Laser crystallization of Si film for poly-Si thin film transistor on plastic substrates

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Abstract

In order to realize high performance thin film transistor (TFT) on plastic substrate, Si film was deposited on plastic substrate at 170°C by using inductivity coupled plasma chemical vapor deposition (ICPCVD). Hydrogen concentration in as-deposited Si film was 3.8% which is much lower than that in film prepared by using conventional plasma enhanced chemical vapor deposition (PECVD). Si film was deposited as micro crystalline phase rather than amorphous phase even at 170°C because of high density plasma. By step-by-step Excimer laser annealing, dehydrogenation and recrystallization of Si film were carried out simultaneously. With step-by-step annealing and optimization of underlayer structure, it has succeeded to achieve large grain size of 300nm by using ICPCVD. Base on these results, poly-Si TFT was fabricated on plastic substrate successfully, and it is sufficient to drive pixels of OLEDs, as well as LCDs.

1. Introduction

Recently, Active matrix flat panel displays on plastic substrate has attracted considerable attentions due to the ruggedness, lightweight, flexibility and possibility of adapting to roll-to-roll processing. Poly-Si thin film transistor (TFT) on plastic substrate has clear advantage of higher performance compared with a-Si:H TFT or organic TFT (OTFT). This high performance of poly-Si TFT enables the drive an organic light emission diode (OLED) and the integration of peripheral circuit. Even though this advantage makes poly-Si TFT on plastic one of interesting research topic,[1,2] a major bottleneck to establish high performance TFT is the difficulty of getting Si film having low-defect and large grain for active channel without the degradation of plastic property.

The Excimer Laser Annealing (ELA) method could be one of the best approaches for crystallization of Si film, because laser energy is efficient to melt the silicon films, and the pulse-duration is short enough to avoid heating of the plastic substrate.[3,4] However, it is indispensable is to reduce the

