Hole mobility enhancement in extremely-thin body Asymmetrically-strained (100) GOI pMOSFETs

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1. Introduction

Extremely-thin body (ETB) channels attract much attention for logic applications in advanced technology nodes because of its superior electrostatic control. However, mobility degradation accompanied by the reduction of body thickness (T_{body}) remains as the most challenging issue in sustaining performance of ETB transistors [1]. We have so far demonstrated mobility improvement in ETB pFETs with body thickness down to 2 nm by using Ge-on-insulator (GOI) and biaxial strain channel through the optimized Ge condensation technique [2]. However, the device performance enhancement is still limited by severe influence of thickness-fluctuation scattering. To further improve effective hole mobility (μ_{eff}), uniaxial strain along the channel direction is essential in ETB channels. In this work, impacts of asymmetric strain on hole mobility enhancement in ETB GOI pMOSFETs are systematically studied.

2. Experiment

15-nm-thick GOI substrates with 1.4% biaxial compressive strain were fabricated by the optimized Ge condensation technique with 4-hour slow cooling [2]. After removal of a top thermal oxide, asymmetric strain was introduced by relaxation of transverse stress within channels with narrow width, as shown in Fig. 1, fabricated by electron beam lithography and plasma dry etching. The GOI thickness was thinned down by using the cyclic digital etching process [3], which contains plasma oxidation and HCl wet etching of GeO_x layers. Surface passivation was immediately formed after thin-down process by 300ºC plasma oxidized GeO_x and ALD Al_2O_3. Source/Drain regions were formed with 50-nm-thick Ni through lift-off. Subsequently, Al films were deposited on back side of Si substrate as gate electrode.

3. Results and Discussion

Strain relaxation was confirmed by Raman peak shift on 10.6-nm-thick GOI substrate, as shown in Fig. 2(a). As decreasing channel width down to nano-scale, Raman peak shifts from as-condensed biaxial strain toward un-strained bulk Ge condition, leading to high degree of asymmetric strain. The remaining value of averaged strain within asymmetric strain channels were estimated through Raman peak shift for GOI with different T_{body}, as shown in Fig. 2(b). We have also confirmed asymmetric strain by oil-immersion Raman spectroscopy [4], allowing us to separately evaluate stress along transverse and longitudinal direction. It was found that asymmetric-strain channels were also successfully fabricated on ETB GOI substrate with T_{body} less than 5 nm.

Fig. 3(a) shown I_d-V_g characteristics of 10.6-nm-thick GOI pFETs with asymmetric-strain and biaxial-strain channels. The on-state current was greatly improved in asymmetric-strain channels, attributable to reduction of the effective hole mass [5]. As a result, 2.7x on-state current enhancement was achieved in the 67-nm-wide channel without degradation of off-state current, leading to $I_{on}/I_{off} > 6 \times 10^5$ at V_d = -50mV. Moreover, it was found that the asymmetric-strain devices provide better cut-off characteristics than the biaxial-strain one. Fig. 3(b) shown μ_{eff} of asymmetric-strain and biaxial-strain GOI pFETs as a function of T_{body}. Although μ_{eff} was monotonically decreased with a reduction of T_{body}, the asymmetric-strain channels provide the enhanced mobility even under the ETB condition. For 3.8-nm-thick GOI pFETs, μ_{eff} of 312 cm^2/Vs was achieved with the 58-nm-channel width, leading to 2.4x mobility enhancement against the biaxial-strain channel.

4. Conclusions

The effectiveness of asymmetric strain on mobility enhancement of GOI pFET was demonstrated under the ETB condition. The effective hole mass was largely reduced in the asymmetric strain channels, leading to on-state current and mobility improvement even in T_{body} less than 5 nm. The asymmetric strain channels as the mobility booster provide an enabler for enhancing performance of an ETB transistor in future scaled nodes.

Acknowledgements This work was supported by JSPS KAKENHI Grant Number 17H06148, Japan. A part of this work was conducted at Takeda Sentanchi Supercleanroom, The University of Tokyo, supported by "Nanotechnology Platform Program" of MEXT, Japan, Grant Number JPMXP09F-20-UT-0007.

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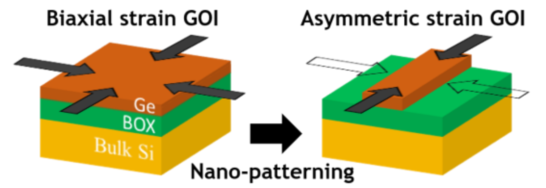

Fig.1: Formation of asymmetric strain GOI through transverse strain relaxation by nano-patterning.

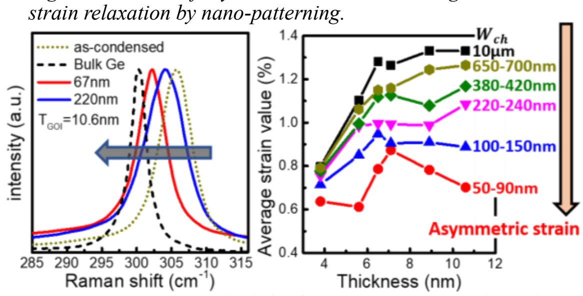

Fig.2: (a) Raman peak shift of asymmetric strain channel on 10.6-nm-thick GOI and (b) estimation of remaining averaged strain value as a function of GOI body thickness.

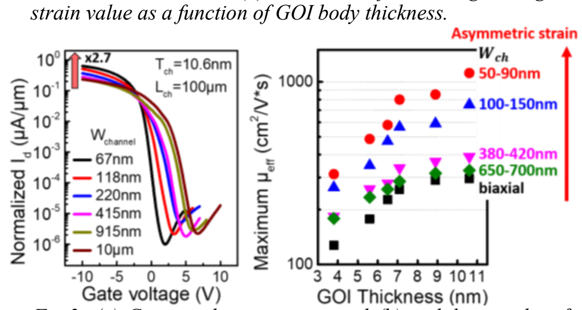

Fig.3: (a) Current characteristics and (b) mobility results of asymmetric strain and biaxial strain ETB GOI pFETs.