Excimer laser crystallization of sputtered a-Si films on plastic substrates

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ABSTRACT

In this work, thin films of amorphous silicon (a-Si) were formed on plastic substrates by sputtering deposition and crystallized using excimer laser irradiation. As the entire process is conducted at room temperature, and the laser irradiation-induced heating is confined to the thin film, the plastic substrate is not subjected to thermal stresses. The microstructure resulting from the laser irradiation was dependent on the laser irradiation energy density and the composition of the underlying buffer layers. It was found that a layer of AlN deposited as a buffer between the plastic and the a-Si film increased the endurance of the a-Si film under laser irradiation, and resulted in polycrystalline Si grains up to 100nm in diameter.

1. Introduction

Flexible displays on plastic substrates, using polycrystalline Si (poly-Si)-based thin film transistor (TFT) devices to drive active matrix liquid crystal displays (AMLCDs) are expected to be a driving force of the display industry in the near future [1]. The reason is that, in general, TFTs using poly-Si as the active channel material exhibit higher carrier mobility than those using a-Si. Therefore, poly-Si TFT devices fabricated on plastic substrates are an ideal combination for applications requiring high performance as well as mechanical flexibility. Also, the driving of active matrix organic light emitting diodes (AMOLEDs), which are ideal for integration with plastic substrates, often requires high mobilities that are not easily attainable using a-Si TFTs [2].

The main challenges that are anticipated in the manufacture of poly-Si TFTs on plastic are the deposition of the precursor a-Si or poly-Si layer, and the crystallization of this layer, both at temperatures compatible with the plastic substrates – generally below 200°C. Excimer laser crystallization (ELC), using high-power pulses of short duration, has emerged as an ideal method for crystallizing a-Si films, as it is capable of completely melting the Si film at the surface while minimally affecting the substrate [3]. While chemical vapor deposition (CVD) methods have been used successfully to deposit a-Si films on glass substrates, they inherently incorporate hydrogen gas during the deposition process, which may explosively release during ELC. Removal of hydrogen from the as-deposited film requires annealing at temperatures too high for use in plastic substrates. Sputtering is considered an ideal method of depositing a-Si precursor material because it may be conducted at room temperature and does not incorporate hydrogen [4,5]. It is therefore natural to envision combining the approaches of sputtering deposition and ELC to realize high-quality poly-Si films on plastic substrates.

2. Experiment

The substrates used in this study are PES plastic sheets with an organic coating to prevent gas diffusion. Before deposition of the a-Si layer, two types of intermediate buffer layers were deposited between the plastic substrate and the Si film: (1) 200nm thick SiO_2, and (2) 200nm thick SiO_2 on top of 100nm thick AlN. The SiO_2 layers were deposited by a low-temperature (170°C) inductively-coupled plasma CVD (ICP-CVD) method, while the AlN layer was deposited by reactive sputtering of Al in an N_2 atmosphere.

An a-Si layer was deposited using rf sputtering with Ar or Xe plasma. The pressure of the sputtering gas was kept at 5 mTorr, and the deposition rate was approximately 1 Å/sec using Ar gas, and 0.5 Å/sec using Xe gas.

The a-Si films prepared in this manner were irradiated by excimer laser pulses (308 nm) of energy density ranging from 100 mJ/cm2 to 300 mJ/cm2. The resulting film morphology was observed using optical microscopy and SEM analysis.

Also, the microstructure of the as-sputtered a-Si film was analyzed using TEM analysis, and the in-film compositions of the respective sputtering gases were analyzed using RBS (Rutherford Backscattering Spectroscopy).