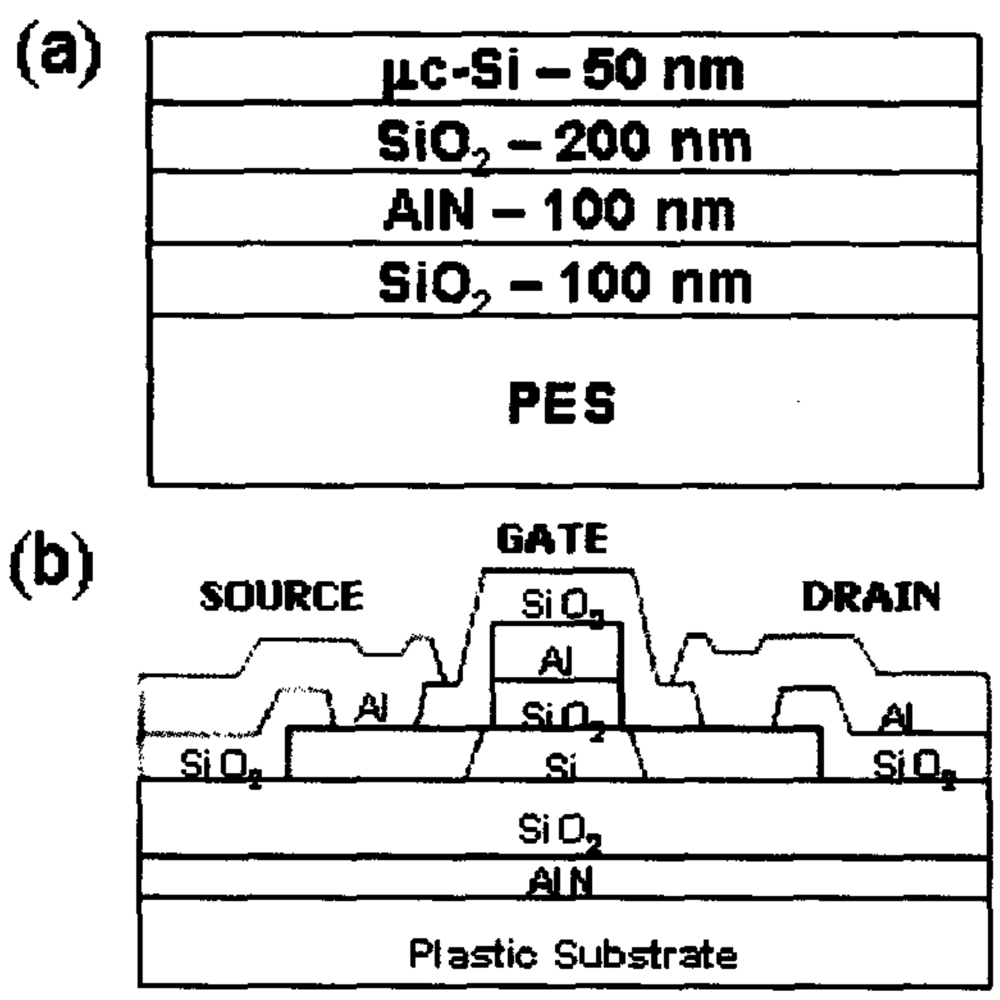

Fig. 1 (a) Schematic diagram of sample structure for crystallization (b) Poly-Si TFT structure on plastic substrate

concentration of impurity in precursor Si film deposited at low temperature that is restricted by the property of plastic substrate, in order to realize high-quality Si active channel as on glass substrate. In general, low pressure chemical vapor deposition (LPCVD) is not suitable for Si deposition because process temperature is too high for plastic substrate. And Si film deposited by using plasma enhanced chemical vapor deposition (PECVD)[5,6] has relatively high hydrogen content of 10~20 % which make film ablation during laser crystallization process. inductivity coupled plasma chemical vapor deposition (ICPCVD) could be one of the solutions for high purity Si film at low temperature,[7] because high density plasma reduces the deposition temperature, film contamination, and radiation damage caused by direct ion-surface interaction. ICPCVD system has further advantage, such as easy to produce uniform plasma in large-diameter, and can make a compact and simple source with reducing the plasma damage against the film.

In this work, we studied the characteristics of Si film deposited by using ICPCVD and crystallization phenomena by excimer laser annealing.

2. Experiments

Figure 1(a) shows the schematic diagram of sample structure. Polyether sulfur (PES) substrate used in these experiments was specially coated on both sides. SiO_2 was deposited as a buffer layer between the substrate and the a-Si film to suppress the conduction of heat to the substrate; Aluminum nitride film with a much higher thermal conductivity than SiO_2 was deposited beneath the SiO_2 layer in order to protect PES substrate from thermal energy during laser crystallization

