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Hole Mobility Behavior in Strained SiGe-on-SOI p-MOSFETs

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A compressive strained SiGe channel grown-on-SOI structure which can be applicable to next generation high performance CMOSs was applied to p-MOSFETs. The mobility behavior depending on effective fields, E_{eff}, was investigated by varying Ge concentrations in the SiGe layer. We confirmed that the mobility enhancement factor increases with both Ge concentration and E_{eff}, and quite depends on E_{eff}. In particular, we demonstrated that hole mobility enhancement factor at the effective fields of 0.13 MV/cm amounted to 1.51 for 34 at% Ge. In addition, we observed that the strain of 0.23 induced by 56.5-at% Ge concentration in SiGe grown-on-SOI structure could not increase hole mobility at the effective fields range from 0.05 to 0.13 MV/cm because of high density of dislocations.

Introduction

A compressive strained SiGe channel structure for complementary metal–oxide–semiconductor field-effect transistors (CMOSs) have attracted much interests for applying high performance CMOSs because of higher hole mobility enhancement of a compressive strained SiGe channel compared to a tensile strained Si channel. In particular, the higher Ge concentrations in SiGe layer such as the Ge-rich SiGe or Ge channel lead to more mobility enhancement (1). In addition, as the design rule of MOSFETs becomes below 45 nm, many reports have presented hole mobility enhancement using several compressive strained SiGe structures such as strained SiGe-on-insulator, strained SiGe grown on relaxed SiGe-on-insulator, and Ge-on-insulator. This is because both electron and hole mobility enhancements are necessary in high performance CMOS by applying novel device structures (2-5). We have fabricated p-MOSFETs using a compressive strained SiGe channel grown on silicon on insulator (SOI) structure to enhance the hole mobility. We investigated the behavior of the electrical characteristics of p-MOSFET's by varying Ge concentrations, x, of 16.2, 29.7, 34.3, and 56.5 at%, and compared it with that of SOI wafer without SiGe layer. In particular, we demonstrated the dependence of hole mobility on electric fields and compared the enhancement factor difference between the strain and relaxed SiGe channels as a function of effective fields.

Experiments

An optimized process of low-temperature ultra-high vacuum chemical vapor deposition (UHV-CVD) was utilized to grow a strained SiGe layer on SOI structures by an epitaxial growth method (6). The SiGe layer was grown on a 200 mm p-type SOI substrate wafer at 550 ^{o}C by varying the Ge concentration of 16.2, 29.7, 34.3, and 56.5 at%. The SiGe layer thicknesses for 16.2, 29.7, and 34.3 at%, were 28.4, 28.9, and 28.7 nm respectively, confirmed by a cross sectional transmission electron microscope (TEM) images. Thermal oxidation in a dry O_2 ambient was carried out at 880 ^{o}C for 10 minutes to fabricate the 7-nm-thick gate oxide. An in-situ poly-Si film was deposited with a phosphorus concentration of 10^{20} cm^{-3} as gate electrodes followed by the plasma immersion doping with boron, which was implanted with a concentration of 10^{20} cm^{-3} in order to form shallow source and drain regions (7). A conventional SOI wafer with a 28-nm-thick Si layer was processed together with four strained SiGe layer samples as a control group.

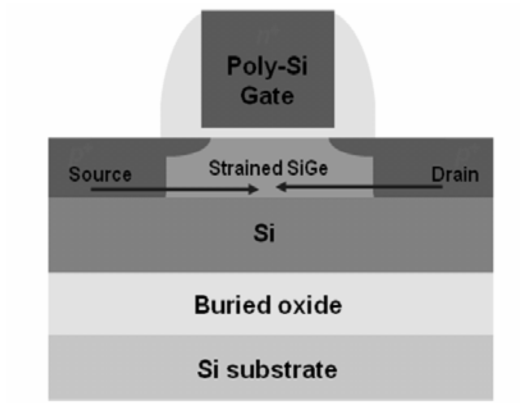


Figure 1. Sample structure

Figure 1 illustrates a cross-sectional schematic p-MOSFET structure. It depicts that the buried oxide thickness and experimental conditions are summarized in Table I. As shown in Fig. 2, it was confirmed by x-ray diffractometer (XRD) that four samples of SiGe layers are compressively strained and the strain values for four samples are 0.6, 0.78, 0.83, and 0.23. Particularly, for a sample of Ge concentration of 56.5 at%, it was observed that the strain was almost relaxed because a 25-nm-thick SiGe layer was thicker than a critical thickness when the SiGe layer was grown at 550 ^{o}C (8). The current characteristics of p-MOSFETs fabricated on a strained SiGe layer-on-SOI with a gate length of 20 μm were analyzed as a function of the Ge concentration in the SiGe layer.

