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Back Gate Modulation of Ultra-Thin-Body InGaAs-OI nMOSFET

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Abstract

This paper discusses the back gate modulation of front gate ultra-thin-body InGaAs-OI nMOSFETs with 8-nm-thick InGaAs and 15-nm-thick InGaAs. The results show that the back gate bias changes the distribution of carriers in the InGaAs film and affects the on-current, channel capacitance and carrier mobility. The formation of back channel could help boost the electron mobility under the high electrical field.

1. Introduction

With the conventional scaling down of Si MOSFETs, it is increasingly difficult to go further more [1]. As promising alternative channel materials, InGaAs has attracted lots of interest as it has much higher electron mobility than that of Si[2].Meanwhile, high performance ultra-thin-body (UTB) InGaAs-on-insulator(InGaAs-OI) nMOSFETs have been reported to suppress the short channel effect [3]. Unlike Si-on-insulator (SOI) MOSFETs, the electrical characteristics of UTB InGaAs-OI nMOSFETs have not been fully understood yet.

In this work, we fabricated 8-nm-thick and 15-nm-thick InGaAs-OI nMOSFETs with UTB InGaAs-OI substrates, which were obtained by the direct wafer bonding (DWP) technique [4]. Owing to the superior crystal quality of the InGaAs-OI substrates, the peak effective mobilities of 8-nm-thick and 15-nm-thick InGaAs-OI nMOSFETs reach 643 and 1167 cm^2/Vs, respectively. The effect of back gate bias on the electrical characteristics of UTB InGaAs-OI nMOSFETs is systematically investigated to study the modulation on the electron mobility of InGaAs-OI channels.

2. Experiment

DWB technique was carried out to realize high quality UTB InGaAs-OI substrates. N-type Ge wafer with a resistivity of 10~20 ohm.cm and p-type $In_{0.53}Ga_{0.47}As$/InP wafer with doping of 10^{16} cm^{-3} were manually bonded together in the air after 50 nm Al_2O_3 deposition with the atomic layer deposition (ALD). After the annealing in N_2 ambient, InP was selectively etched by HCl solution and finally InGaAs-Al_2O_3-Ge substrates were obtained.

Fig. 1 summarizes the gate first process for fabricating UTB InGaAs-OI nMOSFETs. InGaAs film was etched by H_3PO_4:H_2O_2:H_2O solution to define the active areas of nMOSFET after the substrate pre-cleaning. NH_4OH treatment of the InGaAs surface was employed before 15 nm Al_2O_3 deposition in ALD chamber at 300 °C as the gate oxide. After the post-deposition annealing, Tungsten was sputtered and patterned by diluted H_2O_2 solution to form the gate stack. Source and drain were formed by the self-aligned process with Ni evaporation and Ni-InGaAs metallization in N_2 ambient at 400 °C for 1 min. Finally, Al contact pad was evaporated as the back gate.

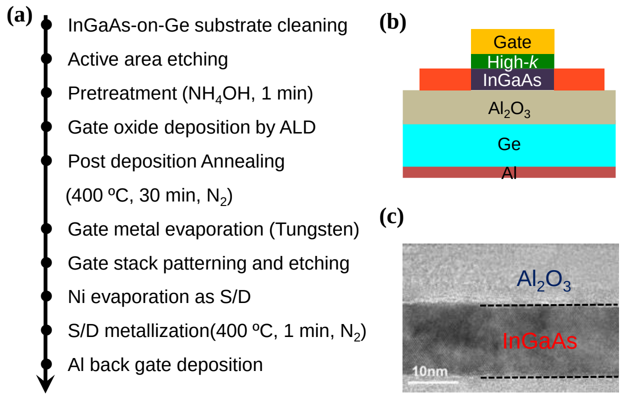

Fig. 1 (a) Fabrication flow, (b) device structure and (c) high resolution TEM image of UTB InGaAs-OI nMOSFETs with body and BOX thickness of 100 nm and 15 nm, respectively.

