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An Impurity-Enhanced Oxidation Assisted Doping Profile Evaluation for Three-Dimensional and Vertical-Channel Transistors

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1. Introduction

To overcome the short-channel effect, three dimensional (3-D) transistor structures such as double gate structure[1] and FINFET[2] have been developed. In our research, a 3-D structure with high-aspect ratio channel called "beam channel transistor (BCT)" is proposed[3]. One application is multi channel structure called "corrugated-channel transistor (CCT)", as shown in Fig. 1[4]. This provides high drive current and is suitable for power transistor.

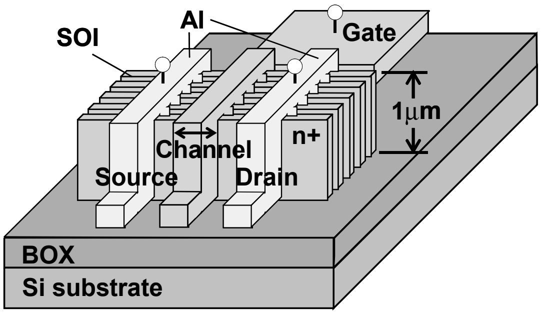


Fig. 1 Corrugated-channel transistor [4].

One key process to realize BCT is 3-D impurity doping. Using conventional ion implantation technology, doping to sidewall cannot be performed due to its directionality even with the use of oblique implantation. Therefore, nearly isotropic plasma doping is better for 3-D doping which was reported in previous work[5].

In our study, plasma doping is characterized for special application to CCT with an emphasis on 3-D doping profile evaluation even with an adverse effect of sputtering.

2. Experimental and Discussion

Schematic diagram of a plasma doping apparatus used in this study is shown in Fig. 2. Plasma is discharged with 13.56-MHz RF power supply and minus bias is applied by direct current.

First, doped planer substrate is evaluated. Sheet resistance as a function of arsenic dosage is shown in Fig. 3. Detailed

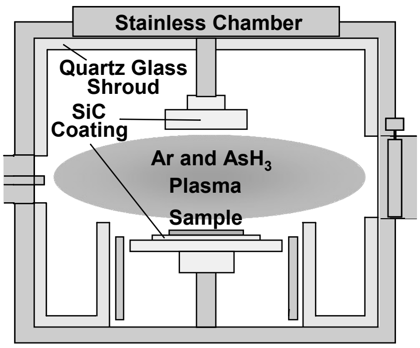


Fig. 2 Plasma doping apparatus.

Table 1 Experimental Condition and results

Sample	A	B	C	D
Applied Bias (V)	-720	-820	-900	-900
Gas Flow Ar/AsH_3 (sccm)	27/3	45/5	27/3	27/3
Pressure (Pa)	2.0	4.0	2.0	2.0
Anneal Temperature (^oC)	900	900	900	1000
Anneal Time (sec)	10	10	10	10
Calculated Dose (/cm^2)	1.8e16	2.7e16	1.8e16	1.8e16
Evaluated Dose (/cm^2)	6.8e13	5.6e13	1.5e14	2.6e14
Doped Ratio (%)	0.38	0.21	0.83	1.4

conditions are indicated in Table 1. "Calculated Dose" is evaluated by total substrate current. Approximately 1 % of the substrate ion current is effective as dopants. This may be caused by sputtering and measurement without direct wafer current. SIMS profiles of plasma doping are shown in Fig. 4 as compared with those of ion implantation. In the experiments, a 2-nm screen oxide does not affect the doping profile. The screen oxide is removed before SIMS measurement.

Then, doping profiles for comb-shaped structures are evaluated as follows. First, the structures are formed by anisotropic etchant of 2.5-% TMAH at 75^{o}C. Next, plasma doping is performed for them. An SEM image after doping is shown in Fig. 5. The BOX-SiO_2 layer is under etched by subsequent HF solution treatment. Compared with the initial shape, it is observed the upper part is sputtered. It is estimated that enhanced electric field causes the sputtering at the upper edges. Sputter angle dependence is measured and shown in Fig. 6. Here, angle of perpendicular to the substrate is defined to be 0 degree. Almost the same phenomenon was reported in case of plasma CVD[6].

Since there has been no effective method to evaluate 3-D doping profiles, an indirect evaluation method utilizing impurity-enhanced oxidation (IEO)[7] is developed in this study. IEO is more enhanced at lower temperature. Obtained data of IEO are shown in Fig. 7. Since the upper surface of comb-shaped structure is (110) and a sidewall surface is (111), it is necessary to take into consideration the difference in the oxidation rate by orientation. An Arrhenius plot of oxidation rate of (111) and (110) is shown in Fig. 8.

Oxidized, doped comb-shaped structure is shown in Fig. 9 (a). Compared with oxidized, non-doped comb-shaped structure is shown in Fig. 9 (b). It is shown that oxidation rate is increased obviously for doped structures. Considering the dependences of impurity concentration and crystal orientation, 3-D doping concentration is evaluated as shown in Fig. 10. In Fig. 10 oxide thickness dips are clearly observed at the top and the bottom portions of non-doped beam. This may be caused by stress[8]. Thus, doping concentration evaluation becomes slightly inaccurate for sharp edges.

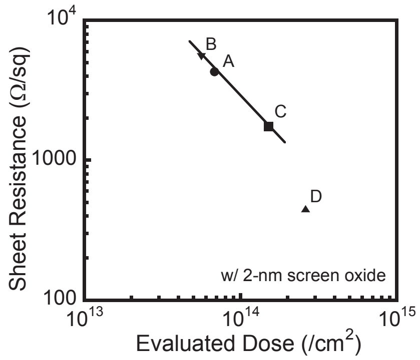


Fig. 3 Sheet resistance vs As dosage evaluated by SIMS profile.