TABLE I. Experimental condition list for ε-SiGe-on-SOI p-MOSFETs

T_{SiGe} [nm]	T_{Si} [nm]	Ge x [at%]	Rms [nm]	State
28.4	25.1	16.2	0.101	strain
28.9	26.1	29.7	0.159	strain
28.7	27.6	34.3	0.220	strain
28.0	26	56.5	0.850	partially strain

Results and Discussion

The effective hole mobility in the inversion layer of a compressive strained SiGe and a conventional SOI channel p-MOSFETs was extracted as a function of effective fields, as shown in Fig. 3(a). It shows that the hole mobility for the conventional SOI p-MOSFET is almost same as that of the universal mobility at a high E_{eff} range. However, for a strained SiGe-on-SOI p-MOSFET, the mobility tendency depending on both E_{eff} and Ge concentrations shows quite differently between the high and low E_{eff} regions. In other words, in high E_{eff} regions greater than 0.05 MV/cm, it was confirmed that the hole mobility of the compressive strained SiGe p-MOSFETs (20-nm-thick SiGe, 15-nm-thick Si, and 145-nm-thick SiO_2) is higher than that of the control SOI p-MOSFET, owing to the compressive strain in the SiGe channel. On the other hand, in low E_{eff} regions greater than 0.05 MV/cm, it is lower than that of conventional SOI p-MOSFET. In particular, we observed that the mobility of the conventional SOI p-MOSFETs decreases dramatically with increasing electric fields compared to those of the strained SiGe p-MOSFETs. In addition, the mobility of the strained SiGe p-MOSFETs increases with Ge concentrations and slowly decreases with increasing effective fields, compared with that of conventional SOI p-MOSFET. It can be inferred that the mobility enhancement occurred in the range of effective fields, which can be classified as phonon scattering dominant region. However, for the sample case of 56.5-at% Ge concentrations, we found that the mobility tendency as a function of effective fields looked like that of conventional SOI p-MOSFETs and shows a lower value than conventional SOI p-MOSFETs in a whole range of effective fields, unlike compressive strained p-MOSFETs. This indicates that the strain of 0.23 induced by 56.5-at% Ge concentration in SiGe layer is not enough to enhance the mobility.

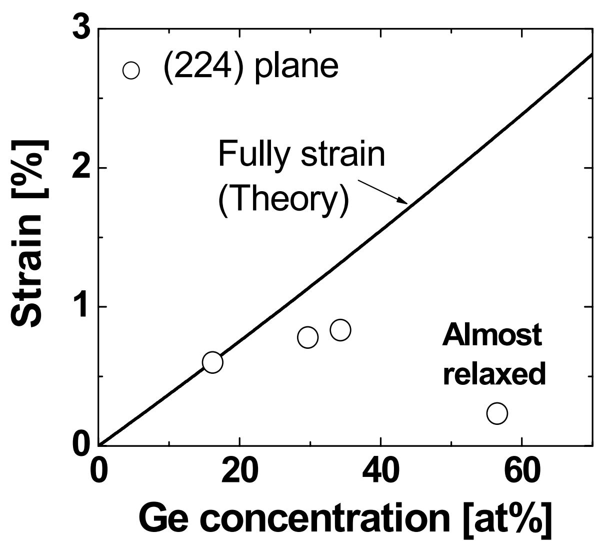
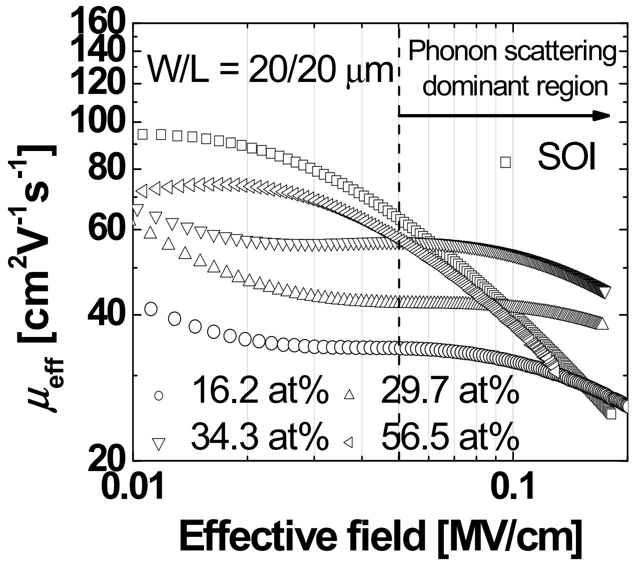
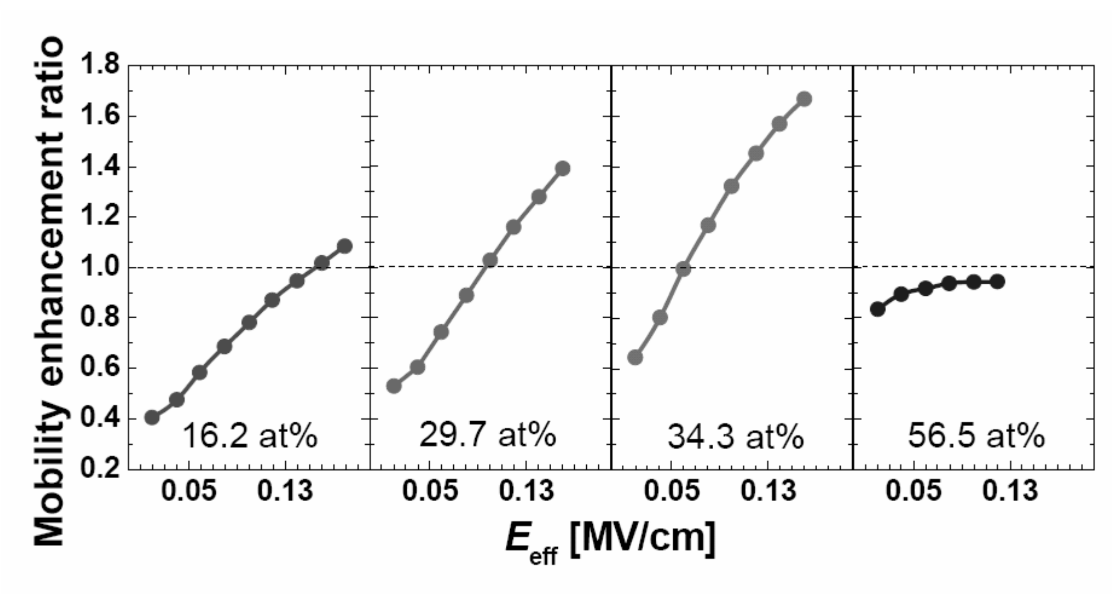