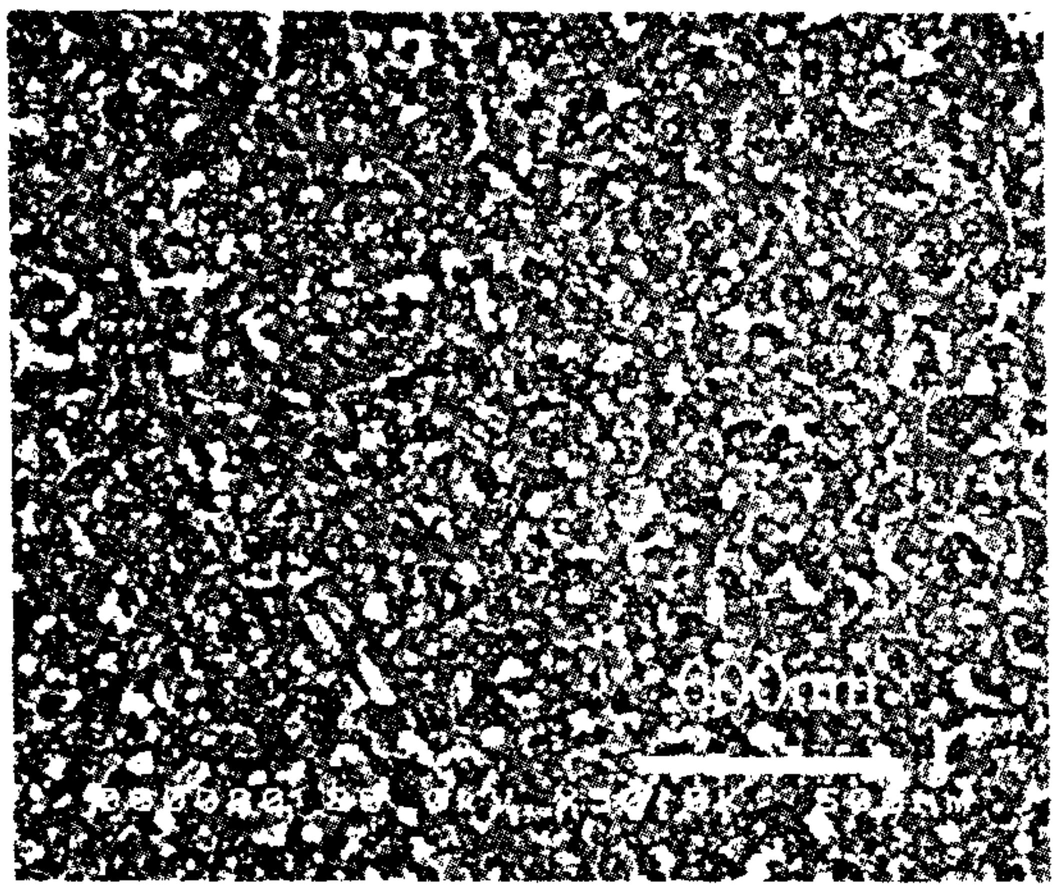

Figure 1. SEM image of sputtered a-Si film on SiO_2 buffer layer, after 1-shot, 100mJ/cm^2 ELA, showing damage due to delamination of the film.

