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Fabrication of a Novel Vertical pMOSFET with Enhanced Drive Current and Reduced Short-Channel Effects and Floating Body Effects

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Fabrication of a Novel Vertical pMOSFET with Enhanced Drive Current and Reduced Short-Channel Effects and Floating Body Effects

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Abstract

We have fabricated, for the first time, a novel vertical p-channel metal-oxide-semiconductor field-effect transistor (MOSFET), so called high mobility hetero-junction transistor (HMHJT). Significantly reduced short channel effects and floating body effects, and enhanced drive current have teen achieved. Compared to a Si control device, the fabricated p-HMHJT has a 1.65X higher drive current (V_{DS} = -1.6 V and V_G-V_T = -2 V), and a 70X lower off-state leakage (V_{DS} = -1.6 V).

Introduction

Strained SiGe has been used in the source of a pMOSFET to suppress bulk punchthrough and drain induced barrier lowering (DIBL) [1-3]. However, the drive current in this type of device is reduced due to the energy barrier in the channel. In order to overcome *this* drawback and take the advantage of the higher hole mobility in strained SiGe, a new Si/SiGe high mobility hetero-junction transistor (HMHJT), which has a strained SiGe source and a Si/SiGe/Si quantum well channel, has been proposed and simulated recently [4-5]. Improved device performance and scalability are expected with this device. In this paper, the fabrication of such a vertical p-channel HMHJT is described, and reduced short-channel effects (SCE) and floating body effects (FBE), and enhanced drive current are demonstrated.

Device Fabrication

A vertical p-HMHJT and a control *Si* device with a 100 nm channel length have been fabricated *using* ultra-high vacuum chemical vapor &position (UHV-CVD) with in *situ* doping. The schematic cross section of the p-HMHJT is shown in Fig. 1. It has a compressively strained $Si_{0.84}Ge_{0.16}$ source, and a $Si/Si_{0.84}Ge_{0.16}/Si$ quantum-well channel. Bandgap engineering is performed in a 2-dimensional fashion. The doping concentration is 2×10^{18} cm" in the n-type layer and 5×10^{19} cm^{-3} in the p^+-type layer. &active ion etch (RIE) is employed to obtain the 20 $\mu m \times 20$ μm mesa. 8 nm thick intrinsic $Si_{0.84}Ge_{0.16}$ and 10 nm thick intrinsic Si cap are then grown on the sidewalls. Gate oxidation is performed at 750°C in wet O_2. The oxide thickness is -6 nm. After oxide growth, the Si cap is -6 nm thick. Boron is diffised into the SiGe/Si cap near the source and drain during the gate oxide growth and p^+-poly Si gate activation anneal. The Si control device has the same intrinsic Si cap, which serves as the channel.

The TEM image of the HMHJT is shown in Fig. 2. Due to the limitation of the critical thickness of strained SiGe, the p^+-source region consists of a 100 nm thick strained-SiGe layer and a 30 nm thick Si layer. The gate oxide, and the SiGe channel/Si cap layers are quite uniform. No dislocation defects are observed in the channel region. Thanks to the Si cap layer, good gate oxide quality with smooth interface is achieved.

Results and Discussions

Fig. 3 and 4 show the I_D-V_G and I_D-V_D characteristics of the p-HMHJT and the Si control device, respectively. No apparent bulk punchthrough and DIBL, better subthreshold sting, and a 70X lower off state leakage current (at V_{DS} = -1.6 V) are observed in the HMHJT when it is measured with the top p^+-SiGe layer as the source. This is due to the additional energy barrier provided by the band offset between the p^+-SiGe source and the n-Si bulk. On the other hand, the HMHJT has a 1.65X higher drive current (at $V_{DS} = V_G$-V_T= -2 V). This is due to higher hole mobility in strained SiGe channel. Furthermore, the kinks in the I_D-V_D curves due to FBE are completely eliminated in the HMHJT, while they are observed in the Si device. This is because the use of strained SiGe in the source makes it easier for electrons to be injected from the channel back to the source, as it can be seen in Fig. 5, in which the simulated conduction and valence band edge energies underneath the channel at $V_{DS} = V_{GS}$= -1.2V are shown.

Fig. 6 shows the comparison of the I_D-V_G characteristics of the HMHJT when it is measured with the source and drain contacts interchanged. Much less DIBL and FBE are observed when SiGe is used in the source rather than in the drain, while the drive current is almost the same at the same gate overdrive. For the Si control device, there is no difference with the source and drain contacts interchanged, as expected. This indicates that the effective suppression of short-channel effects and floating body effects in the HMHJT is indeed due to the band offset at the source junction.

This work has demonstrated that the new device structure, HMHJT, is very promising in improving device performance and extending device scalability. The performance of the fabricated HMHJT can be further enhanced by reducing the gate oxide thickness, increasing the source /drain doping concentrations, using source/drain silicide, and increasing Ge content in the source and the channel. The gate-to-source and gate-to-drain overlap can be reduced by the vertical replacement gate technology (VRG) [6]. The excellent control of short-channel effects in the HMHJT may enable aggressive device scaling down to 10 nm regime.

