Extended Abstracts of the 1994 International Conference on Solid State Devices and Materials, Yokohama, 1994, pp. 736-738

A-8-3

Enhanced Conductivity and Retarded Boron Diffusion in the As Preamorphized p^+Poly-Si Gate

Sang Jik Kwon, Yeo Hwan Kim*, and Jong Duk Lee**

Dept. of Electronics Engineering, Kyungwon Univ., Seongnam-City, Kyunggi-Do 461-701, Korea
*ETRI, Gajung-Dong, Yusong-Gu, Yusong P.O. Box 106, Taejon, 305-600, Korea
**Inter-Univ. Semicon. Res. Center, Seoul Nat. Univ., Gwanak-Gu, Seoul 151-742, Korea

In a deep submicron PMOSFET, the importance of the p^+ poly-Si gate with less boron penetration and higher conductivity increases. By using the As implantation prior to B^+ implantation, the conductivity of the p^+ poly-Si gate was improved and the boron penetration could be suppressed. These phenomena are attributed to the enhancement of the grain growth in the As preamorphized film and the retarded boron diffusion during annealing. DC conductivity of the film preamorphized by As^+ ions at 180keV and $4\times10^{14}cm^{-2}$ was about 36% higher than that of the B implanted film without As preimplantation, in spite of the carrier compensation effect.

1. Introduction

In a sub-half micron CMOS device, the surface channel pMOSFET with p^+ poly Si gate is increasingly required to improve the punchthrough characteristics which is a serious problem in the buried channel pMOSFET with n^+ poly Si gate[1]. However, some of the problems in the fabrication of the pMOSFET with p^+ poly Si gate are the boron penetration through thin gate oxide and the lower conductivity[2,3]. In this work, it is investigated that the As^+ preimplantation with a relatively low dose prior to B^+ implantation into the poly Si can enhance the conductivity in spite of the carrier compensation between As and B, and retard the in-diffusion of boron atoms during annealing[4].

2. Experimental

The wafers used in our experiments were boron-doped 4-inch Si wafers with the resistivity of 10~20Ω·cm. All wafers were cleaned in H_2SO_4 and the native oxide was removed in 10:1 HF solution. Undoped poly-Si film with a thickness of 250nm was deposited by the low pressure chemical vapor deposition (LPCVD) system at 625°C. As^+ ions were implanted to preamorphize the poly-Si film. In the As^+ implantation, the energy was varied as 60keV, 120keV and 180keV in order to vary the thickness of the amorphized layer, and the dose was fixed at $4\times10^{14}cm^{-2}$. Subsequently, B^+ ions were implanted at a dose of $2\times10^{15}cm^{-2}$ and an energy of 20keV. During implantation, the wafer was kept at a tilt angle of 7 degrees. Annealing was carried out in the furnace with nitrogen ambient at 850°C or 900°C for 30min.

For all wafers, including the reference wafer without As preimplantation, the sheet resistance was measured with a four-point probe. The cross-sectional observations were performed by XTEM. Atomic profiles of B and As were measured by using the secondary ion mass spectrometry (SIMS) equipment. Finally, capacitance-voltage (C-V) measurements were taken in order to investigate the difference of the boron penetration between the As-preamorphized and the non-amorphized samples.

3. Results and Discussion

Fig.1 shows the sheet resistance values for the only B implanted and the As preamorphized polysilicons. The sheet resistance of the p^+ poly Si preimplanted by As^+ energy higher than 120keV is lower than that of the only B implanted poly Si, and the value becomes lower as the As preimplant energy increases.

