Asymmetrically-strained (110) SGOI pMOSFETs for hole mobility enhancement in extremely-thin body channels

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1. Introduction

A combination of (110) surface orientation and strain engineering has stirred up much attention toward high speed CMOS devices because of strong enhancement of hole mobility [1]. It has been demonstrated that a SiGe channel along <110> direction on a (110)-oriented substrate provides much improved mobility [2]. Though we have demonstrated sustainable hole mobility in (110)-oriented SiGe-on-insulator (SGOI) pFETs with biaxial compressive strain to address the hole mobility degradation issue in extremely-thin body (ETB) channels [3], the enhanced mobility result is still not enough for future high-speed CMOS devices. In order to further improve effective hole mobility (μ_{eff}), utilization of uniaxial compressive strain along <110> direction on (110)-oriented SGOI pFETs is promising [4]. However, there is no experimental study of the impact of uniaxial compressive strain on the performance improvement in (110)-oriented SGOI pFETs. In this work, we experimentally examine the effectiveness of asymmetric strain on hole mobility enhancement in ETB (110)-oriented SGOI pFETs.

2. Experiment

(110)-oriented $Si_{0.45}Ge_{0.55}OI$ substrates with 0.9% biaxial compressive strain were prepared by the optimized Ge condensation technique with 4-hour slow cooling [5]. After removing the top thermal oxide, the thickness of SGOI was thinned down by using the cyclic digital etching process [3], which contains the generation of $SiGeO_x$ through plasma oxidation and the removal from HF wet etching. The asymmetric strain channels were then defined by using electron beam lithography and plasma dry etching, leading to the relaxation of transverse stress within channels with narrow width, as shown in Fig. 1. Subsequently, surface passivation was formed by 300°C plasma oxidized $SiGeO_x$ and ALD Al_2O_3. The source/drain regions were formed with 50-nm-thick Ni through lift-off. Finally, Al films were deposited on the back side of the Si substrate as the gate electrode.

3. Results and Discussion

Fig. 2(a) shown I_d-V_g characteristics of 6.4-nm-thick (110)-oriented SGOI pFETs with asymmetric strain and biaxial strain channels along <110> and <100> channel directions. Although the improvement in the on-state current was observed in the symmetric strain channels along both <110> and <100> directions, the <110> channel provided much higher on-state current than the <100> one, attributable to the lower effective hole mass [6]. Besides the on-state current improvement, the better cut-off characteristics were also observed thanks to asymmetric strain channels. On the other hand, an unusual result of increased μ_{eff} with a reduction of T_{body} was shown in Fig. 2(b), which might be attributed to removal of surface damage layers on the top of Ge condensation (110)-oriented SGOI by the cyclic digital etching process. As the result, record high μ_{eff} of 807 cm^2/Vs was achieved on 6.4-nm-thick (110)-oriented pFETs with the 93-nm-channel width, leading to 2x mobility enhancement against the biaxial strain channel and 1.7x enhancement against the asymmetric strain (100)-oriented GOI channel with similar T_{body}. Fig. 3 shown a benchmark of μ_{eff} as a function of T_{body} thickness, indicating that (110)-oriented SGOI pFETs provide the highest μ_{eff} among ETB GOI pFETs with T_{body} down to 6 nm, thanks to asymmetric and compressive strain channels on (110) surfaces.

4. Conclusions

The effectiveness of asymmetric strain on mobility enhancement of (110)-oriented SGOI pFET was demonstrated under the ETB condition. Asymmetric strain on (110) surface orientation provide another solution to improve the mobility in ETB channels in future scaled nodes.

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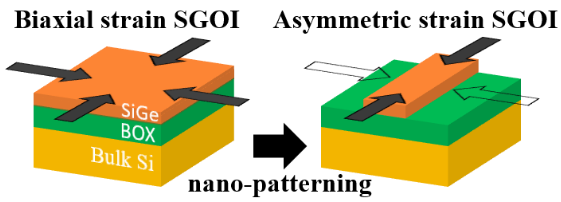

Fig.1: Formation of asymmetric strain (110)-oriented SGOI through transverse strain relaxation by nano-patterning.

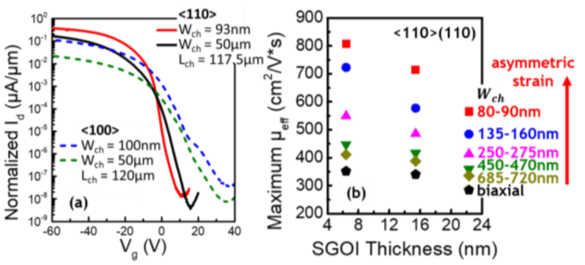

Fig.2: (a) I_d-V_g characteristics of 6.4-nm-thick (110)-oriented SGOI pFETs with asymmetric strain channels along <110> and <100> directions and (b) maximum mobility of pFETs along <110> channel as a function of T_{body}.

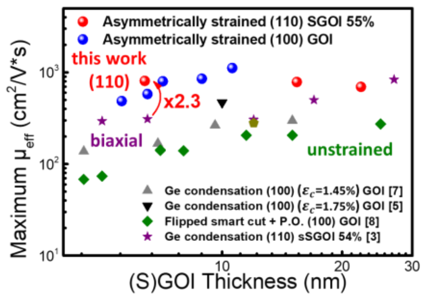

Fig.3: Benchmark of maximum mobility as a function of T_{body}.