SURFACE PASSIVATION EFFECT IN SGOI NANOWIRE BIOSENSOR WITH HIGH GE FRACTION

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Abstract: The increase of surface to volume ratio results in the enhancement of the sensitivity of the nanowires. Our previous studies have shown that the higher Ge fraction of $Si_{1-x}Ge_x$ nano-wire improves the sensitivity of the nanowire biosensor as a result of carrier mobility enhancement in strain-Si. Increasing the fraction of Ge in SiGe-on-Insulator (SGOI) using Ge condensation by oxidation has obtained a significant enhancement in hole mobility, further improving the sensitivity of SGOI nanowire. However, the sensitivity of SGOI nanowire was degraded for exceeding a Ge fraction of 20% (i.e., high Ge fraction), resulting from the unstable surface state. In this work, a top surface passivation SiO_2 layer was deposited on $Si_{0.8}Ge_{0.2}$ nanowire and the sensitivity was about 1.3 times greater than nanowire sample without the top passivation layer.

1 INTRODUCTION

The sensitivity of SGOI can be enhanced by increasing the surface to volume ratio to condense carriers in very thin conductivity layer. The conduction is modified by the surface charges that surround the nanowire surface (Li, 2005). In our previous studies, the higher surface to volume ratio was achieved by utilizing SiGe/a-Si stacking structure (Chang, 2011). Moreover, an increase of a Ge fraction of $Si_{1-x}Ge_x$ improves the nanowire biosensor sensitivity due to higher carrier mobility (Chang, 2008). Ultrathin SGOI with high Ge fraction was fabricated by utilizing Ge condensation and Ge piling up at the SiO_2/SiGe interface by oxidation. However, the higher interface trap density at the SiO_2/SiGe interfaces was about 10^{-12} cm^{-2} after oxidation (LeGoues, 1989). Besides, an unstable surface state of semiconductor with free surface which caused by a lot of dangling bond at free surface and higher Ge fraction of $Si_{1-x}Ge$ has higher surface state and results in fast oxidation rate (Tanaka, 2008). Fast oxidation rate can create more unstable surface state (Yang, 2008).To reduce unstable surface state, a SiO_2 passivation layer is introduced to suppress surface state less than 10^{11} $cm^{-2}eV^{-1}$.The surface state of free surface is around 10^{15} $cm^{-2}eV^{-1}$. In this work, SiO_2 layer is selected as passivation layer to improve interface state and O_2 gas buffer layer to reduce oxidation rate for 20% Ge fraction of SiGe nanowire sensors.

2 EXPERIMENT

An a-Si/$Si_{1-x}Ge_x$ was deposited on the patterned 300-nm-hight bottom oxide. The deposition thickness of a-Si is 200Å, and Ge fraction of $Si_{1-x}Ge_x$ splits in this experiment is 7, 14, and 20 %, respectively. To clarify the influence of passivation layer on the nanowire sensitivity, nanowire sensors with and without the passivation SiO_2 layer were fabricated. The passivation SiO_2 was split in two thicknesses, 100 and 200 Å. The poly-Si nanowire was also fabricated as control group to verify oxidation rate. After the a-Si/SiGe layer formation, the samples

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annealed in O_2 gas mixed with 13% N_2 gas ratio at 950°C for 180 sec, followed by the thermal evaporation of Al films and the definition of the electrodes by the mask process. The poly-Si and SiGe nanowires were implanted in p-type nanowire. To functionalize a-Si/$Si_{1-x}Ge_x$ nanowires, the wires were adopted the 3-aminopropyltri-ethoxysilance (APTES) to modify the surface of the silicon oxide around the nanowires. A hydroxyl functional group on the surface of the oxide was replaced by methoxy groups of APTES modules, and simultaneously, the surface of the nanowire was terminated by amine groups. From our earlier investigations (Chang, 2008), the amine groups were prone to deplete positive carriers, reducing the conductivity of the p-type nanowire. Next, bis (3-sulfo-N-hydroxysuccinimide ester) sodium salt (BS3) was used as a linker between APTES and IgG antibody. BS3 was prone to becoming negatively charged, increasing the conductivity of the p-type nanowire because of the accumulation of the holes on the surface of the nanowire.