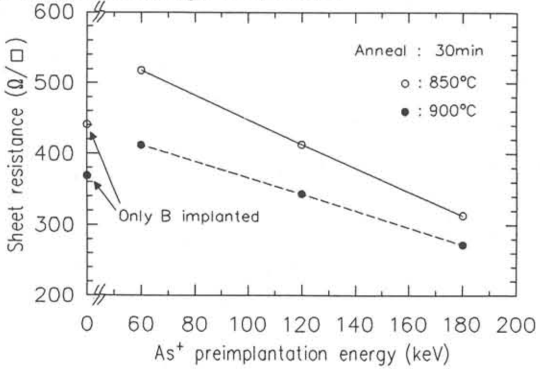

Fig. 1. Sheet resistance variation of the p^+ poly Si film with the As^+ implantation energies. (As dose: $4\times10^{14}cm^{-2}$, B^+ implant: 20keV, $2\times10^{15}cm^{-2}$)

Fig.2 shows the XTEM view for the poly Si preimplanted using As^+ ions of 180keV and $4\times 10^{14}cm^{-2}$. The thickness of about 186nm was amorphized. From Fig.3 which shows the measured values and the calculated ones by TRIM, we can see that the thickness of amorphized layer increases linearly with As^+ energy.

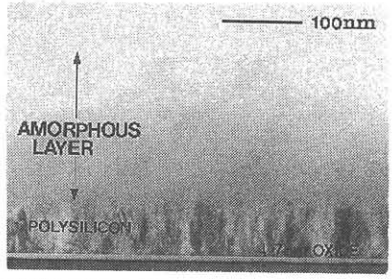

Fig. 2. XTEM view for the sample preamorphized by As^+ ions with an energy of 180keV and a dose of $4\times10^{14}cm^{-2}$.

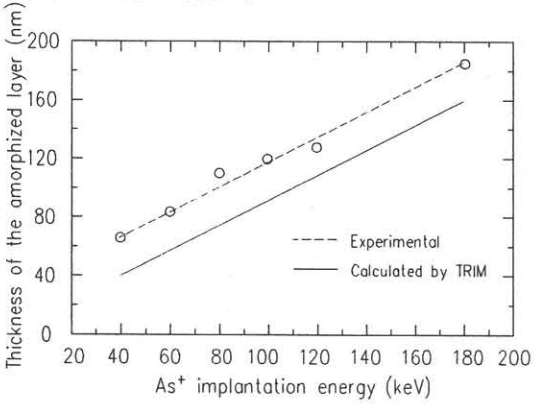

Fig. 3. Thickness variations of the amorphized layer with As^+ implantation energy.

Fig.4(a), (b) and (c) show the XTEM veiws after annealing, corresponding to the only B implanted, the As^+/120keV and the As^+/180keV preimplanted case, respectively. The grain size of As preamorphized sample is much larger than that of only B implanted case. The conduntivity difference in the only B implanted and the As preamorphized samples seems to come from the competition between a carrier concentration and a mobility. The carrier concentration and the hole mobility measured by Hall effect are shown in Table I. The carrier concentration of the only B implanted poly Si is higher than that of the As preamorphized sample, while the mobility increases as the As^+ preimplant energy increases. From the $p\times\mu_p$ product values in the table which are normalized with that of the only B implanted poly Si, we can see that the conductivity of the poly Si preamorphized with 60keV is reduced by 10.4% due to the compensation effect dominance, while those of the samples preamorphized with 120 and 180 keV increase by 8.4% and 35.6% respectively due to the mobility enhancement dominance.

The sheet resistance values calculated from $R_S = (q\mu p \cdot T_{poly})^{-1}$ and the measured ones are nearly same, as shown in the table.