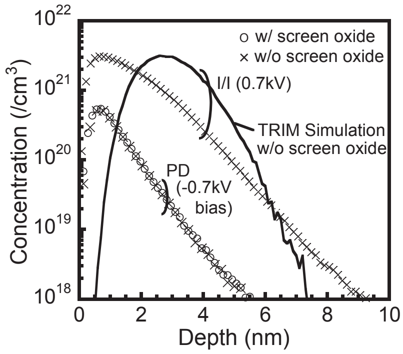


Fig. 4 SIMS profiles of plasma doping (PD) and ion implantation (I/I).

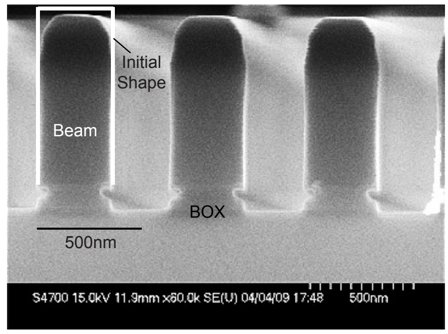


Fig. 5 Cross-sectional SEM photograph of plasma-doped comb-shaped structure.

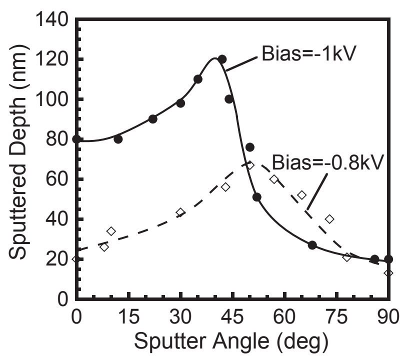


Fig. 6 Angle dependence of sputtering depth.

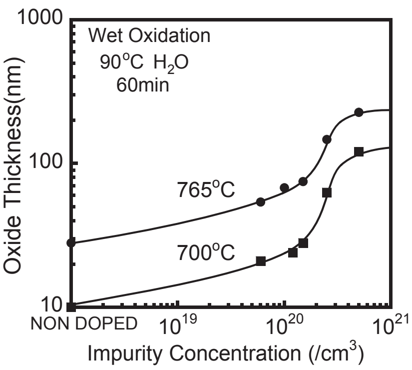


Fig. 7 Imputiry Enhanced Oxidation.

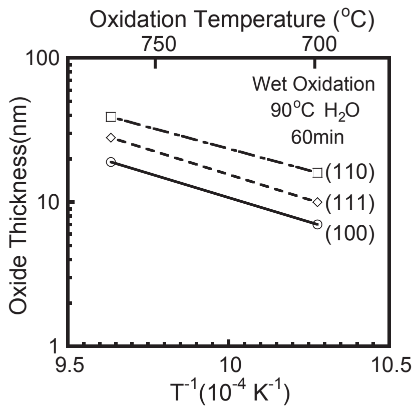
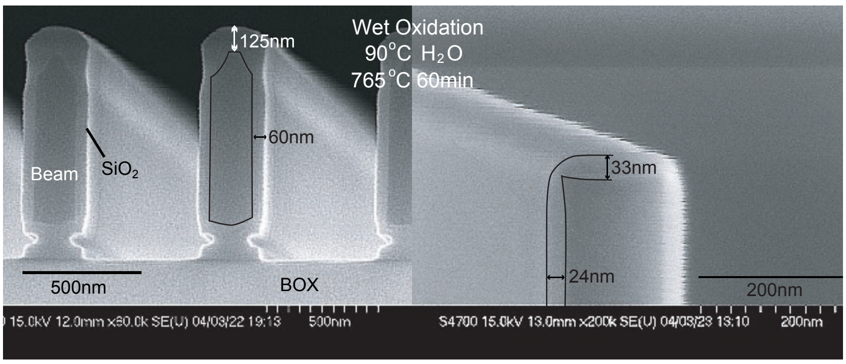


Fig. 8 Arrhenius plot of IEO.



(a) Doped (b) Non-doped

Fig. 9 Cross-sectional SEM photographs for oxidized comb-shaped structures.

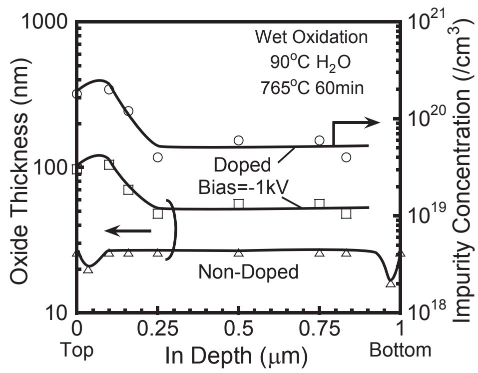


Fig. 10 In-depth doping concentration evaluated by the method proposed.

3. Conclusion

Plasma doping is carried out to comb-shaped structure of 1-μm height and 50-500-nm width. It is observed that sidewalls are doped uniformly at about $5x10^{19}$ cm^{-3}, though top edges are doped at several times higher concentration. Thus a doping profile estimation method utilizing impurity-enhanced oxidation (IEO) is successfully developed. While, an adverse effect of anomalous edge rounding due to sputtering is found. Plasma doping should be carried out coping with this sputtering effect.

Acknowledgements

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