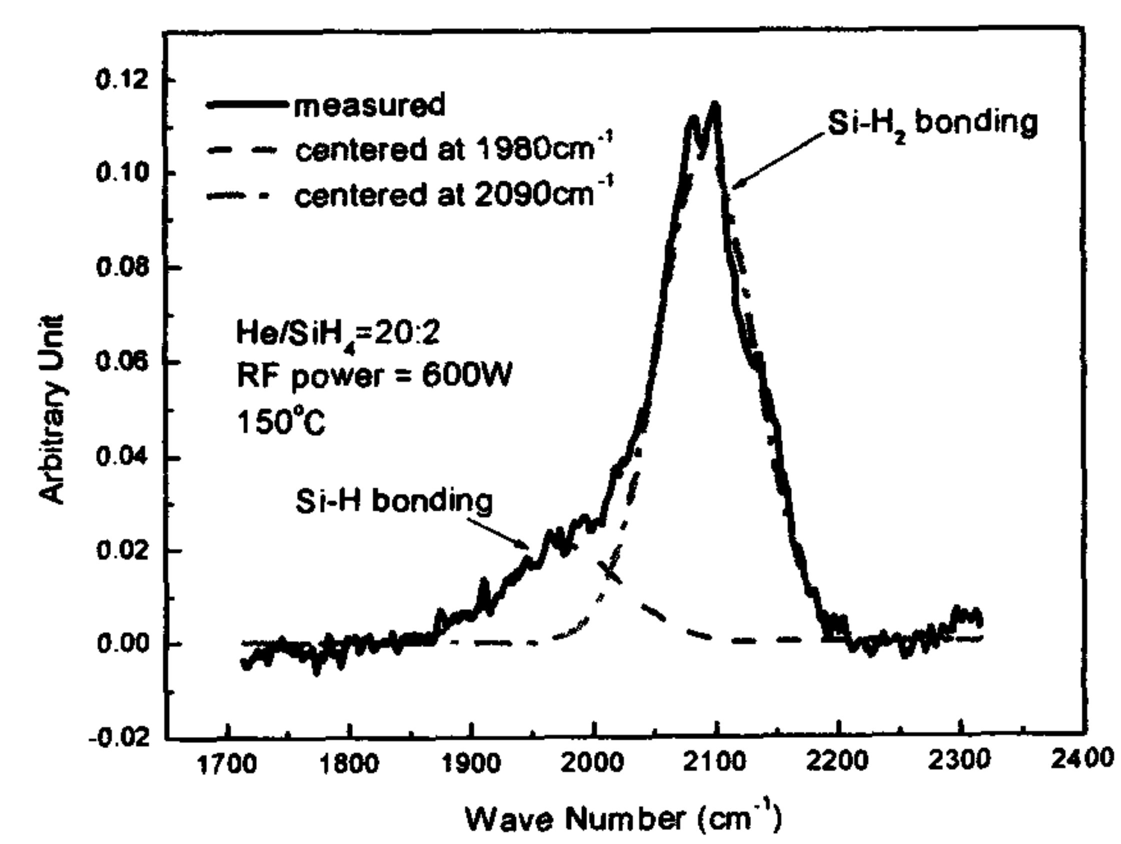

Fig. 2 FT-IR spectra of the deposited silicon film by using ICP-CVD

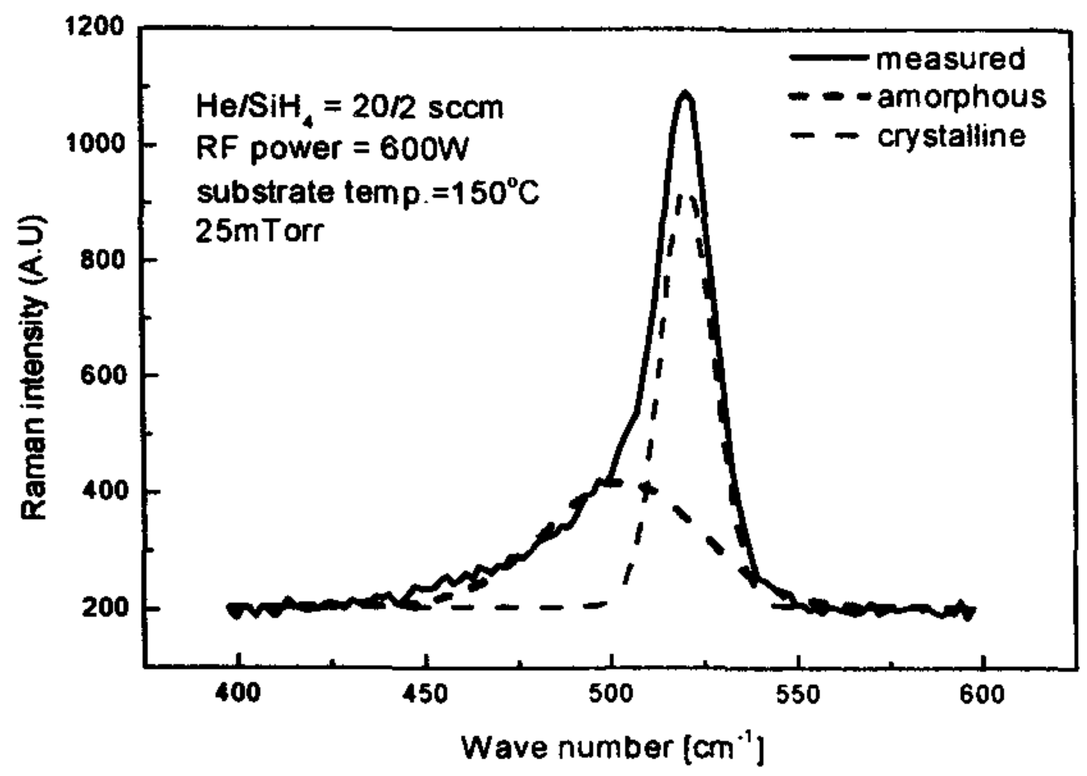

Fig. 3 Raman spectrum of the silicon film deposited by using ICP-CVD

Silicon film was deposited on PES substrate at 170°C using silane diluted with helium by using ICPCVD. Deposition pressure was 25 mTorr and He/SiH_4 flow ratio was 20:3. Deposition rate of the Si film was 16.8 nm/min.

Micro-crystalline Si film was annealed by XeCl Excimer laser (308nm) in order to increase grain size of Si film. When excimer laser irradiates on Si film, laser energy density was increased step-by-step from 100mJ/cm^2 to 290mJ/cm^2, in order to avoid abrupt effusion of hydrogen in Si film.

In order to fabricate poly-Si TFT, the crystallized Si film by laser was patterned into the island structure depicted in Figure 1(b) using mask lithography. The SiO_2 gate insulator material[8] and Al:Nd for the gate electrode material were deposited, using ICP-CVD and sputtering, respectively.

A second mask was used to pattern the SiO_2 and Al:Nd films into the gate stack. Afterwards, the source and drain were doped using ion implantation of phosphorus at a dose of $2x10^{15}$ cm^{-2}, and activated using rather low-energy density excimer laser irradiation.

Device characteristic of the n-type TFTs was analyzed by measuring the basic transfer curve, and the field effect mobility of the channel was calculated.

3. Results and discussions

FI-IR spectrum shows that as-deposited Si film contains 3.8% hydrogen which is much lower than that in film prepared by using conventional PECVD as shown in Figure 2. In addition, Raman spectrum shows as-deposited Si film has micro-crystalline phase rather than amorphous phase (Figure 3). Micro-crystalline phase of as-deposited Si film was also confirmed by SEM image in Fig. 4(a). This result might be attributed to ICP which reduces the number of energetic ions that amorphize crystals grown on substrate compared with conventional PECVD. It is thought that once as-deposited micro-crystalline Si film itself was used for active channel of TFT, it is possible that TFT for pixel driving of OLED was fabricated with laser crystallization process.

Micro-crystalline Si film was annealed by XeCl Excimer laser (308nm) in order to increase grain size of Si film. Figure 4 shows Scanning electron microscopy (SEM) images of Si film irradiated by laser at various energy densities. As the maximum energy density of laser increased, the grain size of Si film also increased up to 230mJ/cm^2 laser energy density. Once the energy density

