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Low Damage In-Situ Contact Cleaning Method by a Highly Dense and Directional ECR Plasma

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In-situ ECR plasma cleaning process has been applied for the cleaning of sub half-micron size contacts in DRAM devices. ECR plasma cleaning shows superior performance over RIE, RF plasma, and dilute HF wet cleaning methods. The high density but low incident energy of the ECR plasma process minimizes the surface damage. In addition, the high directionality of the ECR plasma process effectively removes the surface impurity from the sub half-micron size contacts and results in a low and stable contact resistance. The ECR plasma cleaning process also reshapes the contact profile in favor to the contact filling by Al-reflow. ECR plasma cleaning method has been proven to be extremely effective for contact cleaning and shows great promises as a future contact cleaning technology of the choice.

1. Introduction

Contact cleaning has been one of the main issues for lowering the contact resistance in the sub half-micron DRAM devices. The interface quality between contact materials is one of the key factors in determining the contact resistance. Inadequate cleaning of contacts before metallization leaves third phases such as oxide layers and polymeric residues on the contact bottoms, and results in high contact resistance and poor interfacial quality. As the contact size decreases and the aspect ratio increases, the surface quality of the contacts becomes more important to obtain low contact resistance. In this paper, a contact cleaning method using in-situ ECR plasma has been introduced as a viable method of cleaning small size contacts for the sub-half micron era of DRAM technology.

2. Experimental

For this experiment, ECR plasma and RF plasma were installed in a cluster sputtering machine for in-situ cleaning and subsequent Al-reflow metallization without vacuum break. Ar and an Ar+H_2(10%) mixture were used as ECR plasma gases at a microwave power of 1100W and an RF bias of -100V. For comparison, conventional RIE and HF wet cleaning methods were also investigated. A mixture of CF_4 and O_2 gas was used for RIE cleaning, and diluted HF (DI water : HF = 100 : 1) was used for HF wet cleaning method. N+ and P+ contact resistances have been investigated by an electrical measurement system, surface damage by therma wave and transmission electron microscopy (TEM), contact filling characteristics by scanning electron microscopy (SEM), and impurities by Auger Electron Spectroscopy (AES), respectively.

3. Results and Discussion

Dependence of N+ and P+ contact resistances on the cleaning methods of 0.35μm size contacts is shown in Figure 1. N+ contact resistance for each cleaning method does not vary much but the P+ contact resistance varies significantly. RF cleaning shows an abnormally high P+ contact resistance and the lowest P+ contact resistance is obtained with the Ar ECR plasma cleaning. The increase of P+ contact resistance as the contact size decreases was minimal with the Ar ECR plasma cleaning as shown in Figure 2. RF cleaning again shows a large increase in P+ contact resistance as the contact size decreases. P+ contact resistance is mainly affected by the interfacial quality and Ar ECR plasma cleaning seems to be most effective in removing the unwanted oxide and polymeric residue at the interface.

HF cleaning is one of the most commonly used wet cleaning method. Figure 3 shows the gate contact resistance distribution of HF wet and Ar ECR plasma cleaning methods. While the metal-to-gate contact resistances with the Ar ECR plasma cleaning are low and stable as shown in Figure 3, those with the HF cleaning are very high and unstable, although the metal-to-active contact resistances are compatible as shown in Figures 1 and 2. The reason for this poor metal-to-gate contact resistances by the HF solution is because the HF cleaning efficiency is quite different between the oxides formed on the gate material and on the active silicon. HF wet cleaning method must be less effective in removing impurities from the bottom of small size contacts with high aspect ratio because the cleaning mechanism involves chemical reactions and diffusion of etchant and reaction products. This disadvantage of the HF cleaning will become worse as the contact size decreases to sub-quarter micron size.

The relatively high contact resistance of RIE cleaning can be explained by figure 4. The Auger spectra revealed that contacts opened by dry etching technique contained polymeric residues as well as oxide layer, and that additional RIE cleaning was not able to remove them. On the other hand, etching 70Å of the silicon surface by sputtering was enough to remove the impurities from the silicon surface and this indicates that sputtering was effective in removing the surface impurities. However, in the case of RF cleaning, resputtering of ILD materials on the contact bottoms due to the poor directionality of the incident sputtering species and the lifting of barrier material upon subsequent Al-reflow metallization, as shown in Figure 5, seems to be responsible for the abnormally high P+ contact resistance. The Therma Wave spectra and TEM micrographs in Figure 6 revealed a thicker damaged silicon layer by RF cleaning. Little damage by the Ar ECR plasma is believed to be the benefit of the low incident energy of sputtering species.

