Extended Abstracts of the 2003 International Conference on Solid State Devices and Materials, Tokyo, 2003, pp. 744-745

B-8-4

High-Speed Damage-Free Contact Hole Etching using Dual Shower Head Microwave-Excited High-Density Plasma Equipment

Tetsuya Goto, Hiroshi Yamauchi, Takeyoshi Kato, Akinobu Teramoto, Masaki Hirayama, Shigetoshi Sugawa[1] and Tadahiro Ohmi

New Industry Creation Hatchery Center, Tohoku University, Sendai 980-8579, Japan
[1]Graduate School of Engineering, Tohoku University, Sendai 980-8579, Japan
Phone: +81-22-217-3977 Fax: +81-22-217-3986 e-mail: goto@fff.niche.tohoku.ac.jp

Introduction

Reactive ion etching (RIE) induced damage due to charge-up, implantation and ion bombardment becomes serious problem as scale of LSI device shrinks. Particularly, in over etch period of contact holes, high-energy ion bombardment as well as implantation of carbon and fluorine into silicon substrate cause increase in contact resistance and junction leakage. Therefore, a number of additional steps such as chemical dry etch for removal of damaged layer, ion implantation, post-implantation anneal and etc. are required to keep the performance of ULSI. Since such complicated processes increase the production cost and turn around time (TAT), the damage-free etching technology is required.

Although surface damage-free etching has been proposed using two self-bias voltage (Vdc) conditions of Vdc=-500～-600V and Vdc=-150V(1), conventional etching equipment such as balanced electron drift (BED) etcher or dipole-ring magnet (DRM) etcher(2) are not adequate to satisfy the requirement because the plasma uniformity in these equipments is affected by both the amount of the secondary electron emission from the wafer due to energetic flux of ions and $E \times B$ flow of electrons.

On the other hand, microwave-excited plasma etcher incorporating dual shower head structure (3) has a potential to solve the difficulty because the plasma excitation condition and self-bias condition can be individually controlled due to the separation between the etching process region and the plasma excited region. In this report we describe first results of application of microwave-excited plasma etching equipment to damage-free contact hole etching using two self-bias conditions.

Experimental Apparatus

Figure 1 shows the dual shower head plasma etching system for 200mm wafer(3). Plasma is generated using 2.45GHz microwave uniformly radiated from a radial line slot antenna (RLSA). The etching gasses are introduced using the shower head which is set at 30mm position below the bottom of the dielectric plate. In order to generate self-bias, the wafer stage is connected to a 2MHz rf power supply through a blocking capacitor and a matching box.

Results and Discussions

Figure 2 shows the optical emission intensity of Ar (750.4 nm) as a function of the rf power P_{rf} in the case that microwave power P_{μ} of 1.6 kW, 2.0 kW and 2.4 kW. The working pressure was 5.3 Pa (40 mTorr). Self-bias voltage V_{dc} is also plotted for the case of P_{μ}=2.0 kW. It is found that the emission intensity is the constant with an increase in P_{rf} for each microwave power, while $|V_{dc}|$ increases with increase in P_{rf}. The results show that the self-bias conditions can be determined individually by simply adjusting the rf power. Figure 3 shows etching rate of SiO_2 as a function of |Vdc| in the case that P_{μ}=2.0kW. Ar (460 sccm) was introduced into the upper region for plasma excitation, and $Ar/C_5F_8/O_2$ (40/10/10 sccm) were introduced into the etching process region. Working pressure was 5.3Pa. Etching rate increases with increase in $|V_{dc}|$, and high-speed etching rate of about 500 nm/min is obtained in case of |Vdc|=～500V. Figure 4 shows hole concentration depth profile of boron-doped p^+-Si surface after plasma irradiation for 44 s. Initial profile is also shown by dotted line. Plasma conditions were as follows: P_{μ}=2.0 kW, V_{dc}=-215 V (P_{rf}=0.1 kW), Ar (460 sccm) was introduced into the upper region, and $Ar/C_5F_8/O_2$ (40/10/5 sccm) were introduced into the etching process region. Working pressure was 5.3Pa. In this condition, ion bombardment does not deactivate holes in p^+-Si region. Such plasma irradiation measurements of p^+-Si surface were carried out as a parameter of V_{dc} and O_2 flow rate. Figure 5 shows relation between O_2 flow rate and V_{dc} with respect to the state of the hole concentration of boron-doped p^+-Si surface after plasma irradiation. In the figure, (○) represents that the hole concentration was not degraded, while (×) represents that the hole was deactivated due to ion bombardment. In addition, the boundary between etching mode and deposition mode in case of the SiO_2 substrate is indicated by the dotted line. From the results, a condition of damage-free etching which can suppress deactivation of hole concentration on p^+-Si surface is found in the region of O_2 flow rate of 10 sccm and V_{dc} =~-200V. Contact hole etching was carried out by combining with the high-speed etching mode and damage-free etching mode. Figure 6 shows cross sectional SEM image of 350nm SiO_2 contact hole. First, 90% of contact hole was etched with etching rate of about 450 nm/min under the condition that V_{dc} = -440 V (P_{rf}=0.4 kW) as shown in Fig. 6 (a). Next, remaining SiO_2 was etched with damage-free etching mode under the condition of Vdc = -210V V (P_{rf}=0.12 kW) as indicated in Fig. 6 (c). Cross sectional SEM image of contact hole etching after Ar/O_2 plasma ashing is shown in Fig. 6 (b). Contact hole was successfully etched using two step etching modes.

