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Plasma Doping into the Side-Wall of a Sub-0.5μm Width Trench

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Plasma doping into the vertical sidewall of a trench is presented for the first time. Glow discharge was performed under a pressure of 5×10^{-4} torr using a μ-wave ECR plasma source. Boron was doped without damage to the photoresist by using a water cooling system. The wafer temperature was maintained below 120°C.

1. Introduction

Recently plasma doping has been reported by Ishiwata et al.[1]. They doped impurities into Si at a relatively lower temperature of 200°C and under the pressure of 2torr for a DC glow discharge.

In this paper we will report about the characteristics of plasma doping especially on: 1) doping into the sidewall of a sub-half micron trench, 2) doping at low temperature(~100°C) and low pressure(~10^{-4}torr)so as not to damage the photoresist.

2. Experimental Procedure

We maintained a glow discharge at 10^{-4}torr by using a μ-wave electron cyclotron resonance (ECR) plasma source. RF glow discharge at 13.56MHz was also performed between the chamber and the wafer holder. The wafer holder was cooled with water to avoid thermal effects. The base pressure was kept under 5×10^{-7}torr by using a turbo-molecular pump.

The typical conditions used in this work are as follows. Used gas was 5%B_2H_6/He. The flow rete of the gas was 6sccm, and the pressure was kept at 5×10^{-4} torr. The conditions of glow discharge were kept as follows: the self-bias(V_{DC}) was -700V and the current at the exit of the ECR plasma source was 2mA/cm^2. Annealing was performed at 900°C for 30m.

3. Results

A SIMS depth profile showing the charactaristics of plasma doped ^{11}B is shown in Fig.1. The silicon wafer was bombarded in the plasma for 100sec. The surface concentration is about 5×10^{21}cm^{-3}, and exponentially decreses by 4 decades at a depth of 50nm. The wafer temperature was below 120°C as measured with a Thermindex. Fig.2 is a cross-sectional SEM view of the doping features of a vertical sidewall of a sub-half micron trench. The wafer was bombarded for 1800sec. After bombardment, the specimen was annealed and coated with a CVD SiO_2 film and etched in HNO_3/HF[2] for 10sec. The selectively etched black band is the plasma doped layer. It is clear that the doping is uniform in the vertical

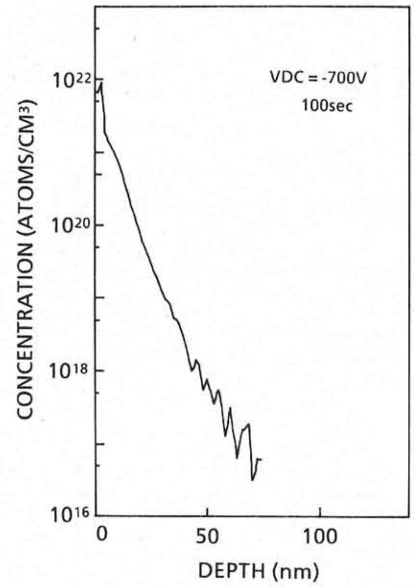

Fig.1 SIMS depth profile of the plasma doped B after bombardment for 100sec.

sidewall, and the bottom face was doped more heavily.

The photoresist is usable under the typical conditions mentioned above. A photoresist which is baked at about 150°C was not damaged during the plasma doping process and it could be stripped with commercially available O_2 plasma asher. However, under the pressure of 2×10^{-3}torr,

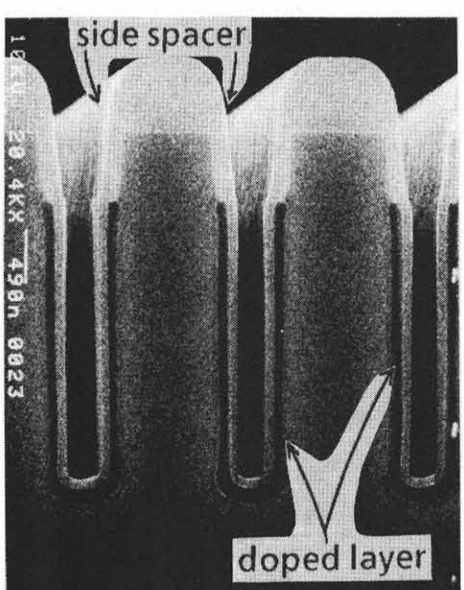

Fig.2 Cross-sectional SEM image of a sub-half micron width trench. The sidewalls are uniformly doped with boron by plasma doping.

small defects appeared and could not be removed with O_2 plasma asher. Thus the pressure during the plasma doping is significant in preventing the deterioration of the photoresist.

