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Strained $Si_{1-x}C_x$ Field Effect Transistor on SiGe Substrate

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In the present technology for fabricating metal-oxide-semiconductor field-effect transistor (MOSFET), strained silicon is formed on the relaxed SiGe layer to generate tensile strain. It had been confirmed that both hole and electron mobility are improved. The present technology, however, has the drawback of asymmetrical speed increasing between PMOS and NMOS even under the same Ge content. Theoretically, when using carbon doping to increase strain of the strained silicon channel, a highly increased current driving force and device speed of PMOS, and therefore improved symmetry of the CMOS, is anticipated, in addition, since carbon has a higher phonon energy than that of silicon, when adding carbon into a strained Si channel, the carrier saturation speed in the strained $Si_{1-x}C_x$ channel exceeds that in the strained silicon channel as phonon energy increases. Furthermore, the added carbon can reduce outdiffusion of boron and phosphorous, so that the source/drain junction and channel has an abrupt doping distribution, preventing short-channel effect and minimizing device dimensions.

Using the difference between Si & C in lattice constant of about 52%, theoretically, the efficiency of 1% addition carbon content equals 10% of Ge doping in relaxed SiGe buffer layer, enhancing the strain and improving the driving current asymmetry between NMOS and PMOS. Figure 1, with varied alloy scattering potential, shows the relationship between the carbon concentration of the strained $Si_{1-x}C_x$ and the electron mobility enhancement factor , wherein the alloy scattering potential is higher in $Si_{1-x}C_x$ than SiGe. When the calculation range of the alloy scattering potential is extended from 0 to 2eV, at a lower potential level, electron mobility enhancement factor rate is significant, and with lower alloy scattering potential level (<0.6eV), the strained effect is meaningful, however the high alloy scattering potential level (>1eV) decreasing the electron mobility enhancement factor rate, showing no effect on electron mobility enhancement factor rate if increasing only the carbon concentration, even lower than the original electron mobility enhancement factor rate of the relaxed silicon. Figure. 2, with varied alloy scattering potential, shows the relationship between the carbon concentration of the strained $Si_{1-x}C_x$ and the hole mobility enhancement factor , in which the hole mobility rate versus the carbon concentration of the strained $Si_{1-x}C_x$ layer depends on the alloy scattering potential value, and in the strained $Si_{1-x}C_x$ layer, the hole energy band is split due to strain, resulting in most of the holes being distributed at the light hole band with the smaller effective mass, and, in addition, whereby the split hole energy band decreases scattering of the valley between bands, increasing hole mobility enhancement factor rate in a planar direction. When alloy scattering potential is at the 0eV level, the holes mobility rate can reach 1200 cm^2/Vs (450 cm^2/Vs for Si), however, with increased carbon concentration in the strained $Si_{1-x}C_x$ layer, the alloy scattering potential increases, conversely, decreasing the hole mobility rate. At a low carbon concentration level, the effect of the alloy scattering is minor, since the inter-valley scattering is greatly decreased due to strain, and the hole mobility enhancement factor rate is increased with the increased carbon concentration. At a high carbon concentration level, however alloy scattering potential dominates the hole mobility mechanism, overcoming the effects of the decreased inter-valley scattering arising from strained $Si_{1-x}C_x$ decreasing the hole mobility enhancement factor rate. Figure 3, at a 0.5% & 1% of the carbon concentration shown in Figure 1 & 2, when altering the substrate from silicon to relaxed SiGe, the mobility enhancement factor of the hole is much higher than the electrons, improving the symmetry of the electron/hole mobility enhancement factor by adjusting the Ge concentration to achieve a PMOS and NMOS with improved current driving force and symmetry speed.

In summary, with the benefit of strain in $Si_{1-x}C_x$ alloy being more significant than in silicon, the MOSFET structure according to the idea uses $Si_{1-x}C_x$ instead, providing better symmetry of the designed current driving force and speed, minimizing the device scale and enhancing the current driving force.

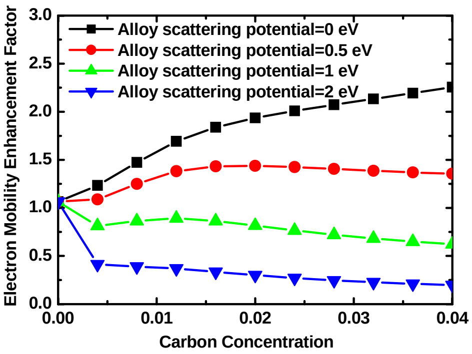

Fig. 1 The relationship between the carbon concentration from 0 to 4% of the strained $Si_{1-x}C_x$ layer on Si substrate and the electron mobility enhancement factor with varied alloy scattering potential.

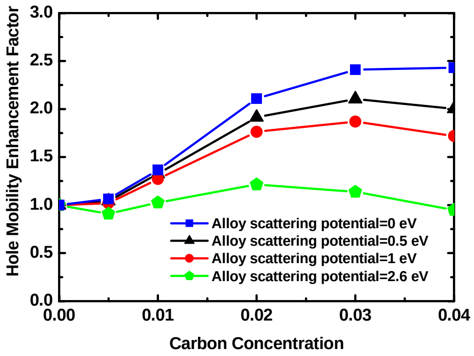

Fig. 2 The relationship between the carbon concentration from 0 to 4% of the strained $Si_{1-x}C_x$ layer on Si substrate and the hole mobility enhancement factor with varied alloy scattering potential.

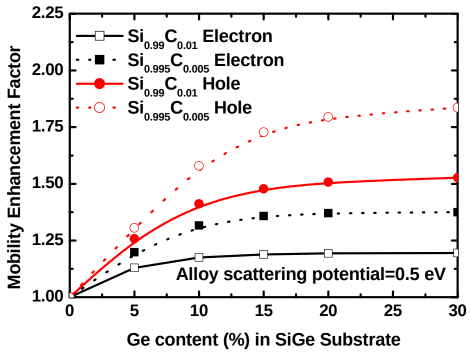

Fig. 3 At 0.5% & 1% of the carbon concentration for Fig. 1 & 2, the relationship between the Ge content (%) of the SiGe substrate and the electron/hole mobility enhancement factor.