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Crystalline SiGe films grown on Si substrates using laser-assisted plasma-enhanced chemical vapor deposition

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Recently, silicon-germanium (SiGe) semiconductors have started to interest due to inherent advantages included narrow and variable bandgap, and process compatibility with Si-based integrated circuits. Owing to those inherent advantages, SiGe semiconductors have been widely used in applications of electronic devices and optoelectronic devices. Widely investigated techniques and methods, such as ultrahigh-vacuum chemical vapor deposition, high-frequency plasma-enhanced chemical vapor deposition, magnetron sputter and molecular beam epitaxy et. al., have been developed to grow SiGe films. In this work, we used a laser-assisted plasma-enhanced chemical vapor deposition (LAPECVD) method to grow crystalline SiGe films on Si substrates at a low temperature and without post thermal annealing.

In the designed LAPECVD system, an external CO_2 laser beam was guided into the chamber of a conventional plasma-enhanced chemical vapor deposition (PECVD) system through a ZnSe window. The CO_2 laser with a wavelength of 10.6 μm illuminated the substrates with an incident angle of 88 degree to prevent heating the substrates. The SiGe films were deposited on (100)-oriented P-type Si substrates using argon-diluted SiH_4 (4%) and pure GeH_4 reactant gases. In the LAPECVD system, not only were the SiH_4 and GeH_4 reactant gases decomposed by RF power, but they can be pyrolytically decomposed by the external CO_2 laser due to high absorption of optical light with a wavelength of 10.6 μm. Comparing with a conventional PECVD system, the SiH_4 and GeH_4 reactant gases were decomposed by both the RF power and the CO_2 laser in the LAPECVD system. Therefore, it can be expected that more Si and Ge atoms were created in the LAPECVD system. The flow rate of SiH_4 and GeH_4 was 150 sccm and 8 sccm, respectively. The reaction working pressure in the chamber was maintained at 0.5 torr. The radio frequency (RF, 13.56 MHz) power and CO_2 laser power density were set at 100W and 2.02W/cm^2, respectively. For the comparison purpose, SiGe films were also deposited using the conventional PECVD system with the same deposition conditions used in LAPECVD system.

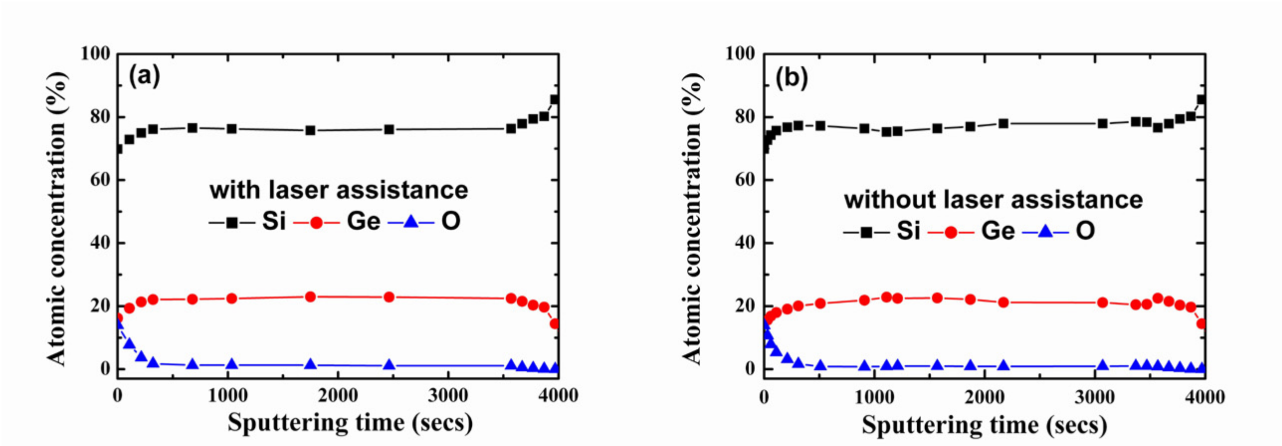

Fig.1 Auger electron spectroscopy depth profiles of SiGe films deposited (a) with and (b) without laser assistance

