Extended Abstracts of the 1994 International Conference on Solid State Devices and Materials, Yokohama, 1994, pp. 643-645

Low Energy Bias Sputtering Filling of SiO_2 into High Aspect Ratio Trench Employing Axially Confined Helicon Wave Plasma

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Filling of the SiO_2 film into high aspect ratio trenches was studied employing directional impinging of highly ionized particles which were generated from sputtered Si in helicon wave plasma with an $Ar+O_2$ mixture. Since distribution of sputtered Si followed under-cosine's law, SiO_2 deposition rate was improved by bringing close the Si target to the substrate as a result of confining axially high density plasma to narrow width. Filled feature characteristics obtained by changes in RF bias voltage and deposition time revealed that shoulders of films deposited around opening windows were cut-off by low substrate RF bias of -30V. Hence, trenches with 0.6μm width and 3μm depth(aspect ratio of 5) was filled by SiO_2. This successful filling could be considered to result from the use of directional introduction of well-collimated highly ionized beams into trenches.

1. Introduction

In the multilevel metallization in ULSI process, $TEOS/O_3$ conformal CVD is used currently for filling of insulator into high aspect ratio trenches. However, the void formation is difficult to be eliminated with increasing aspect ratio. Now considerable attention is paid to the bias sputtering plasma CVD employing high density plasmas of helicon wave or inductive coupled in addition to conventional ECR with SiH_4/O_2[1], because these techniques enables us to fill easily insulators into trenches holes except the particle generation. The major issue is electrical damage induced by high bias voltage required to cut off the overhang feature generated gas phase species highly dissociated from SiH_4. One solution is to introduce directionally collimated ion beam of deposition species to the surface, thereby filling insulators into deep trenches by low bias voltage. For the goal, this paper reports a method that particles liberated from a Si target sputtered in helicon wave plasma with an $Ar+O_2$ mixture were highly ionized by this axially confined plasma and then generated ions were accelerated by low bias voltage toward the surface.

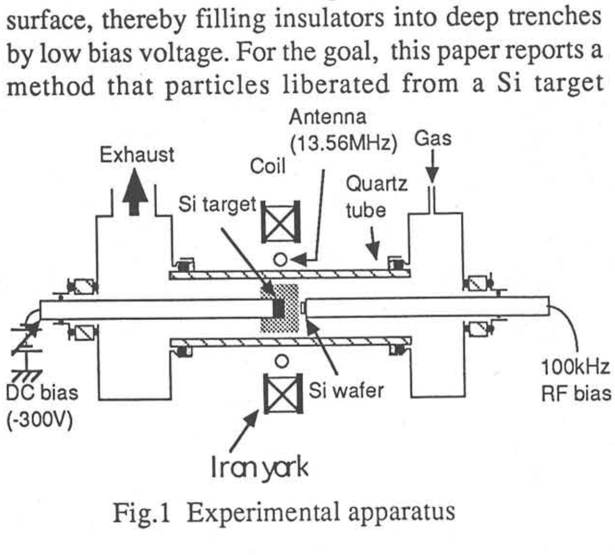

Fig.1 Experimental apparatus

2. Experimental

An experimental apparatus is shown in Fig.1. A reactor consists of portions of an inlet of a gas mixture, a quartz tube of 60mmØ and 50cm long, and an exhaust. A Si wafer(20mmx20mm) and a Si target (20mmx20mm, n type, 300Ωcm) which were set on tip fronts of rods were inserted from both sides into the quartz tube and were arranged face to face. DC bias of -150V and RF bias of 100KHz were supplied to the Si target and the Si wafer, respectively. Two solenoid

