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Enhanced Electrical Characteristics of FinFETs with Strained SiGe Super-Lattice Channel

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Abstract

Although a SiGe super-lattice (SL) channel was proposed in MOSFETs to enhance the carrier mobility, its application on FinFETs is not reported yet. Electrical characteristics of n-channel FinFETs with SiGe and strained SiGe SL channels were studied in this work for the first time. It is clearly found that the electron mobility of n-channel FinFETs with SiGe channel is enhanced by SL structure. A higher on-current and on/off current ratio are also achieved.

1 Introduction

The fin field effect transistors (FinFETs) were widely applied beyond conventional planar devices or fully depleted silicon-on-insulator (SOI) technologies to pursue the Moore's law [1]. Recently, some works about the utilization of epi-SiGe buried channel on MOSFET were reported to improve the on-state current [2]. However, some defects may be generated in SiGe buried channel if the channel thickness is larger than its critical one. SiGe super-lattice (SL) structure was proposed as device channel for MOSFET to obtain a channel with fewer defects and better interface quality because the thickness of each epi-Si/Ge in SL structure is very thin, which is lower than the critical thickness of epi-Si/Ge [3]. Thus, the carrier mobility of MOSFET can be further improved by SiGe SL buried channel [4]. However, the application of SiGe channel on n-channel MOSFET is rarely reported, especially for FinFET. Therefore, it is worthwhile to study the effects of SiGe channel on electrical characteristics of n-channel FinFET. In this work, the buried channels of SiGe/Si SL or SiGe on nFinFET were studied for the first time. nFinFETs with strained SiGe SL buried channel demonstrate enhanced electrical and comparable reliability characteristics, indicating that the SiGe SL would be a promising channel structure to achieve high performance SiGe nFinFETs

2 Experiments

nFinFETs with SiGe and strained SiGe SL channel were fabricated on 8-in p-type (100) wafers. After a standard RCA clean, epitaxial SiGe channels were formed by an ultra-high-vacuum chemical molecular epitaxy (UHVCME) system. A 12-nm thick SiGe layer with 30% Ge content and a 2-nm thick Si-cap layer were grown for SiGe channel sample. Regarding strained SiGe SL channel sample, a 5-nm thick SiGe with 30% Ge content and 2-nm thick Si layer were sequentially formed for 2 times. However, the Si/SiGe/Si/SiGe SL channel structure finally is ~1.9/1.6/4.1/3.7 nm, which are a little different from the planned ones. Hence, the structure is likely a SL structure due to the different thicknesses of the repeated films, which therefore may be called SL-like.

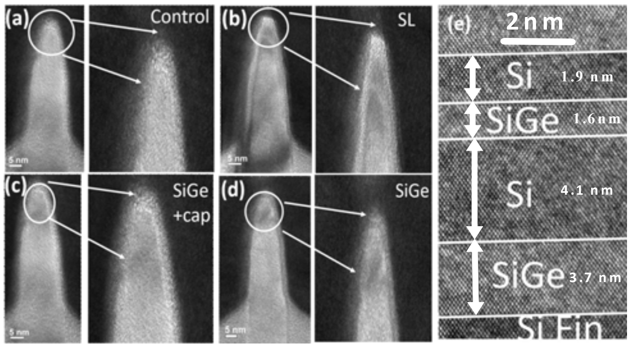

Fig.1 Cross-sectional transmission electron microscopy images of bulk FinFET for (a) control, (b) SL-like, (c) SiGe+Si cap, (d) SiGe w/o Si cap samples, and (e) HRTEM of sample with SL like.

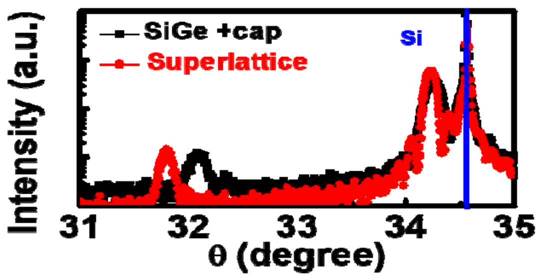

Fig. 2 HRXRD analysis of sample with SL-like and SiGe+Si cap.

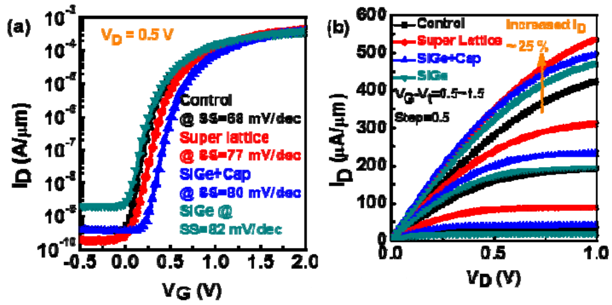

Fig. 3 (a) I_D-V_G, (b) I_D-V_D, of FinFETs for control, SL-like, SiGe+ Si cap, and SiGe w/o Si cap channel samples.

