Extended Abstracts of the 1997 International Conference on Solid State Devices and Materials, Hamamatsu, 1997, pp. 510-511 **C-12-2**

Study of Indium Doping Effect on High Performance Sub-Quarter Micron NMOS: Vt Control and Pocket Implantation

M. TAKASE, K. YAMASHITA and B. MIZUNO

Central Research Laboratory, Matsushita Electric Industrial Co., Ltd, 3-1-1, Yagumonakamachi, Moriguchi, Osaka, Japan Phone//fax +81-6-906-4902//3451, email:takase@crl.mei.co.jp

1. Introduction

To continue improving the performance of MOSFET in the deep sub-micron region, retrograde channel profile will be required. For NMOS, indium is the only candidate for fabricating retrograde profiles[1]. Shahidi et al.[2] and Taur et al.[3] have made sub-quarter micron NMOS using indium as a channel dopant. They showed that when In is used in the channel, the NMOS devices can work fairly well with gate lengths near 0.1 micron.

In this paper, we utilized In ions to change the profile in the channel region, because it has ten times larger mass, can better create retrograde profiles and has lower diffusivity than boron. We also demonstrate that In can be very effective for amorphization before phosphorous deep source/drain (S/D) implants [4] and for pocket implants, suppressing the threshold voltage (Vt) shift due to negligible change of surface carrier concentration.

2. Experiment

Two experiments have been done. First, indium was implanted at an energy of 150 keV to 200 keV and dose of 6×10^{12} cm^{-2} to 6×10^{13} cm^{-2} for a simultaneous pocket dopant and S/D pre-amorphization implant. Then phosphorous was used for deep S/D doping. Second, In was implanted as Vt threshold adjust implant. Carrier concentrations have been obtained with Hall measurements. The of annealing is done with rapid thermal annealing (1000 °C, 10 sec)

3. Results and discussion

First, we dope with In for pocket and S/D pre-amorphization implant. Fig. 1 shows the saturated transconductance (Gm) ratio of phosphorous S/D to arsenic S/D with channel length. In this experiment, phosphorous was adopted as a S/D dopant to achieve electrodes with the lowest sheet resistance[4]. Arsenic implants were used in S/D control samples. The phosphorous doped sample shows improved Gm: for example, 8% higher at the gate length of 0.18 micron. The phosphorous and arsenic doped samples have similar short channel effect results as shown in Fig. 2. The In pre-amorphization was effective in suppressing the phosphorous channeling and diffusion. Fig. 3 shows Vt versus gate length for In pocket samples. The control samples have no pocket implants. Comparing with the pocket doped samples, undoped samples show early punch through.

The Vt shifts with BF_2^+ pocket implants are about 4 times larger than those of In doped samples which are negligibly small in the dose range shown in Fig. 4. Fig. 5 shows the In profile in the Si-substrate (In^+, 200 keV) compared to the B profile in the control sample (BF_2^+, 100 keV). In the B profile, there is evidence of B back-scattering[5], but in the In profile there is not. The In profile also has a low surface concentration because of its low diffusivity. This retrograde profile is very effective in suppressing the Vt shift due to pocket doping as shown in Fig. 4.

In the second experiment, indium is used as a channel dopant. Fig. 6 shows Vt versus gate length. The BF_2 sample shows a large reverse short channel effect, which is usually caused by B segregation under the gate electrode. On the other hand, indium samples showed no reverse short channel effects because of its low diffusivity and profile as shown in Fig. 5. Fig. 7 shows Vt versus dosage of channel doping. Comparing with the sample which has the same projected range of channel doping, the 300 keV In samples have Vt values which are a fourth of the 30 keV BF_2 samples. This implies that the In activation efficiency is less than 25%. Indium is commonly believed to have a very low activation ratio due to its low solid solubility in Si. We have investigated these characteristics with Hall measurements. The activation efficiency and sheet resistance for the In doped samples with doses from 1×10^{13} cm^{-2} to 1×10^{15} cm^{-2} are shown in Fig. 8. Carrier concentration is seen to saturate with 1×10^{14} cm^{-2} implant dose, and the activation ratio is less than 0.02 at a dose of 1×10^{15} cm^{-2}.

4. Conclusion

Indium has been used for Vt control, pre-amorphization and pocket implantation to change the profile in channel region. Pre-amorphization with In halo implants may allow the use of phosphorous as a source/drain dopant. NMOS devices show higher Gm and minimal Vt shift with In pocket implants and phosphorous S/D, and no reverse short channel effect with In Vt control implantation.

Acknowledgments

The authors thank Director Dr. O. Yamazaki,, Dr. T. Takemoto, Dr. K. Ohnaka, Dr. M. Ogura, Dr. M. Niwa, H. Umimoto and A. Hori for valuable discussion and supporting this job. They thank also H. Sato for device analysis and H. Morita for Hall measurement.

References

[1]D.Antoniadis et al., IEDM Technical Digest, p.21(1991).
[2]G.G.Shihidi et al., Symp.on VLSI Technical Digest, p.93(1993)
[3]Y.Taur et al., IEDM Technical Digest, p.127(1993).
[4]A.Hori, M.Takase et al., IEDM Technical Digest, p.575(1996).
[5]B.Mizuno and M.Takase, Ext. Abs. Jap. Soc. Appl. Phys. Spring, p644(1994).

