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Prediction of Abnormal Etching Profile at High-Aspect-Ratio Via/ Hole Etching by using On-wafer Monitoring System

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1. Introduction

The plasma etching process is widely used for the fabrication of ULSI devices, solar cells, LCD, MEMS, and so on. However, the profile failures, such as bowing, etch stop and twisting, have been reported at high-aspect-ratio hole etching (Fig. 1) [1]. To avoid the failures, we have to predict the ion trajectory and etching profile precisely by using the information (potential, etc) around the hole. In this article, we developed the ion-trajectory prediction system at high-aspect-ratio hole by combining the on-wafer monitoring technique and sheath modeling for explaining and predicting the etch stop and twisting.

2. Concept of ion-trajectory prediction system

We have developed the real-time damage prediction system (Fig.2(a)). In this system, the damage is predicted by using the information from the on-wafer sensors. For this prediction system, we developed the electron temperature /density monitoring sensor and charge-up sensors [2,3]. The charge-up sensor also provides the sidewall resistances of holes. To predict ion trajectory in the hole, we have to obtain the potential distribution around the hole. In this paper, we calculated the potential by using the electron temperature, electron density, surface potential and sidewall conductivity from the on-wafer sensors (Fig.3).

3. Prediction of potential distribution

Fig.4(a) shows the simulation model of this work. The potential at the right half around hole was calculated. The charge accumulation and sidewall conductivity were also considered. (Fig.4(b)). Fig.5 shows the calculated potential distribution around the SiO_2 hole with the aspect ratio of 15. The hole bottom was positively charged, which was due to the electron shading effect. Fig. 6(a) shows the calculated and measured charge-up potential (the potential difference between the hole top and bottom) as a function of sidewall resistance. The charge-up potential drastically decreases by decreasing the sidewall resistance. This means the positive charge is reduced by the current flows at the sidewall when the sidewall resistance is low (Fig.6(b)). In addition, the simulated charge-up potential was almost the same value as the measured one, proving the validity of this method.

4. Ion-trajectory prediction

Fig. 7 shows the calculated potential distribution and ion trajectory as a function of sidewall resistance, using the actual values measured by on-wafer sensors. It is found that the ion trajectories also varied significantly by changing the sidewall resistivity. Fig. 8 shows the calculated potential distribution and ion trajectory as a function of hole depth. While the ions reached the hole bottom at the small depth, the ions cannot reached the hole bottom at the high aspect ratio. Fig.9 shows the calculated charge-up potential as a function of aspect ratio. This indicates that both ions and electrons cannot reach the hole bottom above the aspect ratio of 15, which causes etch stop. Accordingly, it is found that this system can predict the etch stop phenomena.

5. Twisting prediction

It is reported that the twisting is due to the small space between holes. To predict the twisting phenomena, we prepared the three kinds of simulation models, such as Fig.10. By using these, we can monitor the change of ion trajectory, causing the twisting. Fig. 11 shows the calculated potential distribution and ion trajectory as a function of the space between the holes. The charge-up potential at the small space was almost the same as that at the large space, however, the ion trajectory at the small space was distorted more than that at the large space. At the space of less than 20nm, the ions are accelerated to the opposite side to the space, which did not reach the depth of the 1μm (aspect ratio: 10). This corresponds to the actual etching profile at Fig.11(b). As space decreases due to resist pattening, the positive charge accumulated at the adjacent hole affects the ion trajectory (Fig12). Accordingly, it is found that this system can predict the twisting phenomena.

6. Conclusions

Ion-trajectory prediction system at the high-aspect-ratio hole etching was successfully developed by combining the on-wafer monitoring technique and sheath modeling. This system revealed that the sidewall conductivity strongly affects the charge-up and ion trajectory in the high-aspect-ratio hole. It also predict the etch stop and twisting phenomena. This prediction system is an effective tool for developing the nano-scaled fabrication.

