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1999 Jpn. J. Appl. Phys. 38 L33

(http://iopscience.iop.org/1347-4065/38/1A/L33)

Jpn. J. Appl. Phys. Vol. 38 (1999) pp. L 33–L 34
Part 2, No. 1A/B, 15 January 1999

The Effects of Shallow Germanium Halo Doping on N-Channel Metal Oxide Semiconductor Field Effect Transistors

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(Received December 4, 1997; accepted for publication November 4, 1998)

In this paper, we report the use of shallow germanium halo doping on improving the short-channel effects of deep submicron n-channel metal-oxide-semiconductor field effect transistors. It is demonstrated that by adding a shallow (i.e., 10 keV) germanium large-angle-tilt implant (LATID), V_{th} lowering in short-channel transistors is significantly improved. The improvement is found to increase with increasing germanium dose. A low germanium dose (*e.g.*, 5×10^{12} cm^{-2}) is also found to effectively improve the drain-induced barrier lowering (DIBL) of the short-channel transistors. Our results also show that junction leakage degradation, which has been previously reported to accompany germanium implants using higher energy, can be minimized by the shallow low-dose implant used in this study.

KEYWORDS: germanium halo implant, large-angle-tilt implant, short-channel effects, drain-induced barrier lowering, threshold-voltage lowering

1. Introduction

Germanium has been applied for improving the short-channel effects of n-channel metal-oxide-semiconductor field effect transistors (MOSFETs) by retarding the diffusion of the source/drain dopants.[1–3] In those studies, a high implant energy (i.e., 125 keV) and high dose (i.e., 5×10^{15} cm^{-2}) were used, which resulted in the extension of the Ge-doped region beyond the metallurgical junction, causing severely degraded junction leakage characteristics.[4] Recently, the reverse short-channel effects (RSCE), which involve a delay or even an increase in threshold voltage lowering, have received significant attention.[5–8] The RSCE has been attributed to the lateral redistribution of the dopant near the source/drain junction. This lateral redistribution is ascribed to the crystal defects formed during post-source/drain implant anneal. In this study, we employ a very shallow (i.e., 10 keV) germanium implant through large-angle-tilt implant (LATID)[9] (i.e., 60°) to form very shallow halo regions abutting the source-drain regions. We demonstrate that the incorporation of such a shallow germanium is also effective in improving the threshold voltage (V_{th}) lowering and the drain-induced barrier lowering (DIBL) characteristics of the transistors, while maintaining a low leakage junction.

2. Experiments

N-channel MOSFETs were fabricated on 6-inch p-type (100) 15–25 Ω-cm silicon wafers. After active area definition by local oxidation of silicon (LOCOS), V_{th}-adjustment and anti-punch-through implants were performed using BF_2^+ and boron implants, respectively. Thin gate oxides were grown in dry oxygen at 900°C, followed by a deposition of 2000 Å-thick polysilicon at 620°C. The plasma resist ashing was employed to achieve the desired short gate length. After polysilicon etching, wafers were split to receive a shallow (i.e., 10 keV) Ge halo implant through 60°-tilt LATID with various doses. Next, shallow (i.e., extended) and deep S/D regions were formed by 10 keV arsenic implant with 4×10^{14} and 1×10^{15} cm^{-2} doses, respectively. A 150-nm tetra-ethyl-ortho-silicate (TEOS) sidewall spacer was formed between the two implants. Finally, a 800°C, 30 min furnace anneal and a 1050°C, 10 s rapid thermal anneal (RTA) were performed to activate the dopants.

The effects of the Ge halo dose on V_{th} lowering are depicted in Fig. 1. It can be seen that while the non-Ge control devices display severe threshold voltage lowering for channel length smaller than 1 μm, V_{th} lowering is significantly alleviated with the Ge halo implant. Although the improvement increases with increasing Ge dose, it approaches saturation for Ge doses higher than 1×10^{13} cm^{-2}. This improvement can be explained by the reduced lateral diffusion of dopant near the S/D region, since Ge is known to retard dopant diffusion.[4] The DIBL effects are measured as a function of channel length and plotted in Fig. 2. The device with light Ge dose (i.e., 5×10^{12} cm^{-2}) shows improved DIBL, especially for shorter devices. However, for the device with 1×10^{13} cm^{-2} Ge dose, although DIBL is reduced for channel length longer than 0.35 μm, DIBL deteriorates for shorter devices. While for the device with the highest Ge dose used in this study (i.e., 1×10^{14} cm^{-2}), DIBL is degraded for all channel lengths. From these results, it can be concluded that a light Ge halo implant can be used to achieve optimum short-channel behaviors, including reduced threshold-voltage lowering and improved DIBL effects.

The reverse leakage current as a function of periphery over area ratio (P/A) is shown in Fig. 3 for n^+/p diodes. For low Ge doses, i.e., 5×10^{12} and 1×10^{13} cm^{-2}, only a minimal increase in area leakage current (i.e., the interception with vertical axis in Fig. 3), compared to that of the non-Ge control is observed, suggesting that the leaky junction reported in previous literature in the case of high-energy implants can indeed be minimized by employing a shallow Ge halo implant with proper dose. For the 1×10^{14}/cm^2 split, however, the area junction leakage current increases more dramatically, suggesting that defects created by such a heavy Ge implant can no longer be fully annealed at the reduced thermal cycle as required for deep submicron processing. Nevertheless, the peripheral junction leakage current (i.e., the slope in Fig. 3) does not increase even for the highest Ge dose of 1×10^{14} cm^{-2}.

