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Characterization of Epitaxial Silicon Films Grown by Atmospheric Pressure Plasma Chemical Vapor Deposition at Low Temperatures (450-600°C)

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1. Introduction

Epitaxial Si growth at low temperatures of less than 650°C is required in many device processes, such as selective Si epitaxial growth for elevated source/drain structures in advanced CMOS devises, backside p^+ layers for Si power devices, or cost effective Si solar cells fabricated on glass substrates. Restrictions of the growth temperature may be imposed either by unwanted interdiffusion of dopants in multilayered structures or by the use of foreign substrates.

Recently, we have reported the growth of defect-free epitaxial Si at 600°C by atmospheric pressure plasma chemical vapor deposition (AP-PCVD) by using porous carbon electrode on entire 4-inch CZ-Si wafers [1]. In this study, we have studied low-temperature growth of epitaxial Si films at 450-600°C by AP-PCVD. Epitaxial Si films are characterized by various methods including room temperature (R.T.) photoluminescence (PL) spectroscopy of which intensity is directly related with effective minority recombination lifetime in Si films.

2. Experimental

AP-PCVD apparatus used in this study was the same as that in our previous studies [1-2]. By applying 150MHz very high frequency (VHF) power, plasma was generated in a narrow gap (0.8 mm) between an electrode and a substrate. Figure 1 shows a schematic illustration of porous carbon electrode (105 mm diameter). Fresh source gases are directly supplied into the plasma region through a porous carbon plate.

Substrate wafers were 4-inch diameter CZ-Si (001) wafers doped with boron to the resistivity of 1-10 Ωcm. Si films were deposited on the substrates in gas mixtures containing He (50 sccm), H_2 (50 sccm) and SiH_4 (75 slm). The film thickness was 0.5-2 μm. Deposited films were characterized by reflection high-energy electron diffraction (RHEED), cross-sectional transmission electron microscopy (XTEM) and secondary ion mass spectrometry (SIMS) and PL spectroscopy. PL measurements were performed at R.T. and also at liquid helium temperature (4.2K). A CW Ar^+ laser operating at 514.5 nm with a beam diameter of about 2 mm and incident power of 60 mW was employed as an excitation source. Penetration depth of the laser light into Si is about 1.25 μm. PL spectra were analyzed by a grating spectrometer and detected by a liquid nitrogen cooled Ge pin photodiode.

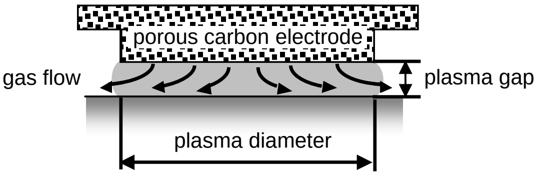


Fig.1 Schematic illustrations of porous carbon electrode.

3. Results and Discussion

Si films grown at 600℃

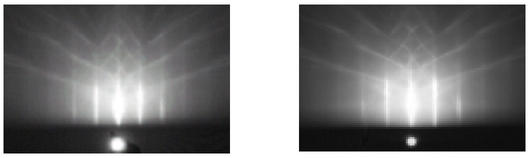
Details of the characterization results on epitaxial Si films grown at 600°C by AP-PCVD using porous carbon electrode have been reported in the previous report [1]. RHEED, XTEM and selective etching methods revealed that defect-free epitaxial Si films were grown on the entire surface of a 4-inch (001) Si wafer with VHF power of 1800 W. The average growth rate was 0.25-0.3 μm/min for SiH_4 flow rate of 50 sccm. Concentrations of impurity atoms (B, Cu, Fe, Ni, Al and Cr) in the epitaxial Si film were below the detection limits of SIMS measurements. When soft baked carbon material is used in the chamber during growth, O, C and N impurities were incorporated in the epitaxial Si (film B). However, by 800°C pre-baking of the porous carbon electrode with flowing high-purity He gas, O, C and N impurities in the film could be reduced below detection limits of SIMS measurements.

Si films grown at temperatures below 600℃

Figures 2 and 3 show RHEED and XTEM images of Si films grown at 550 and 500°C with the SiH_4 flow rate of 50 sccm. Both films are single crystalline and no defect or no interface contrast is seen in XTEM images. By further lowering the substrate temperature to 450°C, Si film becomes polycrystalline as shown by a RHEED pattern in Fig. 4(a). However, we can grow epitaxial Si film by reducing the SiH_4 flow rate to 6 sccm as shown in Fig. 4(b).