Figure 2. Strain of SiGe layer as a function of Ge concentration with a fully strain curve

Figure 3 (b) represents the hole mobility enhancement ratio for strained SiGe-on-SOI p-MOSFETs as a function of E_{eff} with varying a Ge concentration. It shows that the hole mobility enhancement ratio increases with both E_{eff} and Ge concentrations except for the Ge concentration of 56.5 at%. In particular, it represents that the hole mobility enhancement ratio varies significantly with the E_{eff} range of 0.05 to 0.13 MV/cm. In addition, for Ge concentration of 56.5 at%, a relaxed channel, it does not show enhancement at all, indicating that the strain of 0.23 induced by 56.5-at% Ge in SiGe layer is a relaxed SiGe layer rather than a strained SiGe layer.



(a)



(b)

Figure 3. (a) Effective hole mobility as a function of effective field for the Ge concentration of 0, 16.2, 29.7, 34.3, and 56.5 at% (b) Mobility enhancement ratio of hole as a function of effective field range of 0.05 to 0.13 MV/cm.

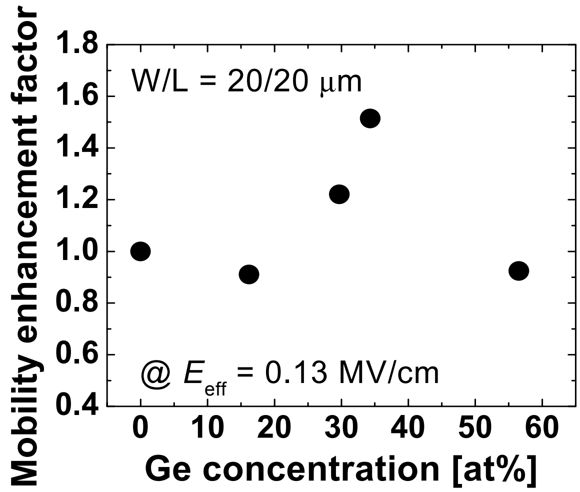


Figure 4. Hole mobility enhancement factor depending on Ge concentration at an effective field of 0.13 MV/cm

Figure 4 shows the mobility enhancement factor extracted at the effective fields of 0.13 MV/cm as a function of Ge concentration. We confirmed that the mobility enhancement factor increases with a Ge concentration, and amounted to 1.51 for 34 at% Ge. On the other hand, it was also confirmed that the mobility for the sample of 56.5-at% Ge concentrations was degraded compared with a conventional SOI p-MOSFET. The degradation can be attributed to the high density of dislocations resulting from higher Ge concentrations in the SiGe layer beyond a critical thickness.

Conclusion

In summary, we demonstrated the behavior of hole mobility enhancement on E_{eff} in the compressive strained SiGe channel p-MOSFET grown-on-SOI wafer applicable to next generation high performance CMOSs. In particular, we observed that the mobility enhancement factor amounted to 1.51 for 34 at% Ge compared with a conventional SOI p-MOSFET.

Acknowledgments

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