ANNEALING TEMPERATURE EFFECT ON THE SENSITIVITY OF SIGE NANOWIRE FOR BIO-SENSOR

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Abstract: Nanowire is widely used in biological sensor because it has the high surface-to-volume ratio. Germanium (Ge) would be beneficial to enhance the sensitivity of silicon nanowire for bio-sensor. In this study, we have successfully fabricated the SiGe on Insulator (SGOI) nanowires with different annealing temperature by side-wall spacer technique, respectively. The 3-amino-propyltrime-thoxy-silane (APTS) is used to modify the surface, which can connect the bio-linker. Nanowire is considered as a resistance, and the change of conductance (ΔG) and sensitivity (S) of different samples corresponding to APTS treatment were investigated. As annealing temperature was elevated from 800 to 950℃, the SiGe nanowire exhibited increasing sensitivity in the chemical detection. However, it was noted that degradation of sensitivity was observed as the annealing temperature increases up to 1000℃. This behavior may be associated with the reduction of the Ge concentration at the surface of SiGe nanowire due to high-temperature diffusion of Ge in Si. So, temperature is a key parameter in the annealing process producing two effects: repairs of defects and Ge diffusion. There would be an optimal annealing temperature between 900 and 1000℃.

1 INTRODUCTION

Silicon nanowire has recently attracted much attention for its potential applications in the biological and chemical sensors. Its sensing mechanism is considered to be the change of its electrical conductance upon surface as the bio-molecular stay on it. Due to the large surface-to-volume ratio and quasi-1D characteristics, the silicon nanowire sensor provides a high sensitivity in chemical detection such as PH buffer solution (Cui et al., 2001), viruses (Patolsky et al., 2004), and DNA (Li et al., 2004). Silicon nanowires are particularly appealing for sensing applications, since the silicon dioxide can effectively passivate surface dangling bonds, and at the same time can be chemically modified through the well known silanol chemistry to provide surface functionalization and selectivity for particular analytes.

Several studies have been attempted to fabricate the nanowire by the advance photo-emission such like Extreme Ultraviolet (EUV) or X-ray (Solak et al., 1999), or the Atomic Force Microscope (AFM) lithography (Nemutudi et al., 2001), or nanoimprint (Yan et al., 2005), or sidewall spacer (Choi et al., 2002), or vapor state synthesis (Mohanty et al., 2007), or vapor-liquid-solid (VLS) growth (Li et al., 2003). The sidewall spacer formation is an easy process for nanowire fabrication with the advantages of high-yield and low-cost. The method only using the combination of the conventional lithography and process technology was demonstrated without complex processes such as electron beam lithography (EBL), scanning probe lithography (SPL) and VLS, etc.

It is reported that SiGe alloy has higher carrier mobility than Si and can be thermally oxidized at relatively low temperature. Moreover, SiGe field

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effect transistor exhibits the higher current change as the same gate voltage applied (Yeo et al., 2000). In the previous works (Change et al., 2008a), it has already demonstrated IgG antibody sensing capability of SiGe nanowire sensor. First, the 3-amino-propyltrime-thoxy-silane (APTS) was used to modify the surface, which can connect the bio-linker. APTS is used to modify the surface of native oxide layer around nanowires. Hydroxyl functional groups on the surface of native oxide layer were replaced by the methoxy groups of APTS molecules. After APTS modification, the surface of nanowire was terminated by amine groups. In the experimental environment, amine group is prone to be positively charged, that is, the surface potential nanowire increased, and the conductance of p-type nanowire decreased. Next, bis-sulfo-succinimidyl suberate (BS3) is used as linker between APTS and IgG antibody. BS3 treatment resulted in negative charges. Hence, the conductance of p-type nanowires increased. After APTS and BS3 modification, nanowire was capable of capturing IgG antibody. Instead of the convention silicon nanowire, SiGe nanowire sensor is expected to have better sensitivity in the chemical detection for higher carrier mobility as the same bio-molecular bind on the surface. It is well known that annealing temperature did repair the interior defects of SiGe. The higher concentration of Ge the higher sensitivity would become. However, excess of Ge will induce more vacancies of surface, which will degrade the adhesion between APTS and interface and decrease sensitivity (Change et al., 2008b).

