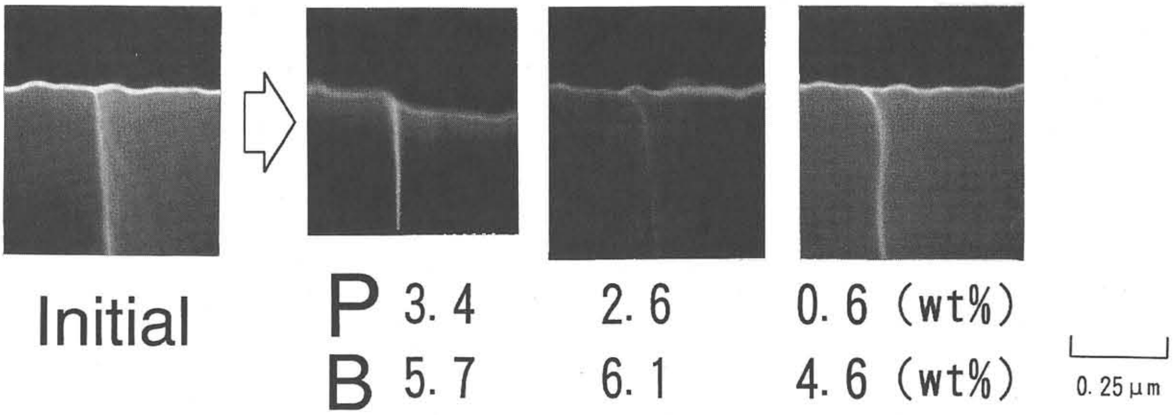

Fig. 1 SEM cross sections of contact hole edges before and after surface reflow for three different composition of BPSG films.

RESULTS AND DISCUSSION

Scanning electron microscope cross sections of contact hole edges are shown in Fig. 1 before and after Ar plasma irradiation for three different compositions of BPSG films. The bombardment energy of ions incident on the substrate surface is precisely controlled at 9 eV. As is seen in Fig. 1, the change in the boron and phosphorous concentration in the BPSG film results in different features of edge rounding under the same ion bombardment condition. This suggests that the rounding is mainly caused by the glass flow occurring at BPSG film surface induced by the low-energy Ar ion bombardment, and not by the physical sputtering effect. It should be noted that the ion-assisted surface reflow occurs at a temperature as low as 450°C.

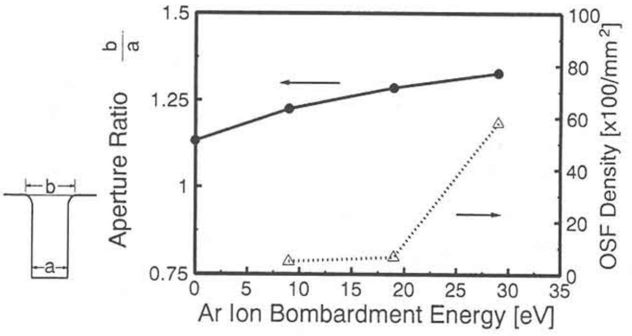

Fig. 2 Ion bombardment energy dependence of aperture ratio and OSF density.

Figure 2 shows the aperture ratio and oxidation stacking faults (OSF) density as a function of the Ar ion bombardment energy. The aperture ratio is defined as b/a as shown in Fig. 2. Here, "b" is a diameter of the aperture of the contact window, and "a" is that at the bottom of the contact hole. SEM cross sections of the contact holes are also shown in Fig. 3 for ion energies of 9 eV and 29 eV. It is clear that a larger rounding effect is obtained with a higher energy, but there is also the increase in the OSF density as the energy increases. Therefore the ion bombardment energy must be precisely controlled at an optimum low energy.

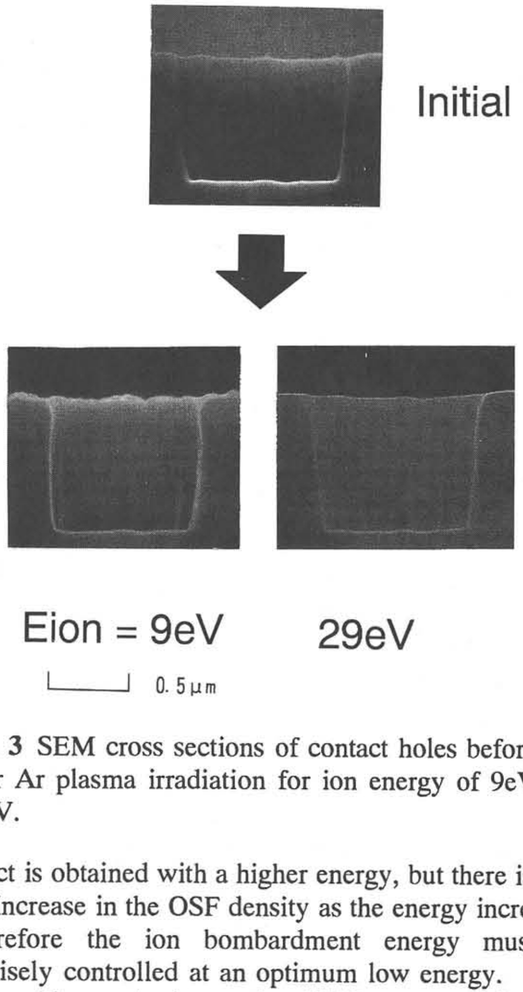

Fig. 3 SEM cross sections of contact holes before and after Ar plasma irradiation for ion energy of 9eV and 29eV.