Contact cleaning methods also affect the contact filling characteristics of Al-reflow process through reshaping of the contact profile. In Figure 7, while a protrusion in the middle of contact wall was produced by the different etch rates of the HF cleaning for different ILD materials and caused the formation of a void, the Ar ECR plasma cleaning modifies the contact profile in favor to Al-reflow by rounding off the top opening of contacts and also by removing the protrusion produced by the HF wet cleaning. The ability of the ECR plasma cleaning to improve the contact profile for better Al-reflow is due to the high directionality of incident sputtering species.

The cleaning effect of the ECR plasma can be improved further by using a mixture of Ar and H_2 plasma gases. The comparison of P+ contact resistances between Ar and Ar+H_2 ECR plasma is shown in Figure 8. The Ar+H_2(10%) ECR plasma cleaning resulted in lower P+ contact resistances and the amount of increase in P+ contact resistance as the contact size decreases is less than that of Ar ECR plasma cleaning. The low contact P+ resistance is attributed to the formation of an uniform and high quality $TiSi_2$ layer as shown in the XRD analysis in Figure 9. The mechanism of the promotion of $TiSi_2$ formation by Ar+H_2 ECR plasma cleaning, however, is yet to be known.

4. Conclusion

The contact cleaning method using in-situ ECR plasma shows a superior performance over other cleaning methods such as RIE, RF plasma, and HF wet cleaning. The high density but low incident energy of ECR plasma minimizes the surface damage, and the high directionality of the ECR plasma not only effectively removes the surface impurities from the sub-half micron contact sizes, but also reshapes the contact profile in favor to the contact filling by Al-reflow. ECR plasma cleaning has been proven to be extremely effective in obtaining low and stable contact resistance and shows great promises as a future contact cleaning technology for the sub-half micron era of the DRAM devices.

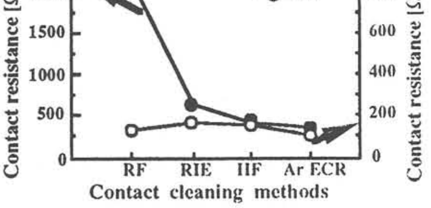


Fig.1 N+ and P+ contact resistances of 0.35um contact size as a function of different cleaning methods.

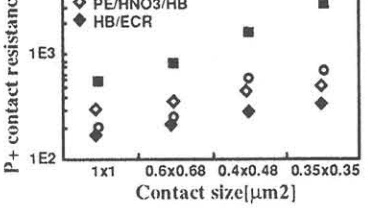


Fig.2 Comparison of p+ contact resistances by different cleaning methods.

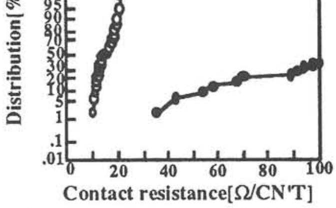


Fig.3 The cummulative distributions of metal- to-gate contact resistance by the Ar ECR and the HF cleaning methods.

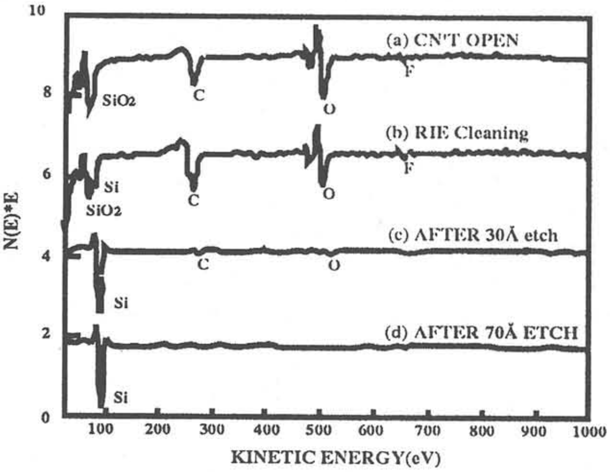


Fig.4 Polymer analysis by the Auger Electron Spectroscopy at large patterned area.