In this paper, we used the sidewall spacer technique to fabricate the $Si_{0.93}Ge_{0.07}$ and $Si_{0.86}Ge_{0.14}$ nanowires with different annealing temperature for discussion of the sensitivity, respectively. We focus on investigating the change of conductance (ΔG) and sensitivity (S) of different samples corresponding to APTS treatment.

2 EXPERIMENT

The structure is shown in Figure 1. All test samples were fabricated on p-type (100)-oriented bare silicon wafer with 1~10 Ω-cm resistivity. The poly-Si, $Si_{0.93}Ge_{0.07}$ and $Si_{0.86}Ge_{0.14}$ nanowires were fabricated by the side-wall spacer technique using the combination of the conventional lithography and processes technology, respectively. Starting with standard RCA clean of silicon substrate, wet oxidation was performed by SVCS Furnace system at 980℃ for 7 hours to grow the bottom oxide of about 5500 Å as an insulator oxide. After lithography patterning of active area, oxide was etched by Tokyo Electron Limited TE5000 Reactive Ion Etch (RIE) system to form a 3000 Å oxide step. Then, standard RCA clean was performed, followed by a amorphous silicon (α-Si) film of 200 Å deposition by SVCS Furnace system at 650℃ as seed layer for SiGe film deposition. Then, a polycrystalline SiGe film of 600 Å was deposited by the ultra-high-vacuum chemical vapor deposition (ANELAVA SiGe UHV-CVD) at 665℃. After lithography patterning of the Source/Drain (S/D) contact region, the SiGe film (800 Å, 20% over etched) was etched by Transformer Coupled Plasma (TCP) poly etcher. Only the S/D contact region and the side-wall spacer retained SiGe. The residue SiGe film is called SiGe nanowire. After lithography patterning of removal of unwanted sidewall spacer, the SiGe nanowire were etched and isolated. Finally, Boron was heavily doped with 5×10^{15} atoms/cm^2 at 10 keV to form p-type SiGe nanowire. Next, the samples were subject to activation annealing in nitrogen (N_2) ambient at 800, 900, 950 and 1000 ℃ for 30 minutes. The aluminum was deposited by thermal coater and patterned to reserve the S/D region and sintered at 400^{o}C for 30 minutes.

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 ate every stage of surface modification, and the average conductance was then extracted from I_D-V_D characteristics with V_D = 3~6 V.

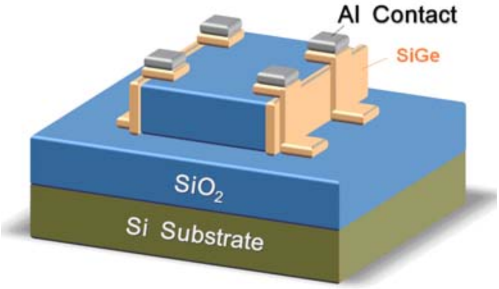

Figure 1: Schematic representation of SiGe nanowire structure by the side-wall spacer technique.

3 RESULTS AND DISCUSSIONS

The sensitivity (S) of a nanowire-based sensor is defined as the ratio of the magnitude of conductance change to the baseline conductance value：

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

, 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. Figures 2 and 3 show the sensitivity of the $Si_{0.93}Ge_{0.07}$ and $Si_{0.86}Ge_{0.14}$ nanowire with different annealing temperature after APTS modified, respectively. Adequate Ge concentration will be more helpful to enhance the sensitivity of silicon nanowire for bio-sensor. The sensitivity increased slightly with increasing annealing temperature from 800 to 900℃. It is supposed that the annealing energy is insufficient for repairing the defects. Furthermore, it is observed that the raise of the sensitivity is more obvious at temperature of 950℃ due to enough energy to arrange. The sensitiveity of $Si_{0.86}Ge_{0.14}$ nanowire could be 11.67% at 950℃ because of better concentration and quality of Ge. However, it is noted that a higher annealing temperature of about 1000 ℃ resulted in degraded sensitivity. This behavior may be associated with reduction of Ge concentration at the surface of SiGe nanowire because the velocity of Ge diffusion toward Si would be increased at higher temperature (Sugiyama et al., 2004). Figure 4 is a schematic of the Ge diffusion at low and high temperatures. So, temperature is a key parameter in the annealing process producing two effects: repairs of defects and Ge diffusion. There would be an optimal annealing temperature between 900 and 1000℃.