Auger electron spectroscopy (AES) measurement was used to analyze the composition of the 900 nm-thick SiGe films. Figure 1 (a) and (b) shows the AES depth profiles of the SiGe films deposited by the LAPECVD system and the PECVD system, respectively. From the AES experimental results, the composition ratio of $Si_{0.78}Ge_{0.22}$ and $Si_{0.79}Ge_{0.21}$ films deposited with and without CO_2 laser assistance were obtained, respectively. Owing to the similar composition of the deposited SiGe films, it can be deduced that the pyrolytical decomposition rate of SiH_4 and GeH_4 reactant gases by the CO_2 laser is similar with that using RF power.

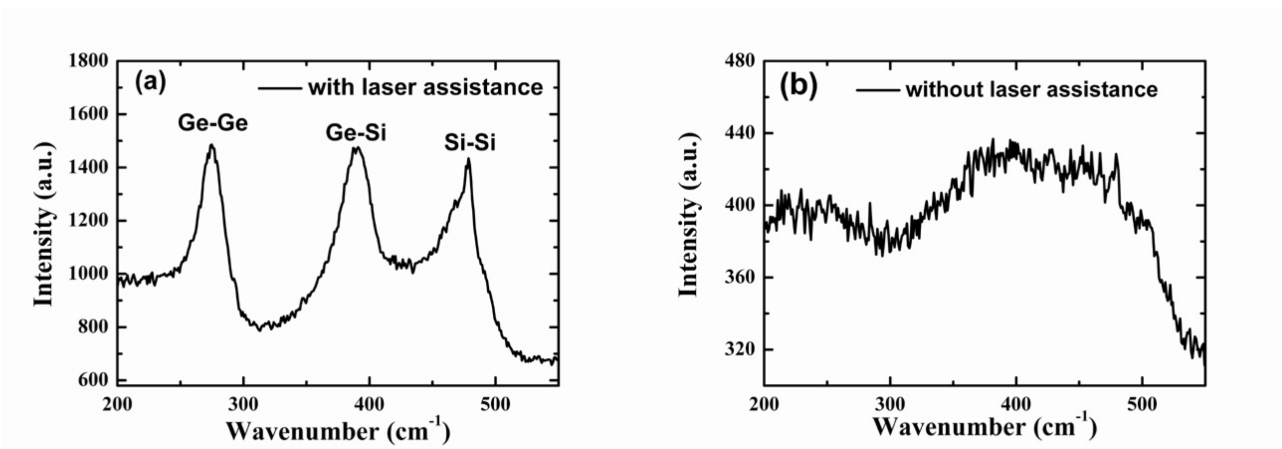

Fig.2 Ramma spectra of SiGe films deposited (a) with and (b) without laser assistance

Raman scattering measurement with a Nd: YAG laser (wavelength of 532 nm) was used to investigate the chemical bonding configurations of the deposited SiGe films with and without CO_2 laser assistance. Figure 2(a) and (b) shows the Ramna spectra of SiGe films deposited with and without CO_2 laser assistance, respectively. It can be found that there are three sharp peaks located at ~290 cm^{-1}, ~390 cm^{-1}, and ~480 cm^{-1}, which corresponds to the Ge-Ge, Ge-Si and Si-Si bonding configurations shown in Fig. 2(a). Moreover, no sharp spectrum was observed in Fig. 2(b) for the SiGe films deposited without CO_2 laser assistance. According to the measured results, it can be deduced that the SiGe films deposited with CO_2 laser assistance have better crystallization compared with that without the assistance of CO_2 laser.