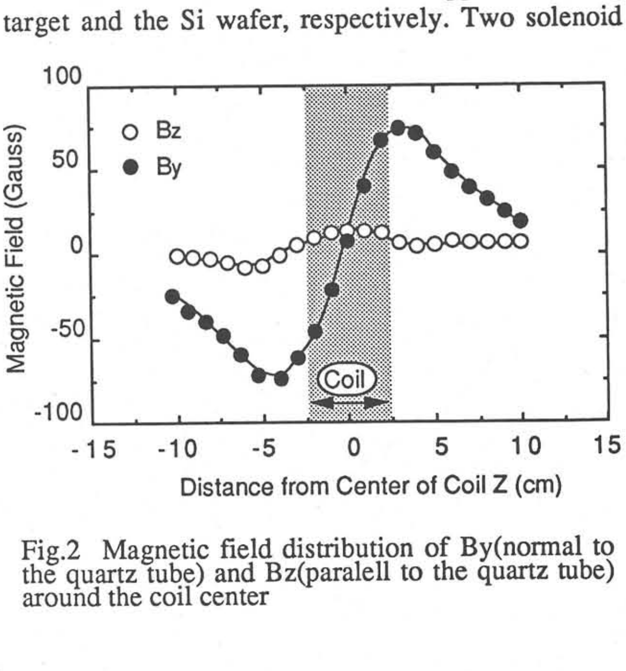

Fig.2 Magnetic field distribution of By(normal to the quartz tube) and Bz(paralell to the quartz tube) around the coil center

coils whose end plates were covered by iron yokes were laid at both sides of the quartz tube as both coil axes were parallel to the axis of the quartz tube. Yokes were used for suppressing the longitudinal(z-axis) magnetic field. A single turn loop antenna[2] to which 13.56 MHz RF power was supplied was winded around the tube in the center position of the coils. A 80%Ar+20%O_2 mixture was used. RF power was fixed at 1.2kW and pressure was 5 mTorr.

3. Magnetic Field Configuration

At the beginning of this experiment, the quartz tube was inserted into the coil and helicon wave plasma was generated by the usual longitudinal(z-axis) magnetic field. But the plasma expanded to the whole volume of the tube, because the plasma propagated

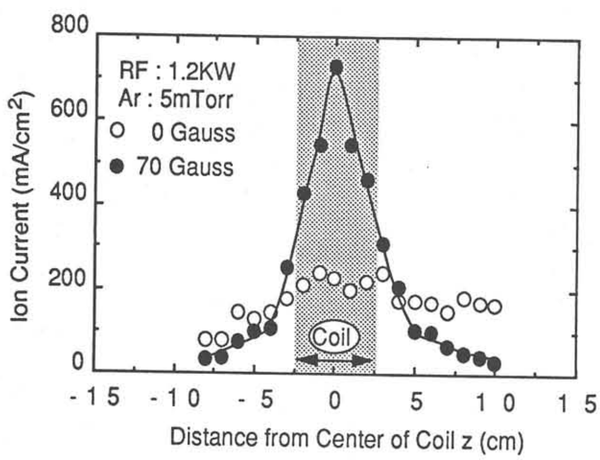

Fig.3 Ion current distributions at the z-axis direction for magnetic field of O and.70 Gauss, RF power:1.2kW, Ar:5mTorr.

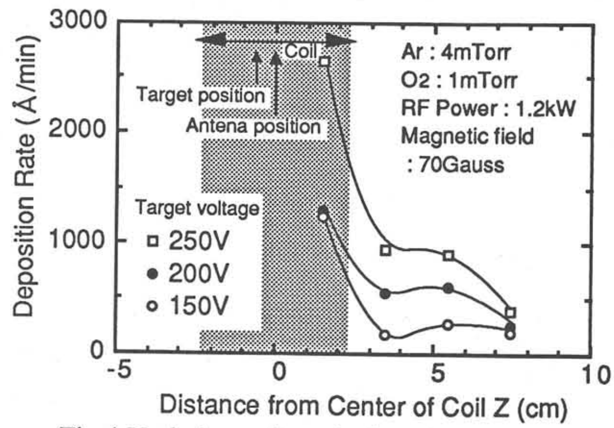

Fig.4 Variations of z-axis deposition rates for different target voltages.