The transistor off-state leakage current (measured at gate voltage of 0 V and a drain voltage of 2.5 V) is shown in Fig. 4. It is observed that at low Ge halo dose, the off-state leakage

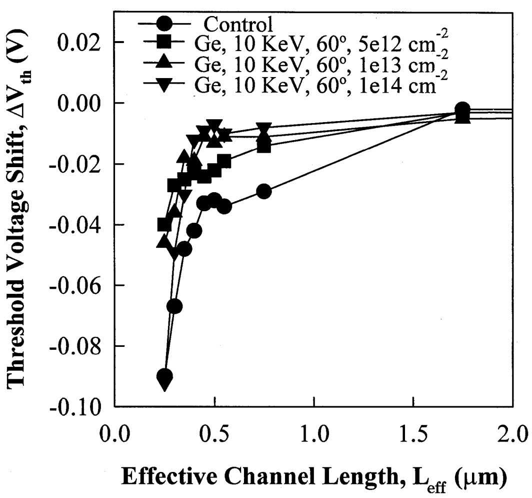

Fig. 1. Threshold voltage roll-off as a function of channel length for control devices and devices with various germanium halo implant doses.

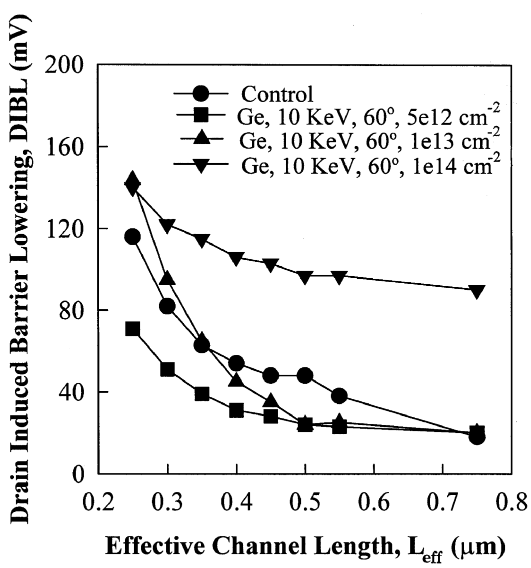

Fig. 2. Drain-induced-barrier-lowering as a function of channel length for control devices and devices with various germanium halo implant doses.

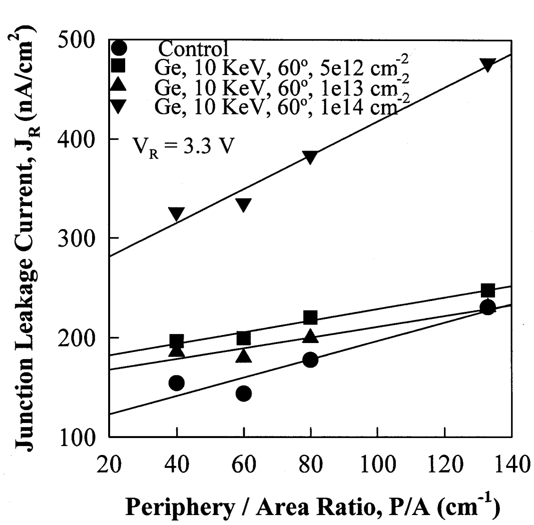

Fig. 3. Diode leakage current density as a function of periphery over area (P/A) ratio. Leakage current is measured at a reverse biased voltage of 3.3 V.

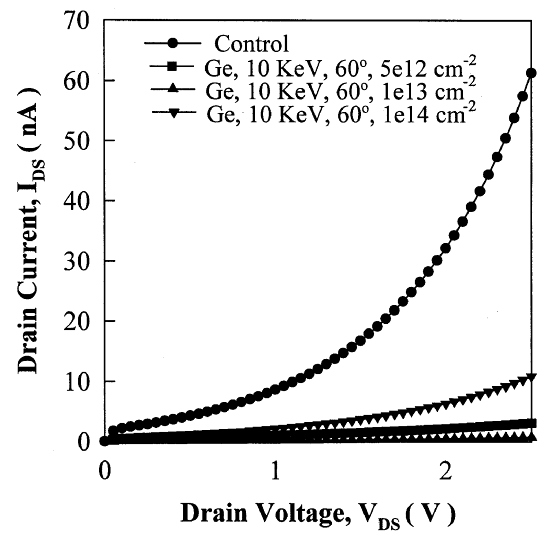

Fig. 4. Off-state leakage current of control devices and devices with various germanium halo implant doses. The effective channel length is 0.25 μm and off-state leakage current is measured at a gate voltage of 0 V and a drain voltage of 2.5 V.

of the Ge-implanted device is indeed significantly improved over the non-Ge control device, suggesting that a light Ge halo implant can be applied to reduce the off-state leakage current of the resultant transistor, due to the improved DIBL effects.

3. Conclusion

The effects of an ultra shallow germanium halo implant have been investigated. Our results indicate that by employing a shallow 10 keV Ge halo region through the large-angle-tilt implant, V_{th} roll-off improves with increasing Ge halo dose. The DIBL effects are also improved with light Ge halo implant (*e.g.*, 5×10^{12} cm^{-2}), although at higher doses DIBL effects actually worsen. Junction leakage degradation, which is known to accompany Ge implants as reported in previous literature, can also be effectively minimized by employing the shallow Ge implant used in this study. N-channel transistors with improved off-state leakage current can thus be obtained.

Acknowledgment

The authors would like to thank National Nano Device Laboratories for wafer processing. This work was partly supported by the R.O.C.'s National Science Council through contracts #NSC86-2722-2317-001, and #NSC85-2215-E009-039.

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