By comparing with the wavenumber of 520 cm^{-1} in a single crystal silicon (c-Si), the Si-Si bonds in the laser-assisted SiGe films shown in Fig. 2(a) shifted to a lower wavenumber of 480 cm^{-1} was caused by the presence of Ge neighbors. Similarly, the Ge-Ge bonds shifted to a lower wavenumber of 290 cm^{-1}, comparing with the wavenumber of 300 cm^{-1} in a single crystal germanium (c-Ge), was caused by the presence of Si neighbors. Moreover, the Raman spectra of the laser-assisted SiGe films are similar to those of the microcrystalline SiGe thin films (μc-SiGe). As shown in Fig. 2(b), the spectrum of Ge-Si bonds without CO_2 laser assistance is broadened with the spectrum of Ge-Ge and Si-Si bonds. Comparing Fig. 2(a) with Fig. 2(b), it can be deduced that μc-SiGe films are deposited with CO_2 laser-assisted PECVD method. It is obviously that SiGe films have better crystallization through the assistance of CO_2 laser.

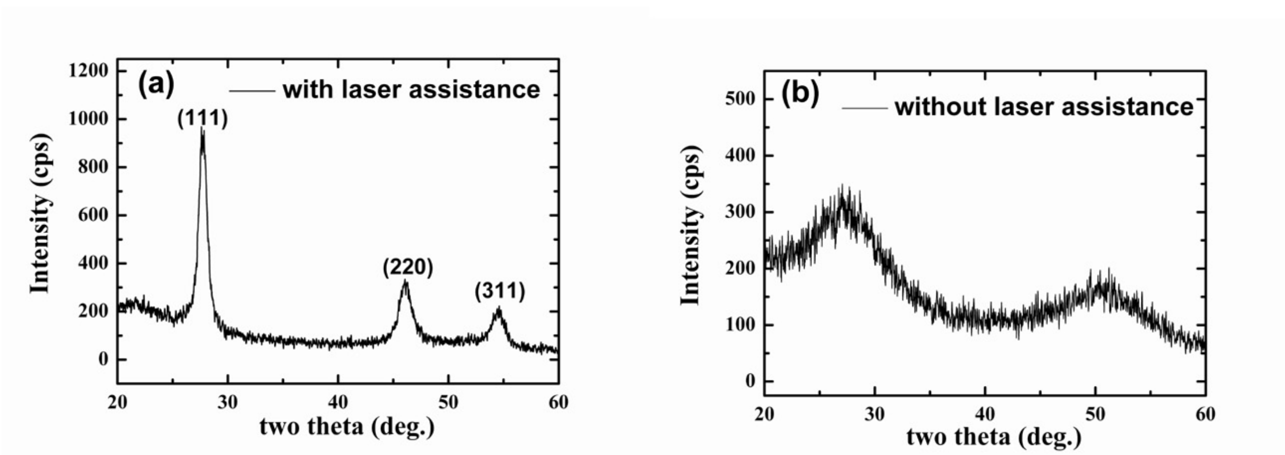

Fig.3 XRD diffraction patterns of SiGe films deposited (a) with and (b) without laser assistance

Glancing incident angle X-ray diffractometry (GI-XRD) and high-resolution transmission electron microscopy (HRTEM) were used to investigate the crystallinity and the texture of the SiGe films deposited with and without CO_2 laser assistance. According to the XRD experimental results shown in Fig. 3(b), the SiGe films deposited without CO_2 laser assistance reveal amorphous structure. On the other hand, the significant diffraction peaks of a diamond-cubic structure (111), (220) and (311) were observed clearly shown in Fig. 3(a). The dominant diffraction peak of (111) located at 2θ of about 28°. The observed XRD diffraction peaks are typical for polycrystal SiGe Films. Usually, narrower XRD full width at half maximum (FWHM) value clearly indicates a better crystal quality. Therefore, It can be concluded that a polycrystal structure by using CO_2 laser assistance of deposited SiGe films can be achieved due to its much narrower FWHM than that without CO_2 laser assistance.