Figure 5 shows the sensitivity of poly-Si, $Si_{0.93}Ge_{0.07}$ and $Si_{0.86}Ge_{0.14}$ nanowire with annealing temperature of 950℃ after APTS modified. The higher concentration of Ge exhibits the higher sensitivity.

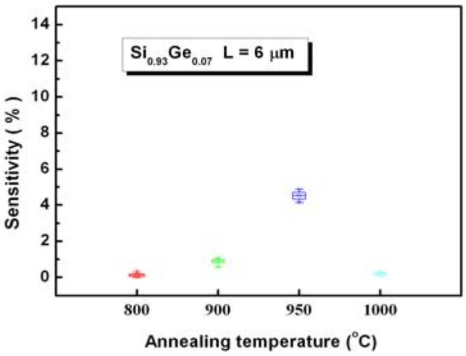

Figure 2: Sensitivity of $Si_{0.93}Ge_{0.07}$ nanowire with different annealing temperature after APTS modified.

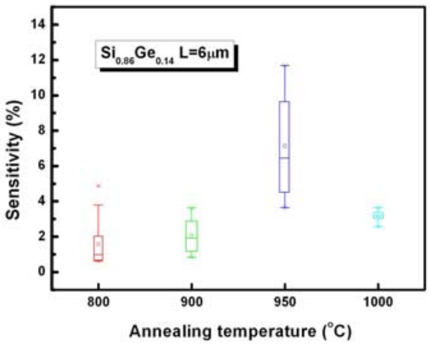

Figure 3: Sensitivity of $Si_{0.86}Ge_{0.14}$ nanowire with different annealing temperature after APTS modified.

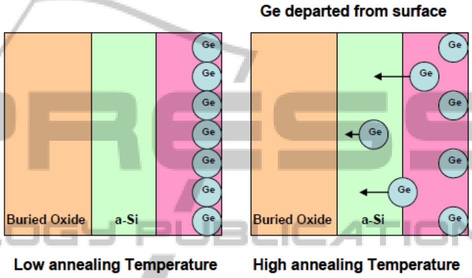

Figure 4: Schematic illustration of Ge diffusion at low and high temperatures.

From the above, we conjecture that nanowire obtains more energy at 950℃ to arrange the lattices more regularly. Therefore, the lower defects make the higher sensitivity increase. Hence, there would be an optimal annealing temperature of about 950℃ in order to obtain better quality and higher sensitivity.

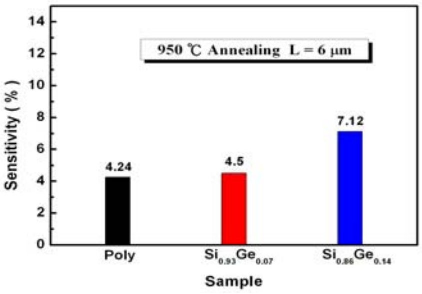

Figure 5: S Sensitivity of poly-Si, $Si_{0.93}Ge_{0.07}$ and $Si_{0.86}Ge_{0.14}$ nanowire with annealing temperature of 950℃after APTS modified. The higher concentration of Ge becomes the higher sensitivity.

4 CONCLUSIONS

In this paper, we have investigated the effect of different annealing temperature on the sensitivity of SiGe nanowire with Ge 7% and 11%. Raising the annealing temperature can bring large sensitivity due to repairs of defects, but it will degraded sensitivity due to Ge diffusion as the annealing temperature increases up to 1000℃. There would be a reasonable annealing temperature between 900℃ and 1000℃. It is concluded from experiments that the optimized annealing temperature is around 950℃. Adequate Ge concentration will be more helpful to enhance the sensitivity of silicon nanowire for bio-sensor. $Si_{0.86}Ge_{0.14}$ nanowire with annealing temperature of about 950℃ can obtain higher sensitivity (~11.67%) in the APTS detection.

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