along the magnetic field[2]. Consequently, the wafer and target rods suffered from severe heating and sputtering. This was one of reasons why the plasma region had to be limited to narrow width by using transverse magnetic field. As shown in Fig.2, the z-axis magnetic field was lost and two y-axis components were generated at both sides from a center of the coil. Hence, helicon waves were considered to propagate to the opposite direction between two coils. This configuration of the magnetic field and the antenna allowed us to confine the helicon wave plasma axially in the width of the coils of 5 cm. Figure 3 shows ion current distributions at the z-axis direction. At 70 Gauss, high ion current of about 700mA/cm² was measured by Langmuir probe and was limited to narrow region around the center of the coil

4. Results and Discussion

At first, fluorocarbon film which was expected as

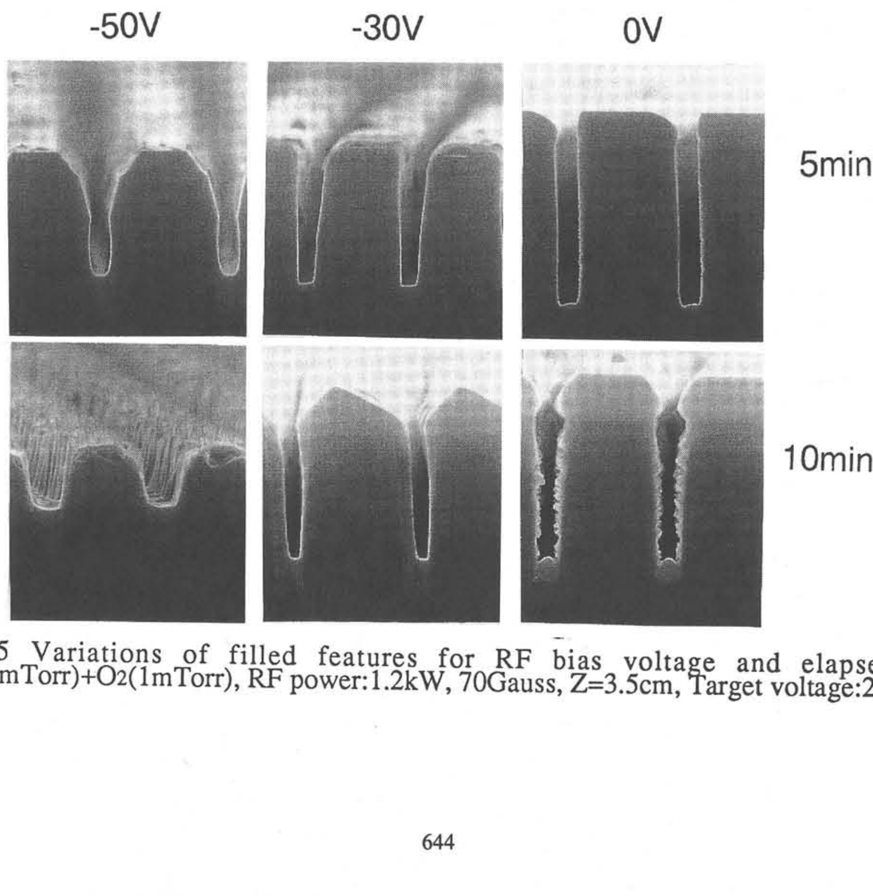

Fig.5 Variations of filled features for RF bias voltage and elapse time. Ar(4mTorr)+O_2(1mTorr), RF power:1.2kW, 70Gauss, Z=3.5cm, Target voltage:250V.

a low dielectric constant film was investigated to fill trenches employing C_4F_8 gas. Variations of filling features for bias voltages and deposition time were investigated. Although filling of the fluorocarbon film were improved with increasing bias voltages, upper opening regions of trench patterns were closed due to the presence of dominant gas phase species. Higher bias caused etching of shoulder of upper regions. Thus, this failure made us decide the use of the solid source like sputtered Si.