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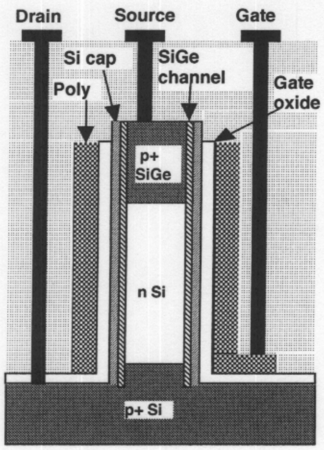

Fig. 1. Schematic cross section of a vertical p-HMHJT with strained SiGe only in the source and channel.

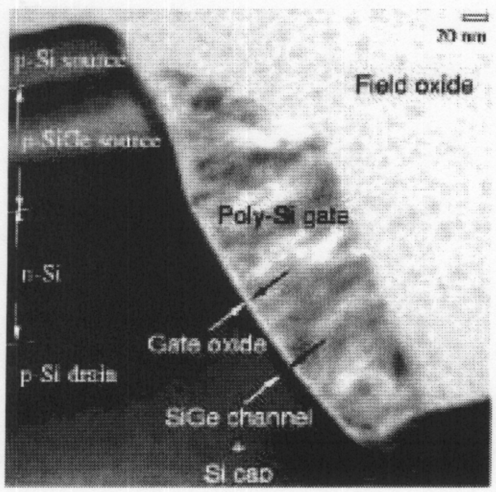

Fig. 2. Cross-sectional TEM image of a fabricated vertical p-HMHJT. The p^+-SiGe source layer is 100 nm thick. Uniformed layer structures of gate oxide (6 nm), SiGe channel plus Si cap (14 nm) are observed on the sidewall.

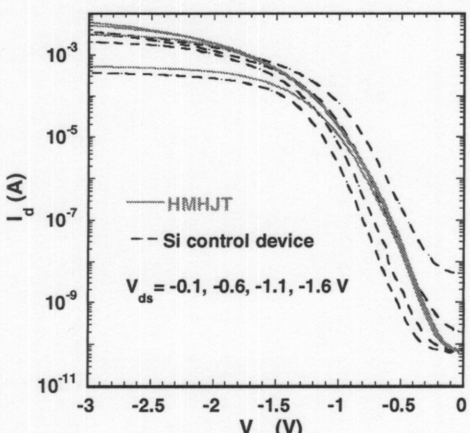

Fig. 3. Measured I_D-V_G characteristics for a vertical Si control pMOSFET and a vertical p-HMHJT with $Si_{0.84}Ge_{0.16}$ in the source and the channel. L_{eff}=100 nm, t_{ox} ≈ 6 nm, W = 80 μm.

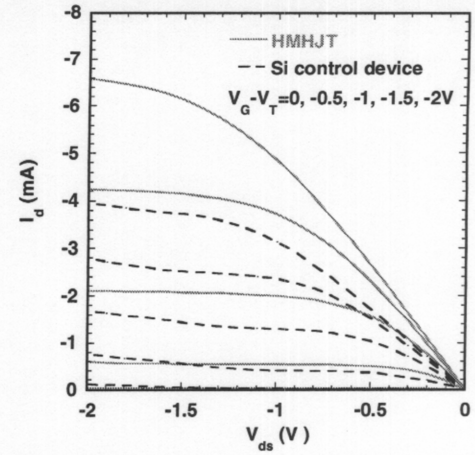

Fig. 4. Measured I_D-V_D characteristics for the same two devices in Fig. 3. The kinks in the Si control device are due to the floating body effect. No kinks are observed in the HMHJT.

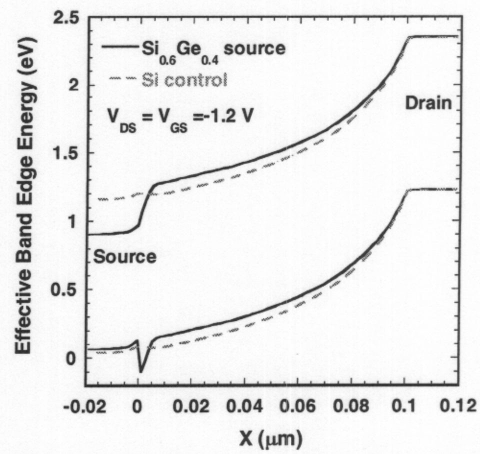

Fig. 5. Simulated effective conduction and valance band edge energies underneath the channel for a HMHJT and a Si control device at V_{DS} = V_{GS} = -1.2V. For better visualization, Ge content is set to be 40% here. The results are obtained using a 2-dimentsional device simulator, MINIMOS-NT [7].

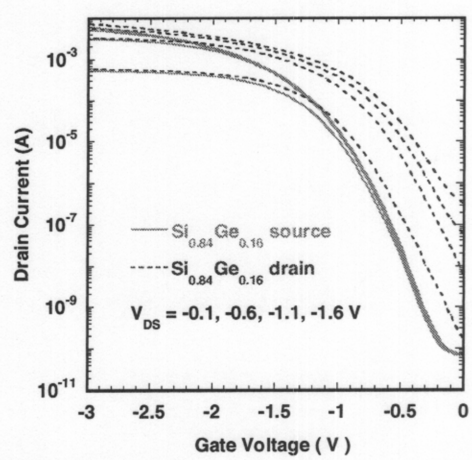

Fig. 6. Measured I_D-V_G characteristics for the HMHJT with the source and drain contacts interchanged. The SiGe source reduces the DIBL and FBE.