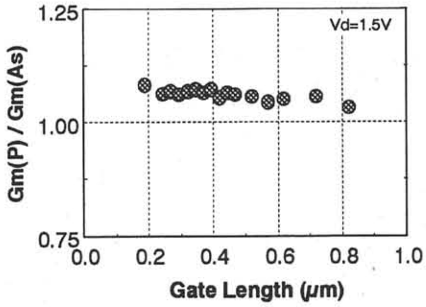

Fig. 1 Comparison of Transconductance between the NMOS devices with phosphorous S/D (P^+, 10 keV, 4×10^{15} cm^{-2}) and arsenic S/D (As^+, 30 keV, 3×10^{15} cm^{-2}). Phosphorous is implanted after indium pre-amorphization (In^+, 200 keV, 1×10^{13} cm^{-2}).

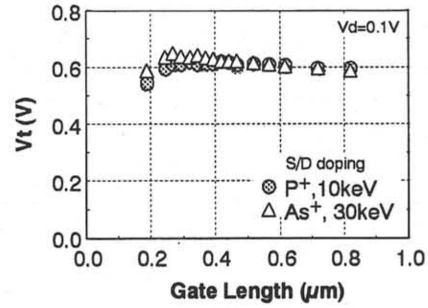

Fig. 2 Threshold voltage as a function of gate length. Comparing with arsenic S/D, phosphorous samples have no degradation due to indium pre-amorphization (In^+, 200 keV, 1×10^{13} cm^{-2}).

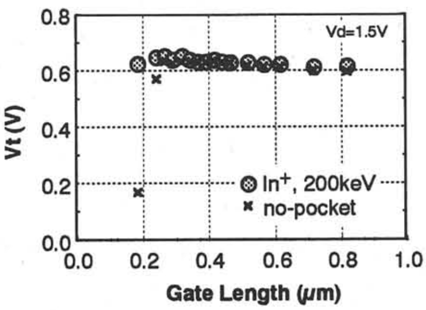

Fig. 3 Threshold voltage of NMOS devices with phosphorous S/D as a function of the gate length. Indium pocket doping (In^+, 200 keV, 3×10^{13} cm^{-2}) is effective in reducing short channel effect.

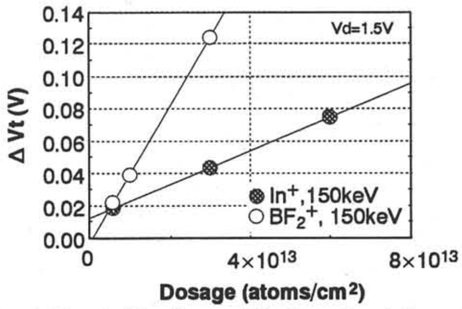

Fig. 4 Threshold voltage shift (from Lg=1.2 μm to 0.18 μm) as a function of pocket dopant dosage. For the pocket doping, In^+ or BF_2^+ are implanted at the energy of 150 keV.

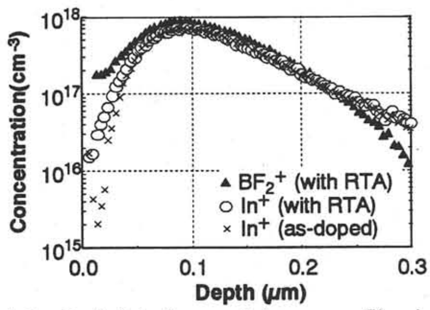

Fig. 5 Implanted indium and boron profiles in Si-substrate by SIMS analysis. 200 keV In^+ and 100 keV BF_2^+ are implanted at the dosage of 3×10^{15} cm^{-2}. Indium ions have no back-scattering and their low diffusivity result in low surface concentration.

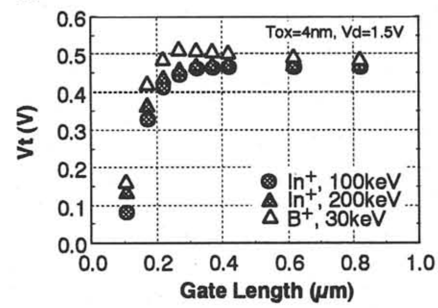

Fig. 6 Threshold voltage of NMOS devices with indium channel doping as a function of the gate length. 100 keV In^+, 200 keV In^+ and 30 keV B^+ are implanted to the dosage of 1×10^{13} cm^{-2}.

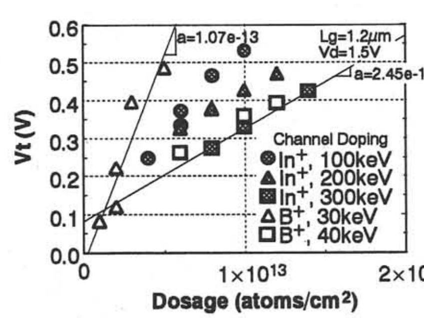

Fig. 7 Threshold voltage as a function of channel dopant dosage. Comparing at implanted energies with the same projected range, Vt with 30 keV B^+ is 4 times larger than that with 300 keV In^+ at the dosage of 1×10^{13} cm^{-2}.

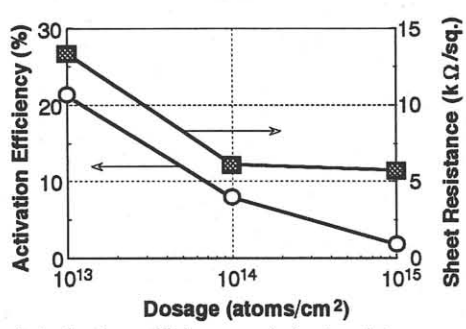

Fig. 8 Activation efficiency and sheet resistance as a function of indium dosage for channel doping. Measured by Hall effect measurements.