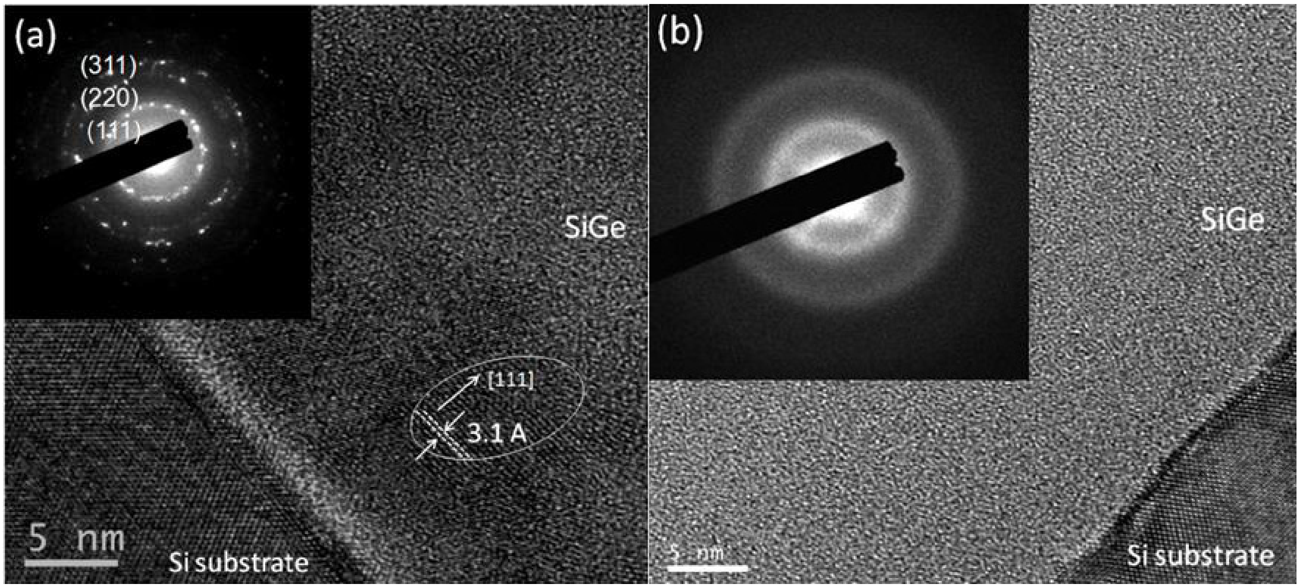

Fig.4 The selective area electron diffraction patterns of the HRTEM images of the SiGe films deposited (a) with and (b) without laser assistance

In the HRTEM images of laser-assisted SiGe films shown in Fig. 4(a), a light contrasty layer at the interface between SiGe films and Si substrate was observed due to the result of the strain effect or the existence of a very thin silicon oxide layer. The selective area electron diffraction pattern of the laser-assisted SiGe films shows distinctive spots forming complete and incomplete rings shown in the insert of Fig. 4(a) which can be indexed as crystallographic planes of (111), (220) and (311) of SiGe films. Therefore, it can be seen that crystalline SiGe Films can be deposited using CO_2 laser assistance. Moreover, there is no distinctive spots observed in the electron diffraction pattern of the SiGe films deposited without laser assistance shown in the insert of Fig. 4(b). It can be concluded that the SiGe films deposited without laser assistance reveal amorphous structure.

In summary, comparing with conventional plasma-enhanced chemical vapor deposition (PECVD), laser-assisted plasma-enhanced chemical vapor deposition (LAPECVD) can be used to deposit crystalline SiGe films on Si substrates at low temperature. In the LAPECVD system, a CO_2 laser with a wavelength of 10.6 μm was utilized to assist the pyrolytical decomposition of SiH_4 and GeH_4 reactant gases. According to the Auger electron spectroscopy measurement, $Si_{0.78}Ge_{0.22}$ films were obtained. From the diffraction patterns of a glancing incident angle X-ray diffraction (GI-XRD) measurement, significant diffraction peaks of a diamond-cubic structure at (111), (220) and (311) were observed clearly. Crystalline SiGe films were also identified by the electron diffraction pattern of high-resolution transmission electron microscopy images. This research provided a guideline to fabricate crystalline SiGe films using in electronic devices.