3. Results and discussion

The I_d-V_g and I_d-V_d characteristics of front gate InGaAs-OI nMOSFETs with 8 and 15 nm InGaAs film are shown in Fig. 2. The on/off ratio of fabricated nMOSFETs is 10^6. Attributed to the difference of film thickness, the off-current and on-current of 8-nm-thick InGaAs channels is smaller than that of 15-nm-thick InGaAs channels. The electron mobility is then extracted by the split C-V method. The peak effective mobilities of 8-nm-thick and 15-nm-thick InGaAs-OI nMOSFETs reach 643 and 1167 cm^2/Vs, respectively.

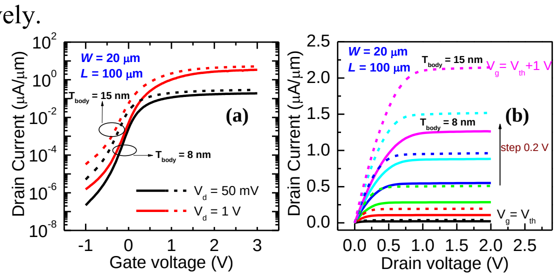

Fig. 2(a) I_d-V_g and (b) I_d-V_d characteristics of front gate InGaAs-OI nMOSFETs with 8 and 15 nm InGaAs body thicknesses

Similar with SOI MOSFETs [5-7], InGaAs channels on the insulator substrates can be modulated by the back gate bias (V_{bg}), especially in the UTB case. Fig. 3 illustrates the I_d-V_g curves of UTB InGaAs-OI nMOSFETs at V_d of 10 mV with V_{bg} sweeping from -8 V to 8 V. The total carrier number in InGaAs channels is reduced under negative V_{bg} bias and the drain current decreases. On the contrary, I_d increment is obviously observed under the positive V_{bg} bias, in company with the larger off-current, which is related to weaker front gate (V_{fg}) control under the formation of back channel.

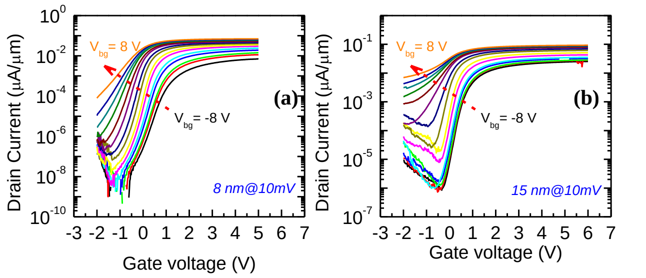

Fig. 3 I_d-V_g curves of (a) 8-nm-thick and (b) 15-nm-thick front channel InGaAs-OI nMOSFETs with V_{bg} from -8 V to 8 V

The channel capacitances, C_{gc}, under different V_{bg} at 50 kHz and 1 MHz, were measured to evaluate the effect of back gate bias on the channel mobility. When V_{bg} sweeps from -8 V to 8 V as shown in Fig.4, C_{gc} curve shifts to the negative side, which is similar to I_d-V_g curves. A kink appears on the C_{gc} curves at 50 kHz when the front channel is not formed under positive V_{bg}. This kink comes from the response of the carriers in UTB InGaAs channel and is an evidence of the formation of back channel. The C_{gc} we measured in InGaAs-OI nMOSFET comes from the combined response of the front channel, the depletion region and the back channel in UTB InGaAs film. When the InGaAs film is thick, the electrical control of the front gate on the whole film is weak under the positive V_{bg}, as shown in Fig. 4(b). Fig. 4(c) and Fig. 4(d) show that channel capacitance C_{gc} at 1 MHz decreases under the positive V_{bg} at a certain V_{fg} in both 8-nm-thick and 15-nm-thick InGaAs-OI nMOSFETs. This phenomenon happens under the high frequency and is another proof that the carriers in the back channel can affect the electrical characteristics of the front channel.