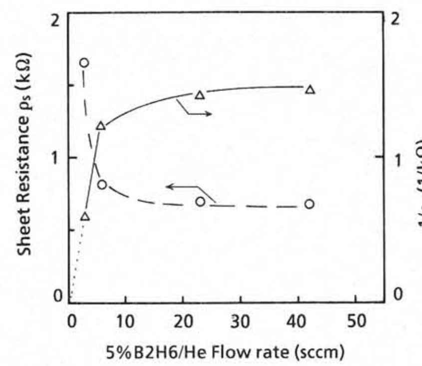

Fig.3 The sheet resistance and its reciprocal value as a function of the $5\%B_2H_6$/He flow.

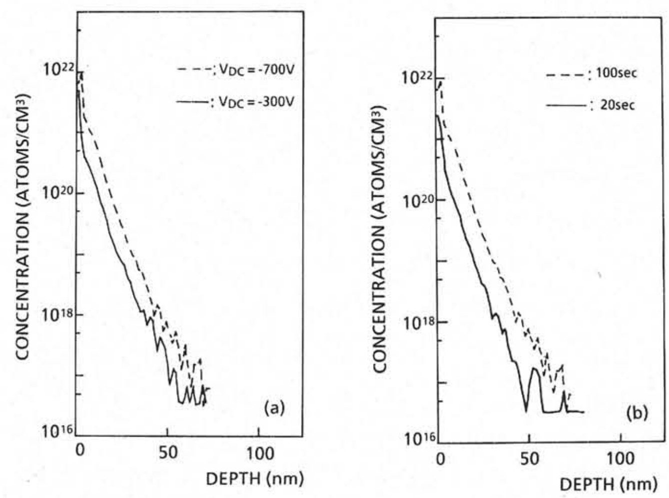

Fig.4 SIMS depth profile showing the controllability of concentration by a) self-bias voltage, b) bombardment time.

For this plasma doping, similar to other plasma processes, several parameters should be considered as follows:

a) Flow rate and mixture ratio

Fig.3 shows the sheet resistance (ρ_s) and its reciprocal value ($1/\rho_s$) as a function of the $5\%B_2H_6$/He flow rate ranging from 3sccm to 42sccm. $1/\rho_s$ increses linearly up to 6sccm and then saturates at about $1.5(1/k\Omega)$. And an interesting observation was found for the mixture ratio. The sheet resistance of $1.6k\Omega/\square$ was

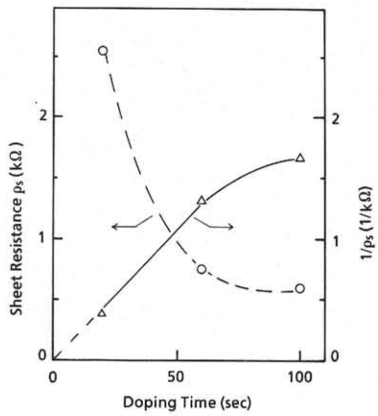

Fig.5 The sheet resistance and its reciprocal value as a function of a bombardment time.

observed for flow rate of 3sccm of $5\%B_2H_6/He$, but alternatively a sheet resistance of $580\Omega/\square$ was obtained by using 1sccm of $5\%B_2H_6/He$ diluted with 99sccm of He. It is evident that the flow rate of He affects the doping process.

b) Doping control

The dopant profile could be controlled by changing the self-bias voltage, the bombardment time and the type of discharge. The SIMS depth profile changed by the self-bias voltage is shown in Fig.4(a). The concentration decreases by reducing the $|V_{DC}|$. Fig.5 shows the ρ_s and $1/\rho_s$ as a function of the bombardment time. Up to 60sec, $1/\rho_s$ linearly increases and then saturates. SIMS depth profile changed by the bombardment time is shown in the Fig.4(b). The doped concentration increases with increasing the bombardment time. For a light doping, just using the ECR plasma (without the RF) is useful. A typical value of the sheet resistance is $5.0k\Omega/\square$ with a 500sec bombardment.

Arsenic was also doped by using $2\%AsH_3/He$ plasma. A sheet resistance of $350\Omega/\square$ was obtained for 100sec bombardment and with the flow rate of 12sccm.