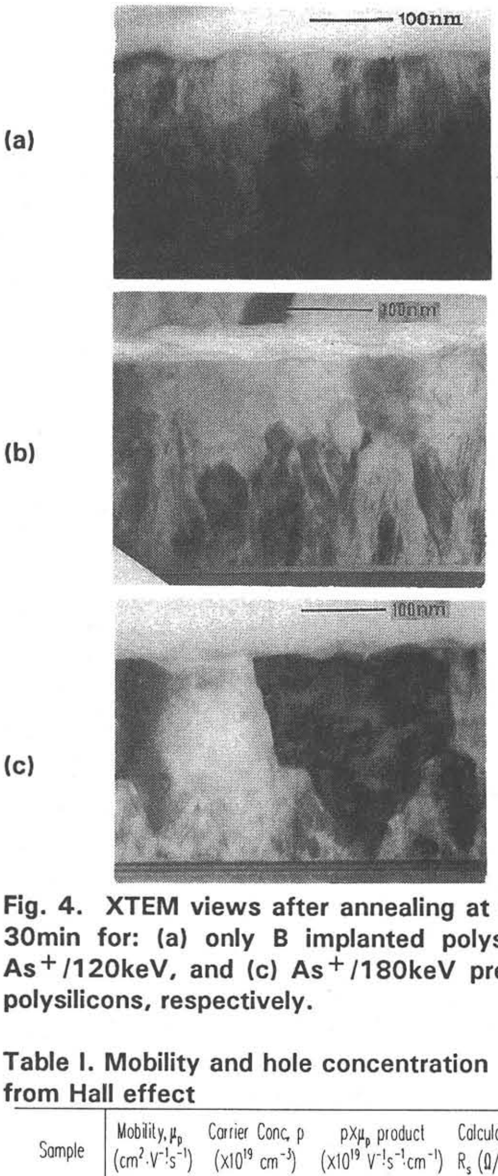

Fig. 4. XTEM views after annealing at 900°C for 30min for: (a) only B implanted polysilicon, (b) As^+/120keV, and (c) As^+/180keV preimplanted polysilicons, respectively.

Table I. Mobility and hole concentration measured from Hall effect

Sample	Mobility, μ_p ($cm^2 \cdot V^{-1}s^{-1}$)	Carrier Conc, p ($\times10^{19}$ cm^{-3})	$p\times\mu_p$ product ($\times10^{19}$ $V^{-1}s^{-1}cm^{-1}$)	Calculated R_s ($\Omega/\square$)	Measured R_s ($\Omega/\square$)
no As	7.9	8.84	69.84 (1.0)	358	370
As/60keV	12.3	5.09	62.61 (0.896)	401	410
As/120keV	13.1	5.78	75.72 (1.084)	330	340
As/180keV	15.5	6.11	94.71 (1.356)	265	270

( ): values normalized with that of only B implanted polysilicon

In the SIMS B profiles for the samples annealed at 850°C for 30min, the B peak is appeared in the As preamorphized samples, while a flat profile is observed in the only B implanted sample as shown in Fig.5. The appearance of B peak may be attributed to the retarded boron diffusion. This retarded diffusion in the As preamorphized film may be caused by the enhancement of grain size, the internal electric field created by As profile and presumably, the As-B complex formation within the grain[5]. This retarded diffusion effect also results in the less penetration of the boron atoms into the Si surface. The modeling on the B diffusivity was undertaken through the SIMS profiles and the TSUPREM-4 simulation profiles.

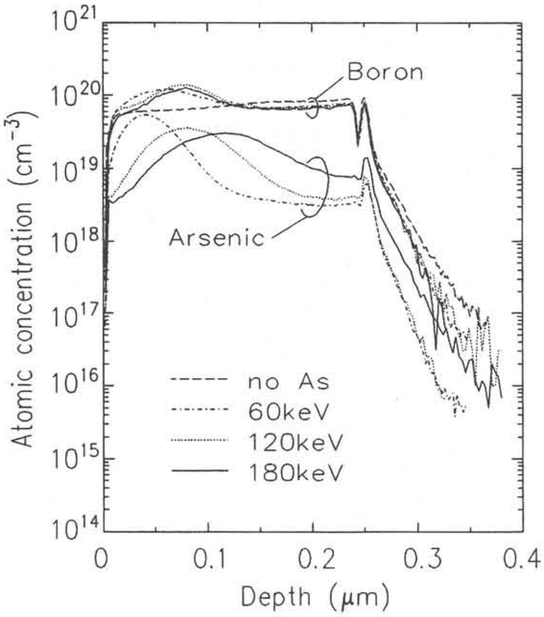

Fig. 5. B and As SIMS profiles in the poly Si preamorphized with various As implant energies. Anneal temperature was 850°C.