The deposition rates were low at wafer positions apart from the coil center as shown in Fig.4. Hence, the high deposition rate was obtained by setting the target near at the center of the plasma and the substrate in the plasma. However, a surface texture of the sample deposited in the plasma was damaged heavily, and the deposition rate dropped rapidly as the Si substrate left the plasma. The latter characteristics demonstrate that the angular distribution of Si sputtered products follows to under-cosine's law. Therefore, the axial confinement of the plasma was necessary to improve the deposition rate as well as the surface morphology.

The maximum rate was obtained in the condition of 20%O_2 in Ar. The preliminary measurement of the film with FTIR showed SiO_2 film with clear stretching peak of 1070cm-1. Important parameters such as refractive index, BHF etch rate, stress, electrical characteristics, etc. were not measured yet.

Figure 5 shows variations of filled features for RF bias voltage and elapse time. Thick film was observed on the upper surface in the no external bias voltage(Vext.) (plasma potential was about 20V), while the considerable film was deposited at the bottom region. This implies that Si ions came directionally to the surface. Although violent sputtering occurred at Vext =-50V bias, shoulders of films deposited around opening windows were cut-off appreciably at Vext.=-30V. Thus, an adequate condition of Vext.=-30V was adopted for filling of SiO_2 into trenches with different size of 1.5,0.8 and 0.35 μm for 3μm depth as shown in Fig. 6. 0.8 μm width trenches was filled completely. The successful filling realized at low Vext.=-30 that bias voltage used for cutting-off the shoulders could be reduced if the filling was carried out directionally by introduction of well-collimated highly ionized beams, while the ionization yield of Si atoms was not measured yet. However, voids stood in a line were caused in 0.35μm trench patterns. It is not clear whether this resulted from change in ion trajectory due to charging-up phenomena in high density plasmas and optimization of conditions was insufficient, or not. In this condition, trenches with 0.6μm width and 3μm depth, that is, aspect ratio of about 5 was filled by SiO_2.

5. Conclusion,

Si ions which were generated by axially confined helicon wave plasma of sputtered Si atoms were collimated vertically to the surface by low bias voltage of-30V, being filled to high aspect ratio trenches under presence of oxygen radicals. This method can be applied to filling of other materials. However, the sputter source and confinement of the magnetic field have to be improved in order to perform high rate and uniform deposition on larger diameter wafer.

References

1. K. Machida and H. Oikawa; Extended Abstracts of 17th Conf. on SSDM, A-4-5 (1985)329.
2. N. Jiwari, T. Fukazawa, H. Kawakami, H. Shindo and Y. Horiike, To be published in J. Vac. Sci & Techno. (1994).

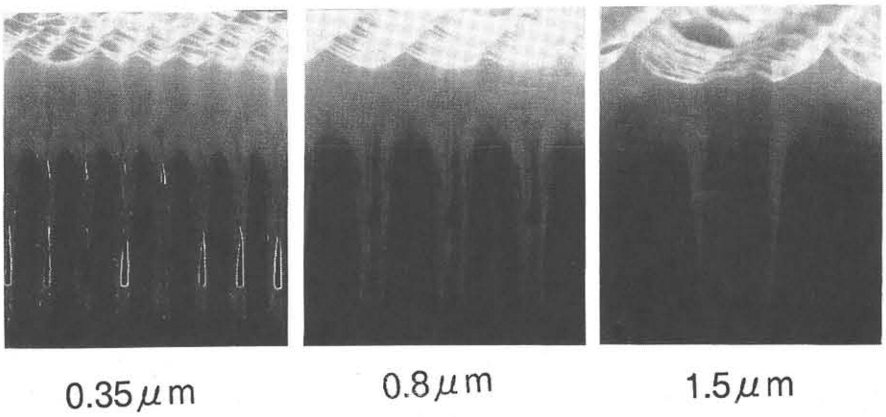

Fig.6 Variations of filled features for different size of 1.5,0.8 and 0.35 μm with 3μm depth. Ar(4mTorr)+O_2(1mTorr), RF power:1.2kW, 70Gauss, Target voltage:250V, Z=3.5cm, RF bias:-30V, Deposition time:40min.