The Hewlett Packard HP 4156A was used in this study to measure the electric characteristics of nanowire sensor. Drain voltage (V_D) was varied from -10 to 10V and 500 mV a step, and back gate voltage was 0 V. The measurement of electric characteristics was performed at every stage of surface modification, and the average conductance was then extracted from I_D-V_D characteristics with V_D = 3~6 V. The sensitivity (S) of a nanowire-based sensor is defined as the ratio of the magnitude of conductance change to the baseline conductance value:

$$S = \frac{|G - G_0|}{G_0} = \frac{\Delta G}{G_0} \quad (1)$$

where G_0 is the conductance before molecule capture, G is the conductance after molecule capture, and ΔG is the different between G and G_0.

3 RESULTS AND DISCUSSIONS

Figure 1 presents the characterization of I-V curve of the a-Si=200 Å /$Si_{0.86}Ge_{0.14}$ nanowires with and without passivation SiO_2 layer. The nanowire with 200 Å passivation layer has higher conductance compared with the ones with/without 100 Å passivation layer. The nanowire sensitivity increases with increasing the nanowire conductance. Figure 2 displays the sensitivity comparison of the nanowires with/without the passivation oxide layer. Compared with the nanowire without passivation layer, the sensitivity increased about 7 and 10 % for 100 and 200 Å passivation layer condition, respectively. By this way, we found the surface state could be reduced by this capping layer and oxidation rate also be reduced. Therefore, the sensitivity can be improved owing to the lower interface state by reducing the unstable surface sate and the oxidation rate.

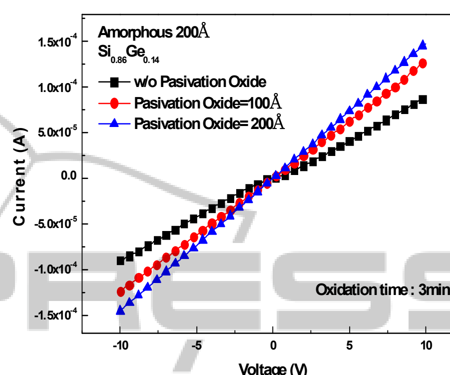

Figure 1: The characterization of I-V curve of a-Si=200 Å /$Si_{0.86}Ge_{0.14}$ nanowires.

Figure 3 shows the sensitivity of SiGe nanowire structure with different fraction of Ge. At 20 % Ge group, the sensitivity has obvious improvement for the ones with passivation SiO_2. The sensitivity of 20 % Ge sample was degraded when passivation layer did not cap on SiGe nanowire. In our previous work, the sensitivity of SiGe nanowire degraded when the fraction of Ge exceeded 14%. Therefore the higher sensitivity of SiGe nanowire with high fraction Ge was obtained by using a suitable capping layer.

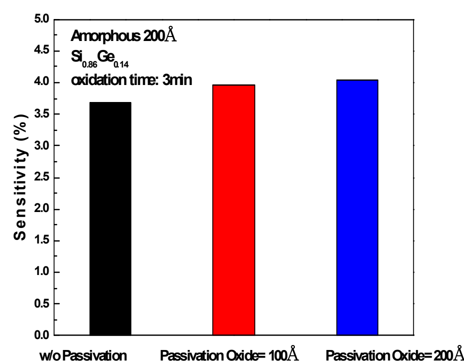

Figure 2: The sensitivity comparison of the nanowires with/without the passivation oxide layer.

Because the oxidation rate was reduced by the deposition of the SiO_2 layer on the SiGe nanowire, Ge condensation phenomenon was impacted. Hence, oxidation time is also another factor to obtain

maximum value of sensitivity in passivation structure.