In the TSUPREM-4, the diffusivity of B in the poly Si is modeled with only a neutral vacancy as following :

$$D_{poly} = (DIX.0)\cdot\exp\left(\frac{-DIX.E}{kT}\right) \qquad (1)$$

However, the B diffusion in the upper half recrystallized Si can be modeled with a neutral and a positive charged vacancy as following:

$$D_{Si} = (DIX.0)\cdot\exp\left(\frac{-DIX.E}{kT}\right) + (DIP.0)\cdot\left(\frac{p}{n_i}\right)\cdot\exp\left(\frac{-DIP.E}{kT}\right) \qquad (2)$$

That is, for the only B implanted poly Si, the B diffusion was modeled with eq. (1) over the total poly Si layer (250nm), but for the poly Si preamorphized with As^+/180keV, the B diffusion was modeled with eq. (2) in the upper half layer (125nm) and modeled with eq. (1) in the lower half layer (125nm). The result was shown in Fig.6. The fitted values of diffusion components used in the simulation are summarized in Table II. Using these values of the diffusion components, D_{poly} was evaluated at 6.0×10^{-13} $cm^2\cdot s^{-1}$ for 850°C, while D_{Si} was evaluated at 1.2×10^{-14} $cm^2\cdot s^{-1}$. From these estimations, the B diffusivity in the recrystallized upper layer of the As preamorphized poly Si is reduced by a factor of about 50 compared with that in the only B implanted poly Si.

Table II. Values of the diffusion components used in the boron diffusion model from TSUPREM-4

	DIX.0 ($cm^2.s^{-1}$)	DIX.E (eV)	DIP.0 ($cm^2.s^{-1}$)	DIP.E (eV)
polysilicon	1854	3.46	–	–
single crystalline Si	18.54	3.46	0.721	3.46

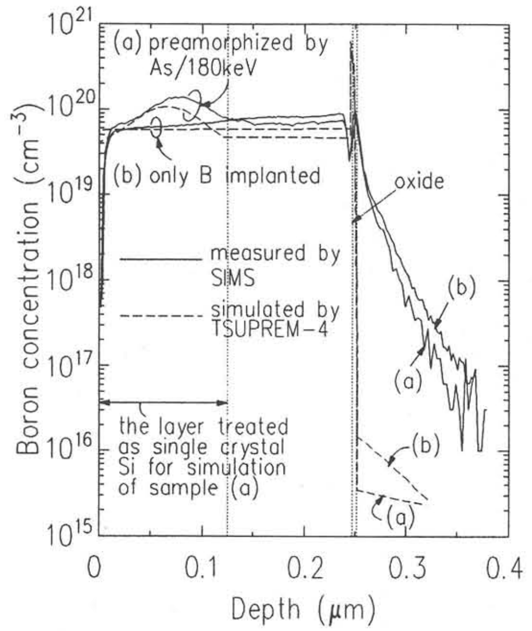

Fig.6 B profiles simulated from TSUPREM-4 in the only B implanted and the As/180keV preimplanted poly Si, including SIMS profile.

4. Conclusions

The conductivity of the p^+ poly Si film preamorphized using As^+ ions was enhanced due to the enhanced grain growth and the retarded boron diffusion, etc. And the As preamorphization can also aid to suppress the boron penetration through the thin gate oxide.

Acknowledgments

The authors would like to thank Mr. Byong Hwa Koak and Dr. Mun Cheol Paek in ETRI for their helpful analysis of SIMS and TEM. This work was made possible by the financial support of ISRC in Seoul National University.

References

[1] T. Skotnicki, et al., IEEE, ED36 (1989) 2548.
[2] J. Y. C. Sun, et al., VLSI Tech. Symp(1989) 7.
[3] I. R. C. Post, et al., IEEE, ED38(1991) 2442.
[4] S.J. Kwon and J.D. Lee, J. Electrochem. Soc., 138(1991) 867.
[5] K. Yokota, et at., J. Appl. Phys., 69(1991) 2975.