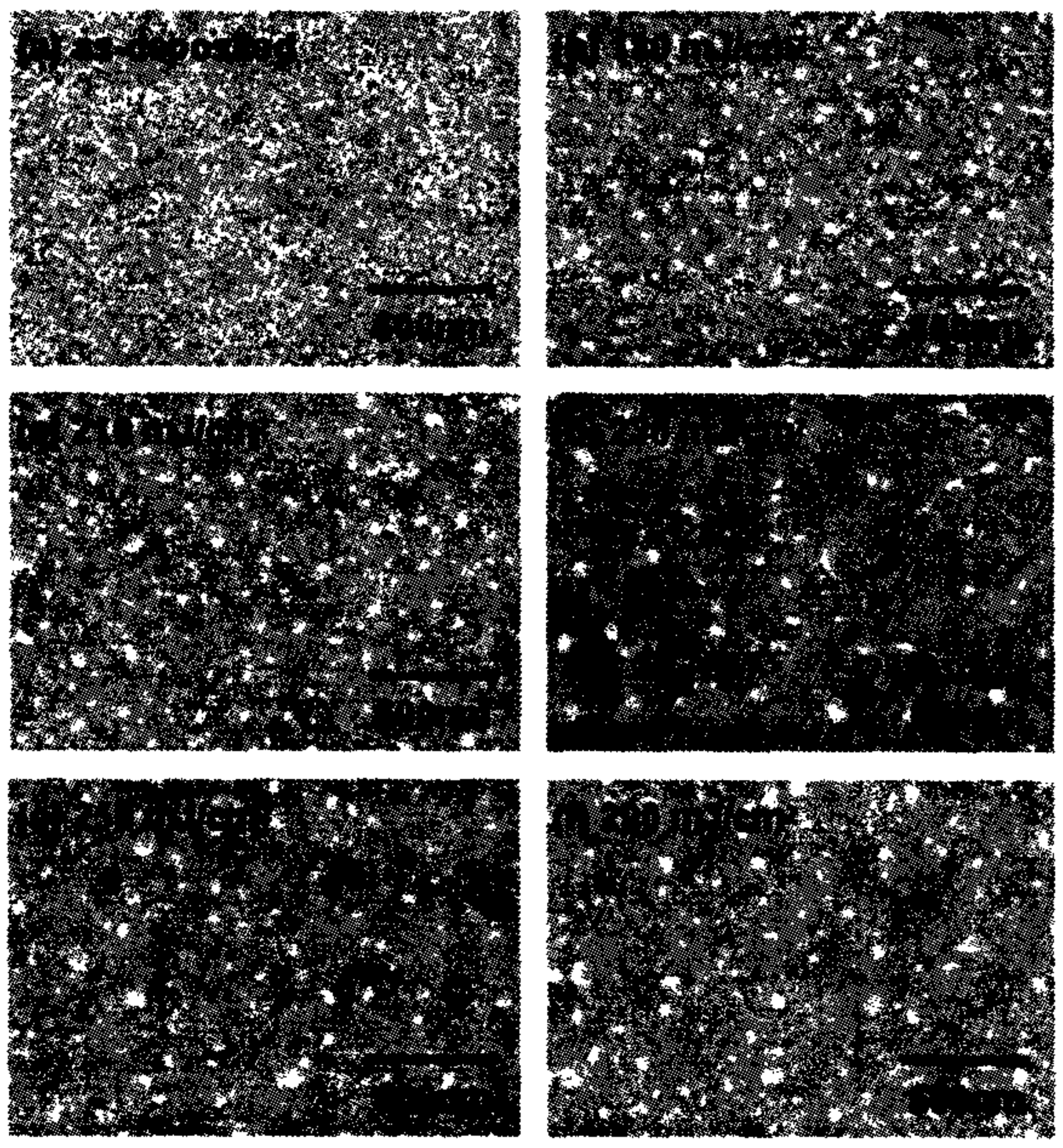

Fig. 4 SEM images of Si film irradiated by laser at various energy densities.

increased over 230mJ/cm^2, grain size decreases.

The similar tendency between grain size and laser energy density was observed in the case of Si film deposited by conventional LPCVD.[9] Maximum grain size was measured by about 300nm at 230mJ/cm^2. It is thought that dehydrogenation and recrystallization were carried out simultaneously during step-by-step laser irradiation.

The typical transfer characteristic of the fabricated n-channel TFTs are shown in Figure 5. The measured maximum field-effect carrier mobility is 11.2 cm^2/Vs. The performance of this poly-Si TFT is sufficient to drive pixels of OLED display, as well as LCDs on plastic. In order to be utilized in peripheral circuits for Active- Matrix FPDs, much higher mobility value is required of both n-MOS and p-MOS TFTs.