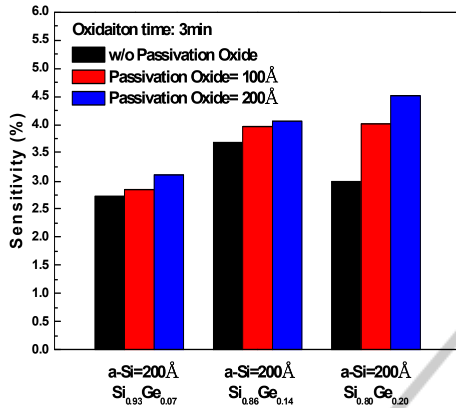

Figure 3: The sensitivity of SiGe nanowires structure with different fraction of Ge.

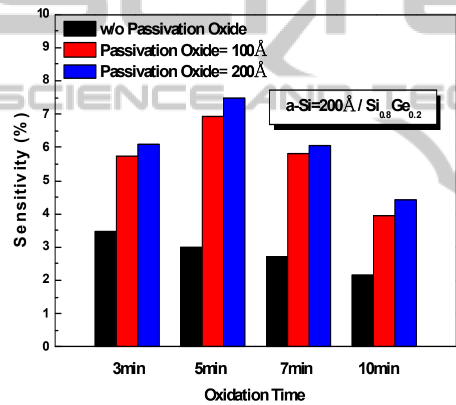

Figure 4: The sensitivity of $Si_{0.8}Ge_{0.2}$ nanowire structure with different oxidation time.

Figure 4 presents the oxidation time effect in different passivation conditions of $Si_{0.8}Ge_{0.2}$ nanowire. The results show that a peak value existed at the oxidation time of 5 min. The sensitivity was about 1.3 times greater than the nanowire sample without the top passivation layer. The sensitivity degraded while oxidation time increased, resulting from the poor Ge accumulation at surface when diffusion effect started to dominated Ge distribution.

Finally, the lower oxidation rate of the sample with capping layer was verified by the poly-silicon nanowires. Figure 5 shows the sensitivity of the poly-silicon nanowires with/without the SiO_2 passivation layer whose oxidation time was split into three cases (3, 5 and 10 min). The sensitivity of the poly-silicon nanowire without the SiO_2 passivation layer was higher than the nanowire with the passivation layer. This is because of the high surface-to-volume ratio of poly-silicon without any passivation layer to reduce oxidation rate. Hence, the reduction of oxidation rate and unstable surface state was realized by a suitable capping layer and the sensitivity of high fraction Ge nanowire can be improved.

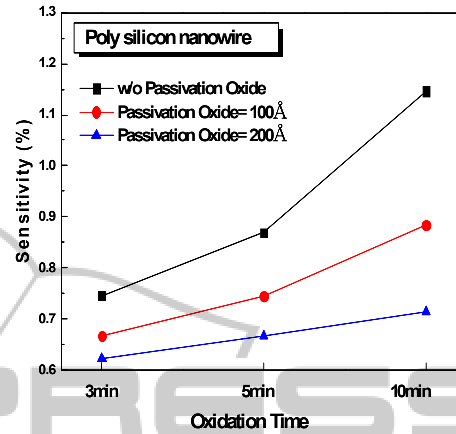

Figure 5: The sensitivity of poly-silicon nanowire structure with different oxidation time.

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4 CONCLUSIONS

In our work, a SiO_2 passivation layer is proposed to reduce the surface state and the oxidation rate for suppressing the interface formation at the SiGe surface. Hence, the sensitivity of the sample with a high fraction Ge can be improved in Ge condensation process. The maximum improvement of the sensitivity of the $Si_{0.8}Ge_{0.2}$ nanowire was achieved at the oxidation time of 5 min for the nanowire with 200 Å passivation oxide layer. The maximum sensitivity enhancement of the passivated nanowire is around 1.3 times higher than that without the SiO_2 passivation.

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