3 Results and Discussion

Fig. 1 shows cross-sectional transmission electron microscopy (TEM) images for (a) control, (b) SiGe SL-like, (c) SiGe+Si cap and (d) SiGe without Si cap channels of bulk FinFETs. Fig. 1(e) shows high resolution TEM (HRTEM) of sample with SL-like. The fin surface of sample with SiGe buried channel is a little rougher than that of control one due to the limited uniformity of epitaxial SiGe and Si-cap layers. It is observed in Fig. 1(b) that a SiGe SL-like structure was formed with 2 periods of SiGe/Si. However, as shown in Fig. 1(e), the thickness of top Si/SiGe layer (~1.9/1.6 nm) is smaller than that of bottom one (~4.1/3.7 nm). SiGe layer without Si cap is a kind of surface channel, and SL-like and SiGe+Si cap are buried channels.

The high resolution X-ray diffraction (HRXRD) of samples with SiGe+Si cap and SL-like are shown in Fig. 2. The epitaxial layers of SiGe+Si cap and SL-like are under strained due to the lattice constant mismatch of Si and SiGe. It is clear that the satellite peaks are found at around θ~32°, indicating that the epitaxial layers of SiGe+Si cap and SL-like are under strained and the strain for SL-like sample is stronger. [5].

Fig. 3(a) shows drain current versus gate voltage (I_D-V_G) characteristics of nFinFETs for control, SL-like, SiGe+Si cap, and SiGe without Si cap samples. The off-state current (I_{OFF}) of SiGe SL-like buried channel sample is the lowest among all ones. The on-state current (I_{ON})/I_{OFF} ratio of SiGe SL-like buried channel sample is about 10^6, which is a half order larger than that of control one, indicating that the Ge up-diffusion may be minor and the influence of SL-like process on high-k gate dielectric can be ignored.

Fig. 3(b) shows drain current versus drain voltage (I_D-V_D) characteristics at gate over-drive (V_G-V_T) from 0.5 to 1.5 V of nFinFETs for control, SiGe SL-like, SiGe+Si cap and SiGe without Si cap samples. It is obvious that the I_{ON} of sample with SiGe SL-like buried channel is the highest among all ones, where the on-state current I_D sat at V_G-V_T =1.5 V of SiGe SL- like buried channel sample is about 10% higher than that of SiGe one, and it is even 25% higher than that of control one. The higher I_{ON} may be attributed to a higher electron mobility obtained by a SiGe SL-like buried channel, while the I_{ON} improvement is not enough by a SiGe one due to the less enhanced mobility.

Fig. 4 shows electron mobility versus carrier density at inversion N_{inv} (μ-N_{inv}) characteristics of nFinFETs for control, SL-like, SiGe+Si cap, and SiGe without Si cap samples. The peak electron mobility for SiGe SL-like, SiGe without Si cap, SiGe+Si cap, and Si control samples are about 377, 326, 344, and 305 cm^2/V-s, respectively. The higher electron mobility in SL-like sample may be attributed to the larger strained channel with a thickness below the critical one. [6] On the other hand, the electron mobility in the SiGe without Si cap channel is lower because its strain is less due to its larger thickness than the critical one.

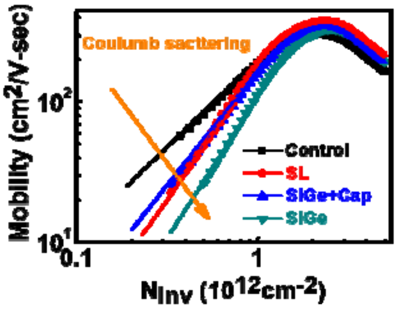

Fig. 4 Electron mobility versus carrier density at inversion N_{inv} (μ-N_{inv}) characteristics of nFinFETs for control, SiGe SL-like, SiGe+Si cap, and SiGe w/o Si cap samples.

The N_{inv} values of peak mobility for samples with SiGe SL-like, SiGe+Si cap and SiGe without Si cap channels are larger than that with Si control one. The lower mobility at low N_{inv} is generally due to the Coulomb scattering, which may be caused by Ge out-diffusion. In addition to a higher electron mobility achieved by a SiGe buried channel, the mobility can be further enhanced with 24% by using a SL-like structure.

4 Conclusions

The effects of SiGe and strained SiGe SL channels on electrical characteristics of nFinFETs were investigated in this work. The device with SiGe SL buried channel shows 23% increase in electron mobility, 29% increase in on-state current, and an I_{ON}/I_{OFF} ratio of ~3x10^6.

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