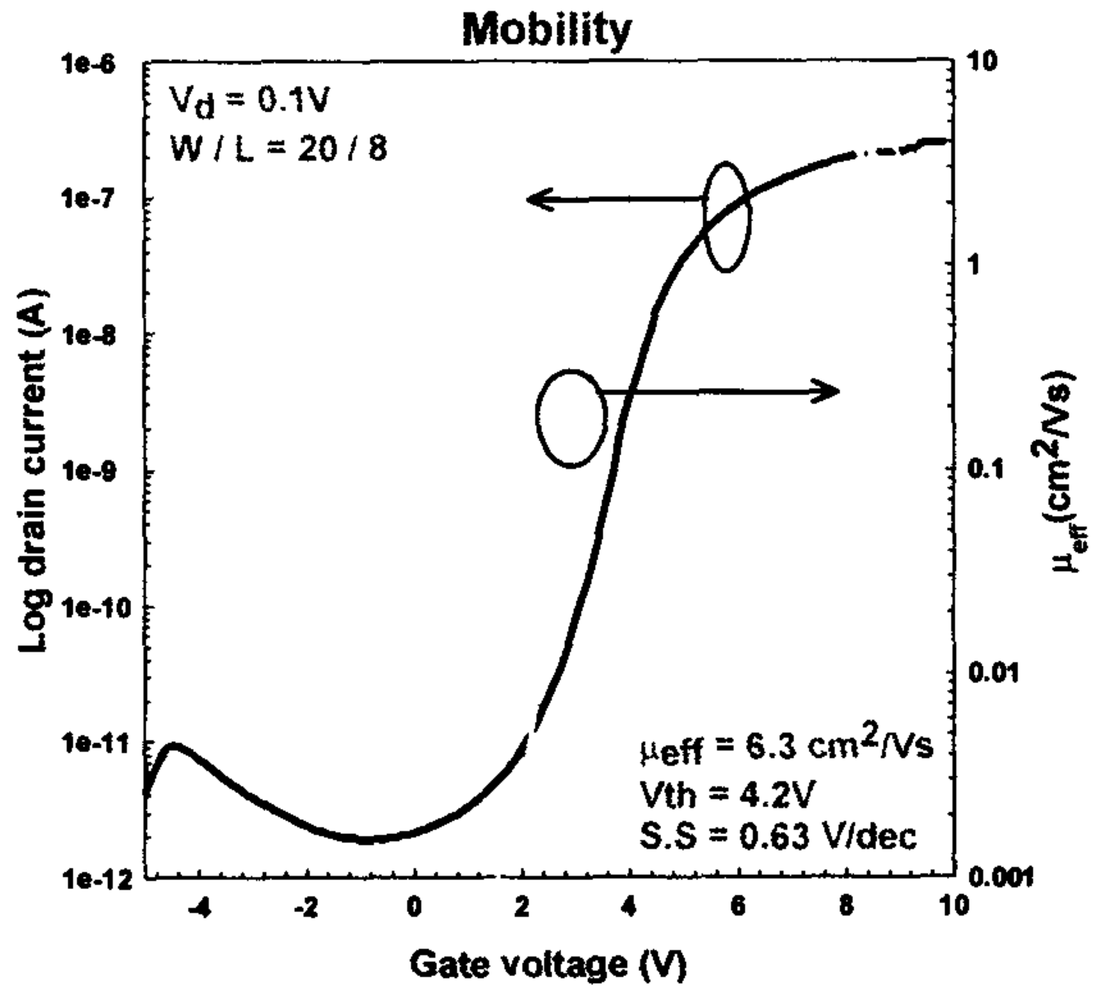

Fig. 5 Poly-Si Characteristics. it is sufficient to drive pixels of OLEDs, as well as LCDs.

Further optimization is required of the initial deposition of Si film, as well as of the subsequent excimer laser crystallization.

4. Summary

Without any damage on plastic substrate, poly-Si film was performed below 170°C. In the case of as-deposited Si film, it has micro-crystalline structure which has excellent spatial uniformity. Moreover, active layer of poly-Si film for high performance TFT could be also realized if laser annealing process was just added. Base on these results, poly-Si TFT was fabricated on plastic substrate successfully, and it is sufficient to drive pixels of OLED display, as well as LCDs.

5. Acknowledgements

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