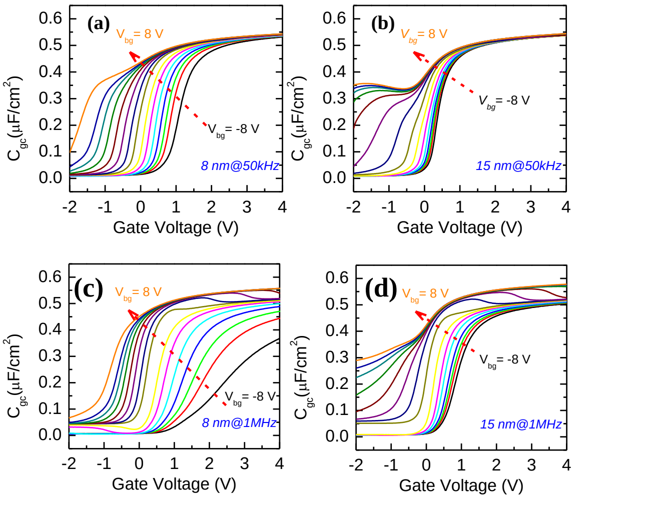

Fig. 4 C_{gc} curves of (a) 8-nm-thick and (b) 15-nm-thick at 50 kHz, (c) 8-nm-thick and (d) 15-nm-thick at 1 MHz front gate InGaAs-OI nMOSFETs with V_{bg} sweeping from -8 V to 8 V

The electron mobility extracted from the I_d-V_g curves and C_{gc} curve at 50 kHz is presented in Fig. 5.The electron mobility of 8-nm-thick InGaAs-OI nMOSFET decreases when V_{bg} sweeps from 0V to -8V. When V_{bg} sweeps from 0V to 8V, the electron mobility has opposite tendency under the small surface carrier density (N_s) and large N_s. The mobility increases under the large N_s and decreases under the small N_s, which is also shown in Fig. 7. The electron mobility of 15-nm-thick InGaAs-OI nMOSFET has the same phenomenon as 8-nm-thick devices. When the electrical field is low (small N_s), the influence of Coulomb scattering is dominant in the channel. Therefore, Coulomb scattering becomes severe if the carriers are confined closer to the gate oxide/InGaAs surface when the back channel is not formed or carriers are scattering by the poor back channel interfaces when the back channel forms. When the electrical field is high (large N_s), due to the surface roughness scattering, the case is the same as the small N_s when the back channel is not formed. However, when back channels appears under the large N_s, the wave function of carriers migrates into the films, leading to the less surface roughness scattering.

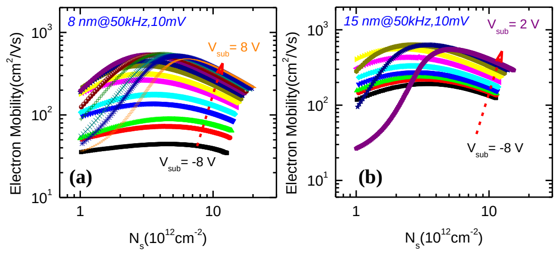

Fig. 6 Electron mobility curves (a) 8-nm-thick and (b) 15-nm-thick front channel InGaAs-OI nMOSFETs with V_{bg} sweeping from -8 V to 8 V

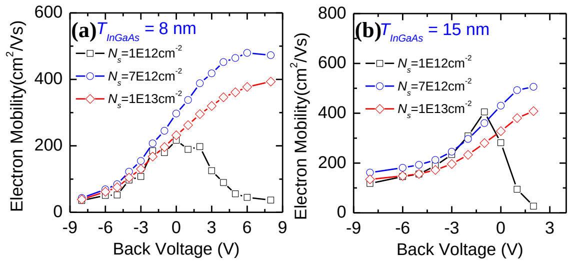

Fig. 7 Electron mobility curves of (a) 8-nm-thick and (b) 15-nm-thick front channel InGaAs-OI nMOSFETs with different N_s(N_s = 1E12 cm^{-2}, 7E12 cm^{-2} and 1E13 cm^{-2}, respectively)

4. Conclusions

High performance UTB InGaAs-OI nMOSFETs have been fabricated by the DWB technique and self-aligned gate first process. The influence of V_{bg} modulation on the UTB InGaAs-OI nMOSFETs has been investigated. Before the formation of the back channel, the mobility decreases with the increase of V_{bg} due to the more severe Coulomb and surface roughness scattering. As the back channel formed, the back channel/BOX interface has a more prominent influence on the carrier mobility, in the low electric field. In the high field, the deeper migration of the wave function towards the InGaAs channel leads to a mobility increase.

Acknowledgements

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