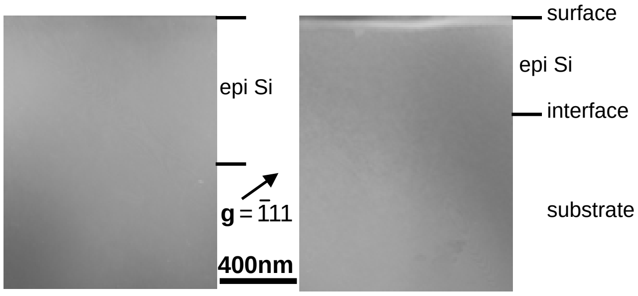
PL spectra of Si films measured at 4.2 K

Epitaxial Si films grown at 500-600°C and a reference CZ-Si sample were measured by PL method. In PL spectra measured at 4.2 K (Fig. 5(a) and (b)), TO-phonon line of the



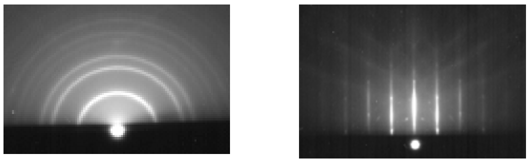
(a) 550°C (b) 500°C

Fig. 2 RHEED images of Si films grown with SiH_4 flow rate of 50 sccm at (a) 550°C and (b) 500°C.



(a) 550°C (b) 500°C

Fig. 3 XTEM images of Si films grown with SiH_4 flow rate of 50 sccm at (a) 550°C and (b) 500°C.



(a) 50 sccm (b) 6 sccm

Fig. 4 RHEED patterns of Si films grown at 450°C with SiH_4 flow rate of (a) 50 sccm and (b) 6 sccm.

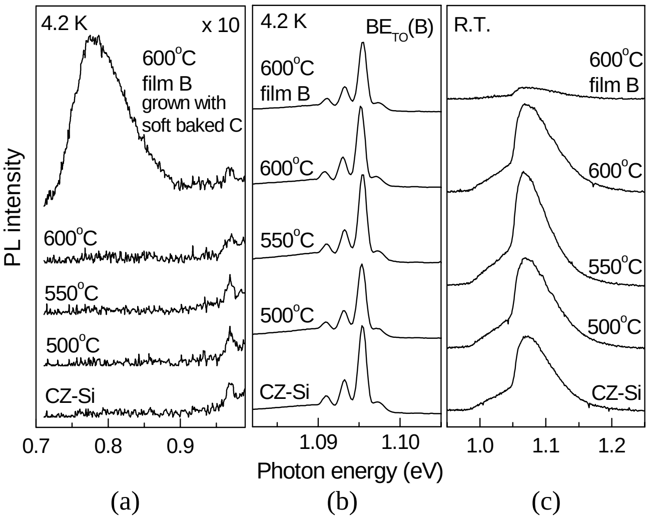


Fig. 5 PL spectra of a reference CZ-Si sample and epitaxial Si films grown at 500-600°C in (a) deep-level region at 4.2 K, (b) band edge region at 4.2 K and (c) band-to-band PL at R.T.

bound-exciton luminescence related with boron ($BE_{TO}(B)$) dominates the spectrum in each sample except for the film B grown at 600°C. In this sample, a broad PL band is seen in the photon energy region below 0.9 eV. Since the film B was grown using insufficiently-baked carbon material, O, C and N impurities incorporated in the film may responsible for deep-levels associated with the broad PL bands. The intensity of $BE_{TO}(B)$ line in each PL spectrum shows little difference between the samples. Since the diffusion length of free excitons at 4.2 K in Si is much larger than the film thickness (0.5-2μm), PL emission is mainly attributed to the recombination of excitons bound to boron impurities in the substrate Si. Therefore, the band edge luminescence at 4.2 K is not sensitive to study the quality of Si epitaxial layers. However, we can say that no deep-level luminescence center is present in the epitaxial Si films grown at 500-600°C by AP-PCVD using well-baked carbon materials.

PL spectra of Si films measured at R.T.

It is known that PL intensity at R.T. is sensitive to non-radiative recombination centers [3] and that band-to-band PL intensity is proportional to the effective minority carrier lifetime (τ_{eff}) [4]. Fig. 5(c) shows PL spectra measured at R.T. in the same samples as in Figs. 5(a) and (b). Each PL spectrum shows a broad band corresponding to the band-to-band recombination of free carriers produced by photoexcitation. PL intensity of each Si film is higher than that of a reference CZ-Si except for the film B. τ_{eff} is related with several factors including surface recombination velocity (S), bulk recombination in the film and film thickness. All PL measurements were performed after careful surface cleaning treatments followed by HF dip. However, PL intensity showed a variation by a factor of two even in the same specimen mainly due to the variation in S. Therefore, from Fig. 5(c) we can say that the epitaxial Si films grown at 500-600°C have τ_{eff} in the same order as that of the reference CZ-Si.

4. Conclusions

High quality epitaxial Si films have been grown at 500-600°C by AP-PCVD. They are defect-free as observed by XTEM and selective etching methods, and show higher PL intensities at R.T. than the CZ-Si substrate.

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