Conclusion

Dual shower head microwave-excited plasma etching equipment for separating plasma excited region from etching process region has been developed. Contact hole was successfully etched using surface damage-free etching process consisting of high speed etching mode ($Ar/C_5F_8/O_2$, V_{dc} = -440V, for 90% of SiO_2 contact hole etching) and surface damage-free etching mode ($Ar/C_5F_8/O_2$, V_{dc} = -210V, for remaining etching). For both modes, the etcher can keep the process uniformity because the etcher can control self-bias voltages without change in other process parameters. Using the etcher, high-speed and damage-free contact etching can be realized, and this etching technology is essential for next generations of ULSI devices.

References

[1] R. Kaihara, et al., The Ninth International Symposium on Semiconductor Manufacturing, Proceeding of ISSM2000, (2000) pp.102-105
[2] M. Sekine, et al., Jpn. J. Appl. Phys. Vol. 34 Part1, No. 11, (1995) pp6274-6278
[3] T. Goto et al., Jpn. J. Appl. Phys. Vol. 42 Part1, No. 4B, (2003) pp1887-1891

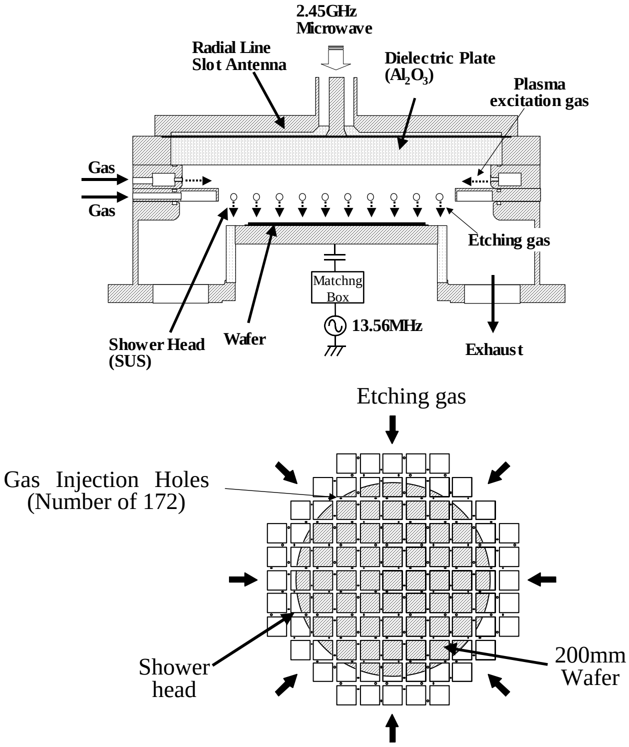

Fig. 1 Schematic of the etching system with the dual shower head structure. Etching gasses are supplied by the shower head installed in diffusion plasma region.

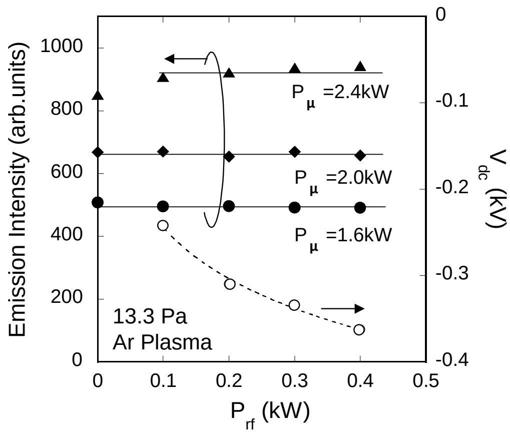

Fig. 2 The optical emission intensity of Ar (750.4 nm) as a function of P_{rf}. Self-bias voltage V_{dc} is also plotted in the case that P_μ=2.0 kW. The emission intensity is the constant with an increase in P_{rf} for each microwave power, while $|V_{dc}|$ increase with increase in P_{rf}. The results indicate that the self-bias condition can be controlled by simply adjusting P_{rf} without change in other plasma parameters.