Acknowledgements

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References

[1] Y. Yang, et. al., *Proc. Int. Interconnect. Tech. Conf.* (2008) 90.
[2] H. Ohtake, et. al., J. Vac. Sci. Technol. B 25 (2007) 400.
[3] B. Jinnai, et. al., J. Vac. Sci. Technol. B25 (2007) 2808.

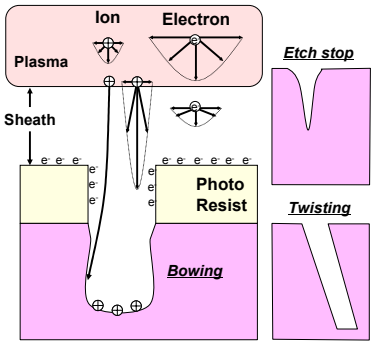

Fig. 1 Bowing, etch stop and twisting due to the electron shading effect in the high aspect ratio holes.

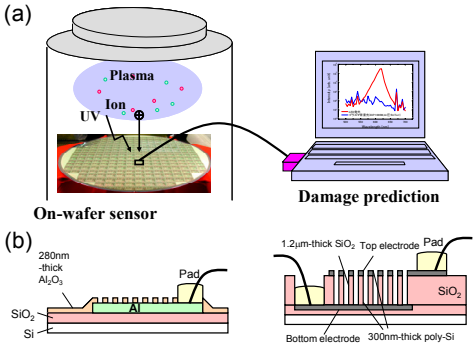

Fig. 2 (a) Concept of real-time damage prediction system by using on-wafer sensors. (b) Electron temperature/ density monitoring sensor and charge-up sensor

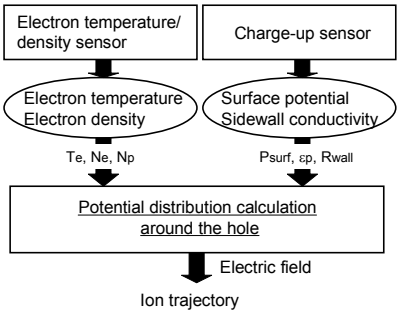

Fig. 3 Concept of ion-trajectory prediction system in this study. Accurate prediction of ion trajectory can be achieved by using measured value around hole by on-wafer sensors

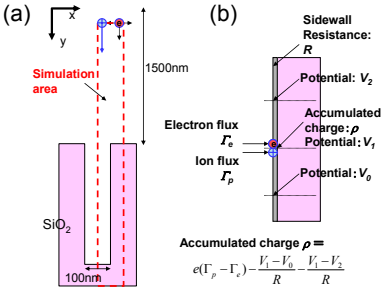

Fig. 4 (a) Simulation model of this work. Potential at the right half around a hole is calculated. (b) Charge accumulation model at the sidewall of holes, considering sidewall conductivity.

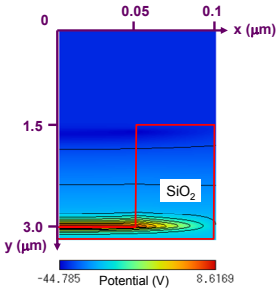

Fig. 5 Calculated potential distribution around the SiO_2 hole. (sidewall resistance: $1x10^{16}\Omega$, surface potential: -40V, electron temperature: 4.3eV, electron density $4x10^9cm^{-3}$).

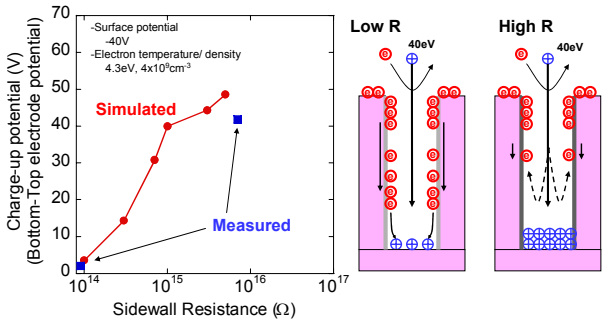

Fig. 6 (a) Calculated and measured charge-up voltage as a function of sidewall resistance. (b) Mechanism of charge-up reduction by decreasing the sidewall resistance.