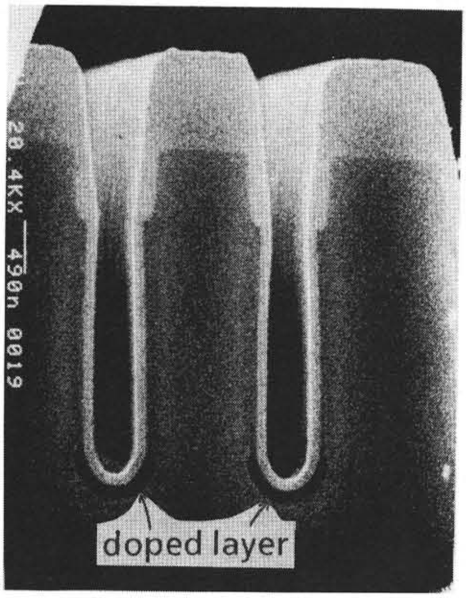

Fig.6 Cross-sectional SEM image of a bowing trench. Just the bottom face was doped.

c) Doping direction

Fig.6 shows the feature of doping for a bowing trench. In this case, the sidewall of the trench was not doped. It is indicated that this doping is strongly anisotropic. The angle of incidence of the doped species was estimated to be in the range of ±2°.

4. Discussion

The kinetic energy of ions in the plasma is lower than -700eV. According to the theory of channeling, the critical angle for channeling of such a low energy ion is large; the order of 10 degrees for boron. If the normal planar channeling occured, such species could not penetrate the vertical sidewalls shown in Fig.2. Fig.7 is a SIMS depth profile showing the difference of the doping characteristics between a single crystalline Si and amorphous Si. The profiles of the both are quite same, and no evidence of axial and planar channeling are seen. According to the results of G. S. Oherlein et al.[3], the projected range of heavy ions such as ^{12}C is 4-5nm for 700eV. From our results and

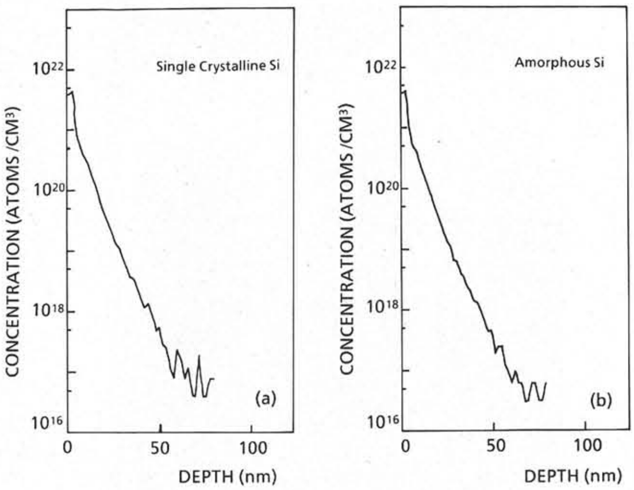

Fig.7 SIMS depth peofile showing the difference of the doping characteristics, a) for single crystalline Si, b) for amorphous Si.

the results of G. S. Oherlein et al.[3], it is clear that the distribution of the boron concentration was not originated from kinetic energy. And from result of the existence of a highly concentrated layer near the surface as shown in Fig.1, we suggest that 2-step processes are participating in this doping as follows. First, anisotropically arrived species stick or implant at the surface. Secondly, excitation occurs at the surface by plasma, which diffuses the sticked species.

A layer of highly concentrated ^{11}B at the near surface, which was also observed on the solid phase diffusion, is considered to be a complex of B and Si. This layer was formed by the sticking of the anisotropically arrived species or by implantation with the projected range mentioned above[3]. The diffusion of the species in this layer is probably accelerated by some mechanism(s), however, diffusion constant of boron in Si at 100°C is about $10^{-47} cm^2/s$ by extrapolation from the high temperature results[4], and so thermal diffusion at this temperature can be neglected. We consider the present plasma doping, as follows: the plasma excites electrons of the Si atoms and the energy of the excited electrons is transferred to the lattice, and then 1)the surface temperature locally increases and diffusion occurs, or rather, 2) this electronic energy is transferred to the lattice vibrational mode of atomic motion, then atomic displacement occurs and the diffusion takes place.

5. Conclusion

1)Doping into a vertical sidewall of a trench is realized.

2)Photoresist is usable as a mask during doping, because of the low temperature and low pressure conditions.

3)A shallow junction is possible with photoresist as a mask.

These features indicate that the plasma doping technique is promising for ULSI processes.

Acknowledgments

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References

1. O. Ishiwata, Y. Itoh, N. Sato, Y. Seki, K. Matsuzaki, and S. Ishida, Extended Abstracts (Spring Meeting, 1987; The Japan Society of Applied Physics), pp.516.
2. G. Fuse, private communication.
3. G. S. Oehrlein, R. M. Tromp, J. C. Tsang, Y. H. Lee, and E. J. Petrillo, J. Electrochem. Soc. 132 (1985) 1441.
4. J. C. C. Tsai, in VLSI Technology edited by S. M. Sze (McGraw-hill 1983) pp.194.