Figure 4 shows the SEM cross sections of contact holes covered with thin Ta films. Figure 4 demonstrates the metal coverage at the contact hole edges with (b) and without (a) Ar plasma irradiation, which was conducted for BPSG surface reflow before the metal deposition. Without the ion-assisted surface reflow, we can see the formation of overhangs at the sharp edges of contact holes as shown in Fig. 4(a). On the contrary, with the surface reflow, wa can eliminate

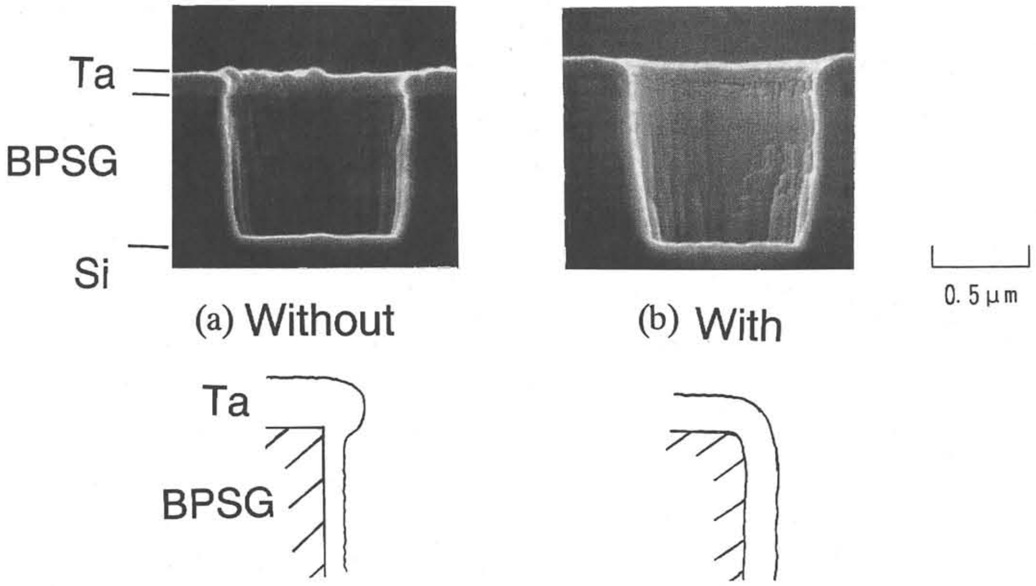

Fig. 4 SEM cross sections of contact holes covered with thin Ta films for the samples without (a) and with (b) Ar plasma irradiation, which was conducted for BPSG reflow before the metal deposition.

the formation of such overhangs as shown in Fig. 4(b). Figure 5(a) shows the effect of the surface reflow on step coverage of the contact hole metallization. The definitions of step coverage are shown in Fig. 5(b). Where t_a is a Ta film thickness on the top surface of the BPSG film, t_b is a Ta film thickness on the vertical wall of the contact hole, and t_c is a Ta film thickness on the bottom of the contact hole. It is clearly seen from this graph that the ion-assisted surface reflow indeed improves the step coverage of the contact hole metallization.

CONCLUSION

We have demonstrated that the improvement in the contact metallization has been achieved by the introduction of the low-energy ion-assisted surface reflow of BPSG films. It has been confirmed that the rounding efficiency depends on the concentration of boron and phosphorous in the BPSG film and the ion bombardment energy. This process will serve as an essential technology of highly-reliable metallization scheme for high-aspect-ratio and ultra-small-dimension contact holes.

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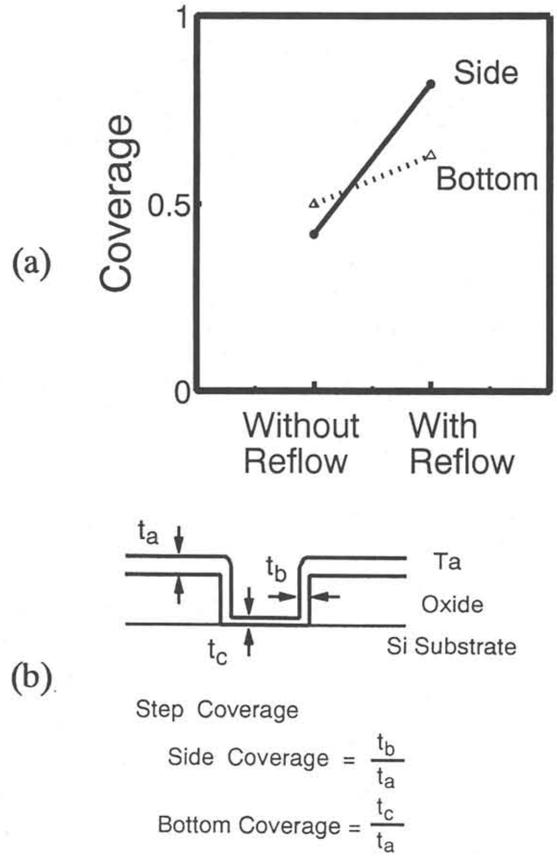

Fig. 5 Difference of step coverage by the ion-assisted surface reflow (a). Definitions of step coverage (b).

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