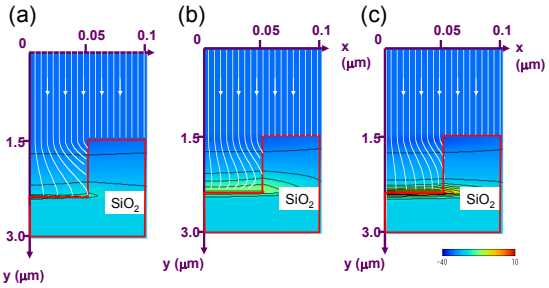

Fig. 7 Calculated potential distribution and ion trajectory (white line) at the sidewall resistance of (a) $2.5x10^{14}\Omega$, (b) $5x10^{14}\Omega$ and (c)$3x10^{15}\Omega$. (surface potential: -35V, electron temperature: 4.3eV, electron density $4x10^9cm^{-3}$).

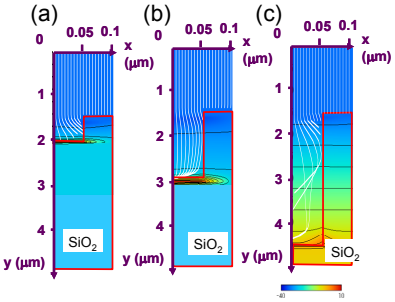

Fig. 8 Calculated potential distribution and ion trajectory (white line) at the hole depth of (a) 500nm, (b) 1.5μm, and (c) 3μm.

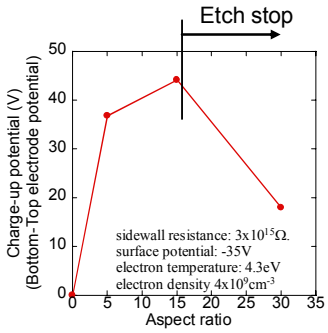

Fig. 9 Calculated charge-up voltage as a function of aspect ratio of hole. The etch stop can be predicted by using this calculation.

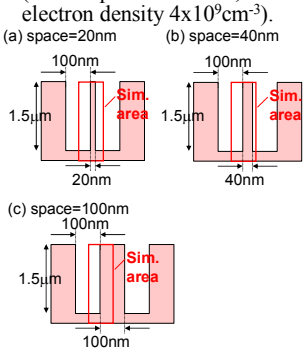

Fig. 10 Simulation model of twisting phenomena. The change of ion trajectory is investigated when the space between holes varies.

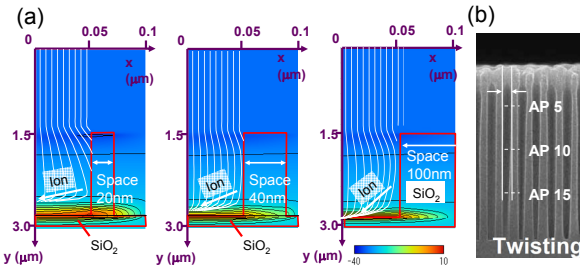

Fig. 11 (a) Calculated potential distribution and ion trajectory (white line) as a function of the space between holes. As the space decreases, the ion trajectory is distorted more. At the space less than 20nm, the ions are accelerated to the opposite side to the space. (b) Twisting profile after hole etching. The space of less than 20nm causes the twisting hole with the aspect ratio of more than 10.

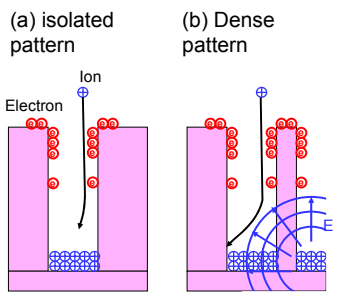

Fig. 12 Mechanism of generation of twisting. As space decreases due to resist patterning, the positive charge accumulated at the adjacent hole affects the ion trajectory.