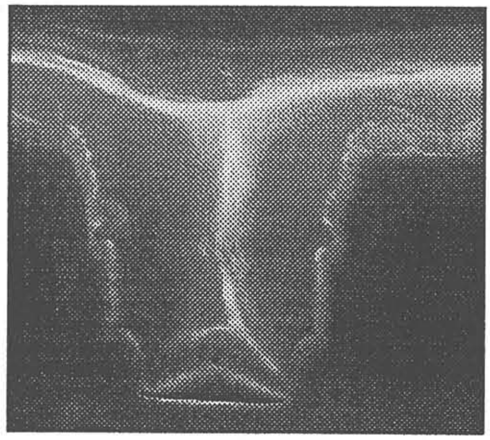
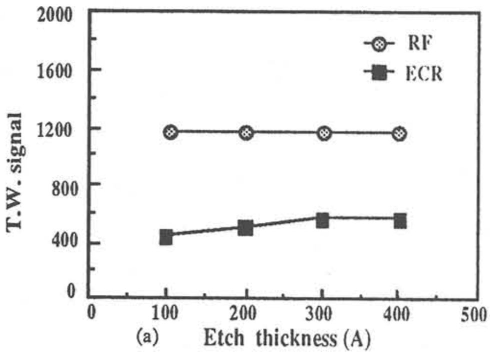
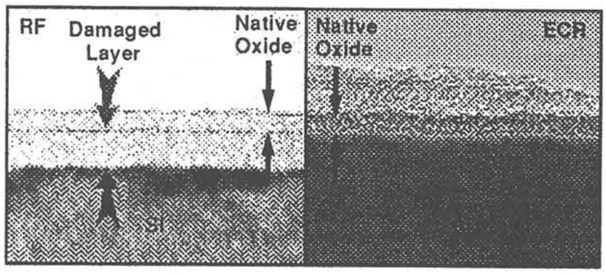


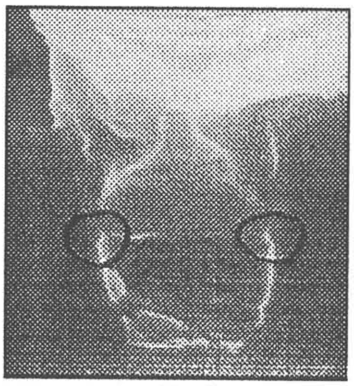
Fig.5 SEM micrgraph of barrier metal lifting at the contact bottom when the RF cleaning was applied.



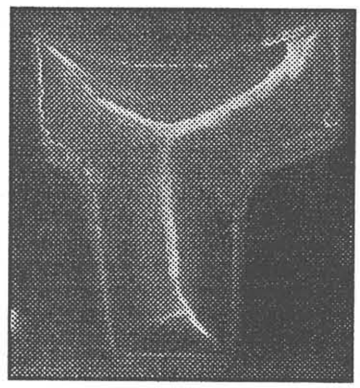


(b)

Fig6. Comparison of surface damage by the Ar ECR plasma cleaning and the RF cleaning methods. (a) T.W signals as a function of etch thickness. (b) TEM micrographs after RF and ECR plasma cleaning.



(a)



(b)

Fig.7 The effect of cleaning method on Al-Reflow process. (a)The HF cleaning and (b) The ECR plasma cleaning.

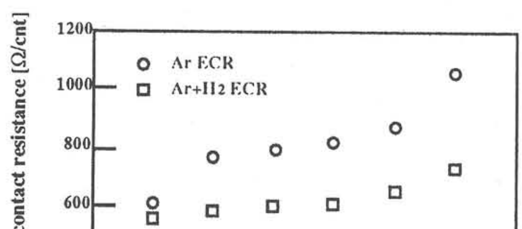


Fig.8 Comparrison of P+ contact resistances obtained by the Ar-ECR and the Ar+H2 ECR plasma cleaning.

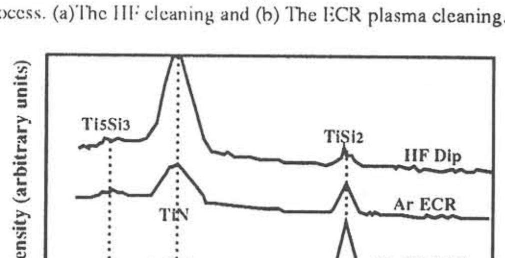


Fig.9 XRD analysis of TiSi2 layers formed by Ti nitridation process after surface cleaning.