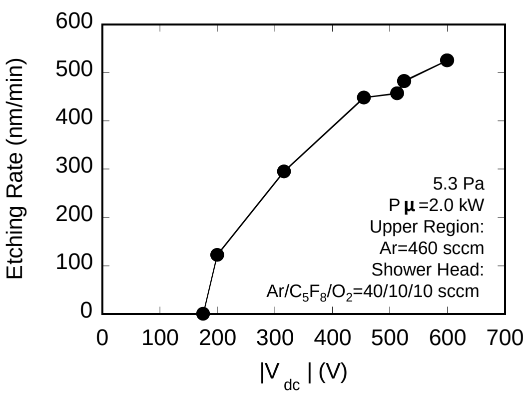

Fig. 3 Etching rate of SiO_2 as a function of |Vdc|. The rate increases with increase in $|V_{dc}|$.

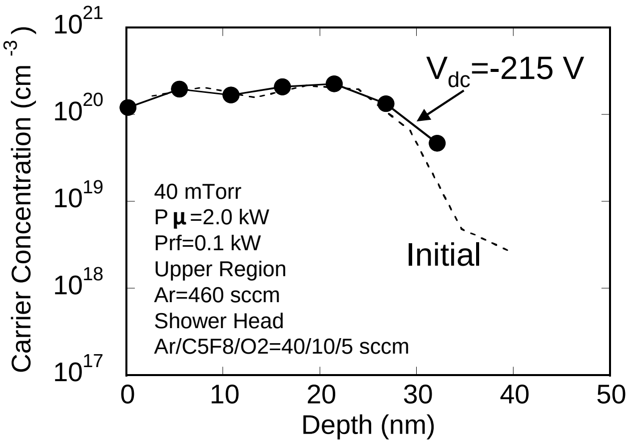

Fig. 4 The hole concentration depth profile of p^+-Si surface after plasma irradiation. Initial profile is also shown by dotted line. In this condition, ion bombardment does not deactivate holes in p^+-Si region.

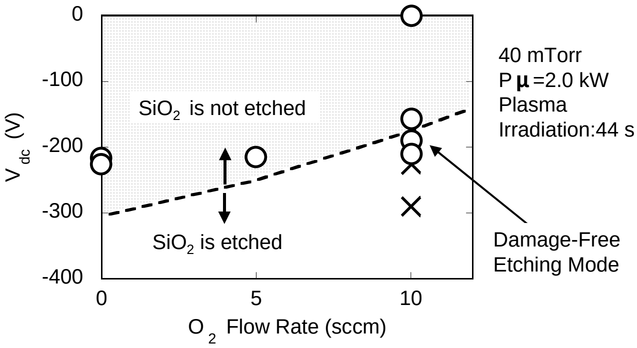

Fig. 5 Relation between O_2 flow rate and self-bias voltages V_{dc} with respect to the state of the hole concentration of boron-doped p^+-Si surface after plasma irradiation. In the figure, (○) represents that the hole concentration was not degraded. On the contrary, (×) represents that the hole was deactivated due to ion bombardment. Dotted line shows the boundary between etching mode and deposition mode in case of the SiO_2 substrate. A condition of damage-free etching which can suppress deactivation of hole concentration on p^+-Si surface was found in the region of O_2 flow rate of 10 sccm and V_{dc} =~ 200V.

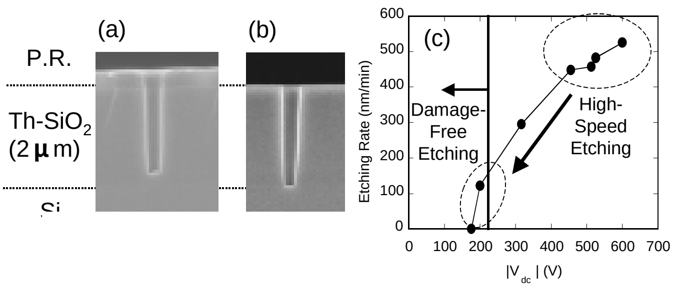

Fig. 6 Cross sectional SEM image of 350nm SiO_2 contact hole. (a) First, 90% of contact hole was etched with etching rate of about 450 nm/min under the condition that V_{dc} = -440 V (P_{rf}=0.4 kW). (b) Next, remaining was etched with damage-free etching mode under the condition of Vdc = -210V V (P_{rf}=0.12 kW). Ar/O_2 plasma ashing was also carried out. (c) Damage-free etching region and high-speed etching region are indicated in Etching rate-$|V_{dc}|$ plot.