Excimer laser crystallization of a-Ge nanowires on Si substrate

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Abstract- The poly-crystalline germanium (poly-Ge) nanowires (100nm) have potential for easier and faster to fabricated on Si substrate. Excimer laser were used to crystallization of amorphous germanium (a-Ge) nanowire array on Si substrate were investigated. The two-step method, consist of higher energy annealing (680 mJ/cm²) to decrease defects and laser annealing many times (10 times/mins) to faster melt the a-Ge. Structural properties of the nanowire array were characterized by Raman spectrum. To characterize the phenomenon, the spectrum is fitted with the Lorentz distribution. Finally, the Raman spectrum are well fitted, whose narrow FWHM of the sample is 5.07 cm⁻¹ and peak position is approach 300 cm⁻¹. Those results show that the processed Ge nanowire array is poly-crystalline.

1. Introduction

The ability to selectively melt an amorphous layer through the absorption of a short laser pulse has made laser crystallization (LC) of amorphous (a) films a standard technique for the fabrication of large area polycrystalline films on low cost substrates. Laser crystallization (LC) of amorphous semiconductors is a promising technique for the fabrication of large area polycrystalline films for applications in flat panel displays [1] and solar cells. LC has also been applied to crystallize (or re-crystallize) an amorphous film on a crystalline (c) substrate.

For this purpose, the deposition of amorphous Si (a-Si) films at a low temperature followed by rapid laser annealing to crystallize the films is widely performed [1,2]. Further, improvements in materials used in the active layer are required in order to realize TFTs with higher carrier mobilities. p-channel polycrystalline Ge (poly-Ge) TFTs with a relatively high hole mobility of 140 cm² / v-s have been fabricated by using the solid phase crystallization (SPC) method[3-6]. The mobility can be further increased by using the Excimer laser annealing (ELA) of Ge films.

In this study, the ELA of Ge nanowires is demonstrated, and formed on the lattice mismatched Si substrates. Draw the schematic diagram of the sample in Figure 1(a).

2. Experiments

Through the process by the Electron Beam Lithography system to define the resist and form the one-dimensional array of the wire. Figure 1(b) show the SEM image of the resist is defined on the si substrate. The thickness of the resist is about 300 nm, and the pitch is 500nm, and all the diameter is 150 nm. To follow, the Ge film of 200 nm thick is deposited by E-Gun evaporator. Ge atoms are filling the nanowires pattern. To proceed, lift off the resist. The size of the nanowires is 120nm finally. The Ge nanowires on the Si substrate are finish. Next, the excimer LC experiments were carried out on 200 nm thick a-Ge nanowires grown on Si (100) substrates by E-Gun evaporator. The samples were crystallized with single pulses from a excimer laser. A Gaussian-like laser beam profile with a diameter (φ = 4 mm) was obtained by using a vacuum spatial filter. The laser pulse energy within the crystallized spot was estimated from the measured pulse energy by assuming a Gaussian profile for the distribution of light intensity on the irradiated area. Then annealed by laser annealing in a dry N₂ ambient at 350 & 700 (mJ/cm²) for three spots and ten spots.

Fig.1 (a) is schematic cross section of the samples. (b) The SEM image of the resist is defined. (c) The SEM image to certify of the final structure. The nanowire size is 100nm.
ment of the Ge nanowires, a single crystal Si wafer, which had a narrow peak at around 520 cm\(^{-1}\), was used to calibrate the Raman system regarding wave number. A single crystal Ge wafer was measured as a reference.

3. Results

The sample was also analyzed by SEM to certify of the final structure. The result of the SEM picture is shown in Figure 1(c). The Ge nanowires is formed obviously, and shows the Ge nanowires is uniform without void during lithography process.

After excimer laser crystallization, a micro-Raman spectrometer was used to characterize the Ge nanowire array quality. It provides the information about the crystallization. The Ge nanowires structure of the laser crystallized depends strongly on the laser fluency. For low laser energy, the coexistence of two phases occurs at laser energy density \( E = 350 \text{ mJ/cm}^2 \) as the Raman spectrum shows a main peak at 296.61 cm\(^{-1}\) corresponding to crystalline Ge, with an appearance of amorphous portion leading to a shoulder on the lower wave number side. As the laser energy density \( E \) (mJ/cm\(^2\)) is increased to 700 (mJ/cm\(^2\)), the amorphous phase vanishes and a sharper symmetrical peak centered at 296.93 cm\(^{-1}\) with the FWHM = 8.76 cm\(^{-1}\) appears. Once the laser spot quantity is further increased from three spots to ten spots, the resultant spectrum exhibits a sharp peak centered at 297.41 cm\(^{-1}\) and the FWHM is further reduced to 5.07 cm\(^{-1}\), suggesting the nanowires was crystallized. Although a shift in peak position can also be due to stress in the nanowire, these results clearly indicate a trend that the peaks shift toward 300 cm\(^{-1}\) (reference Ge wafer position) with increasing laser energy density \( E \) (mJ/cm\(^2\)) and increasing laser spot quantity. The results are shown in Figure 2, where the spectra of a-Ge (before annealing) and c-Ge (single crystalline Ge wafer) are also shown for comparison. Figure 2 is show the different laser energy density \( E \) (mJ/cm\(^2\)) and three laser spots.

![Fig. 2 The Raman spectrum of the samples with (a) the different \( E \) (mJ/cm\(^2\)) and 3 laser spots.](image)

The peak locations and the full width at half maximum (FWHM) values determined by fitting Lorentz peaks of the samples are shown in Table 1. It can be seen that the reference Ge wafer exhibits a sharp TO peak at \( \sim 298.61 \text{ cm}^{-1} \) while those samples no laser annealing exhibit relatively broad TO peaks centered at about 270 cm\(^{-1}\) corresponding to amorphous Ge. Poly-Ge nanowires were prepared by laser annealing of evaporator a-Ge films.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Peak (cm(^{-1}))</th>
<th>FWHM (cm(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>La350(mJ/cm(^2))(3spots)</td>
<td>296.61</td>
<td>9.13788</td>
</tr>
<tr>
<td>La700(mJ/cm(^2))(3spots)</td>
<td>296.93</td>
<td>8.76167</td>
</tr>
<tr>
<td>La680(mJ/cm(^2))(10spots)</td>
<td>297.41</td>
<td>5.06977</td>
</tr>
<tr>
<td>Ge wafer</td>
<td>298.61</td>
<td>3.70279</td>
</tr>
<tr>
<td>NO Laser annealing</td>
<td>270</td>
<td>-</td>
</tr>
</tbody>
</table>

4. Conclusion

Amorphous Ge nanowires can be crystallized, utilizing the high laser energy density \( E \) (mJ/cm\(^2\)) and increasing laser spot quantity can induce the a-Ge nanowires transform to poly-Ge nanowires. The influence of the different laser energy density \( E \) (mJ/cm\(^2\)) and a lot of laser spot quantity to evaluate the crystal quality of the nanowires was investigated by Raman signal measurement. These results showed improved crystalline properties when \( E \) (mJ/cm\(^2\)) and spot quantity increase. High crystalline quality at room temperature obtained in this work suggests our poly-Ge nanowires may be promising for use in field-effect transistor (FET).

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References