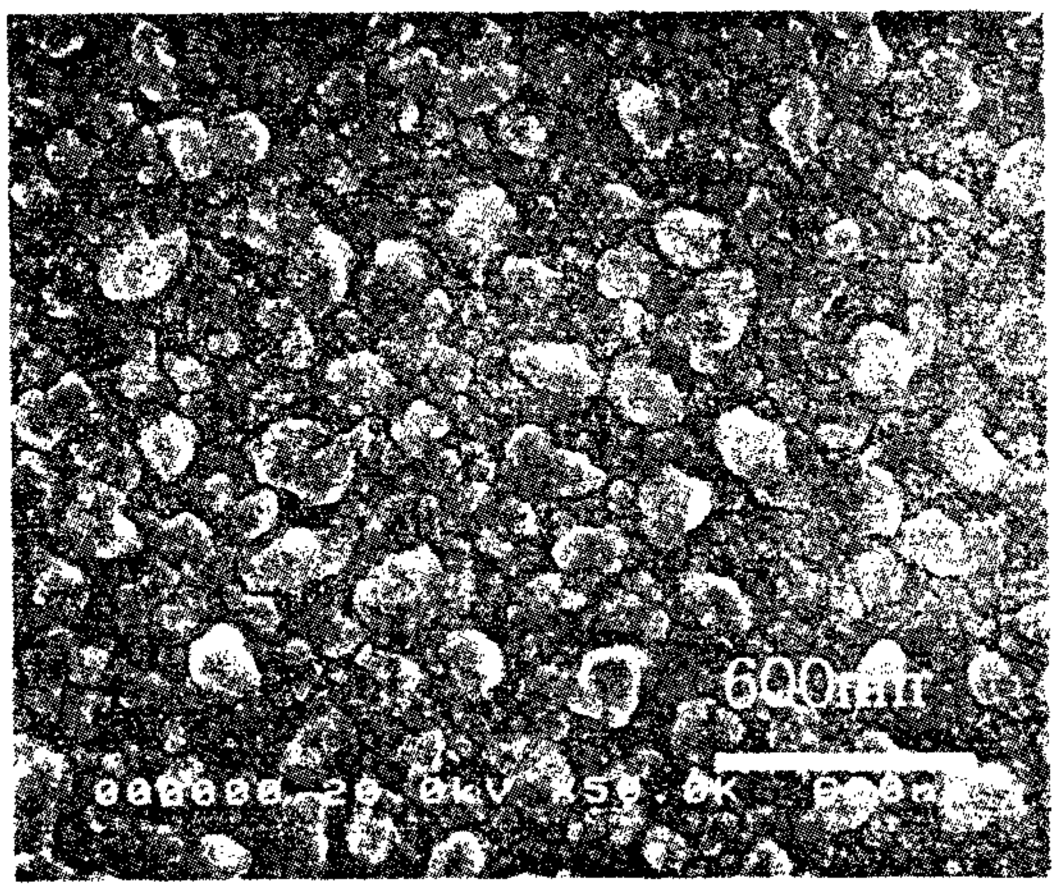

Figure 2. SEM image of sputtered a-Si film on SiO_2 on AlN buffer layer, after 1-shot, 140mJ/cm^2 ELA.

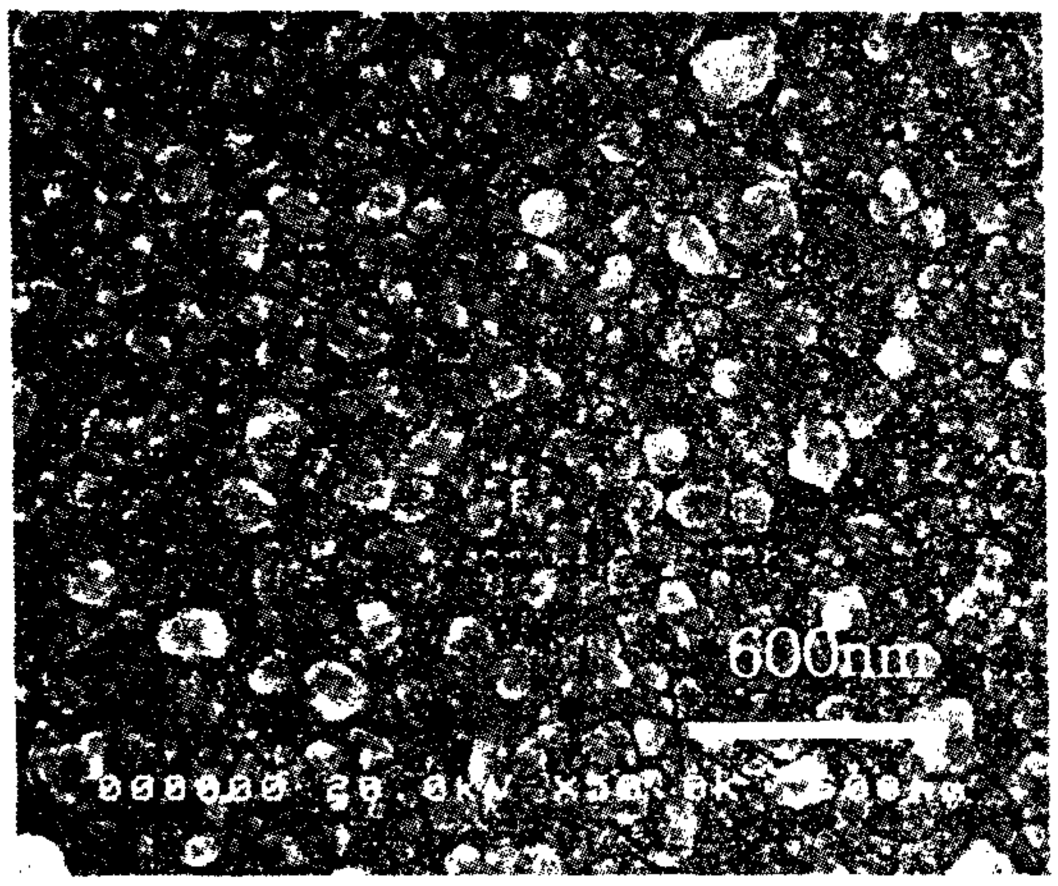

Figure 3. SEM image of sputtered a-Si film on SiO_2 on AlN buffer layer, after 5-shot, 140mJ/cm^2 ELA.

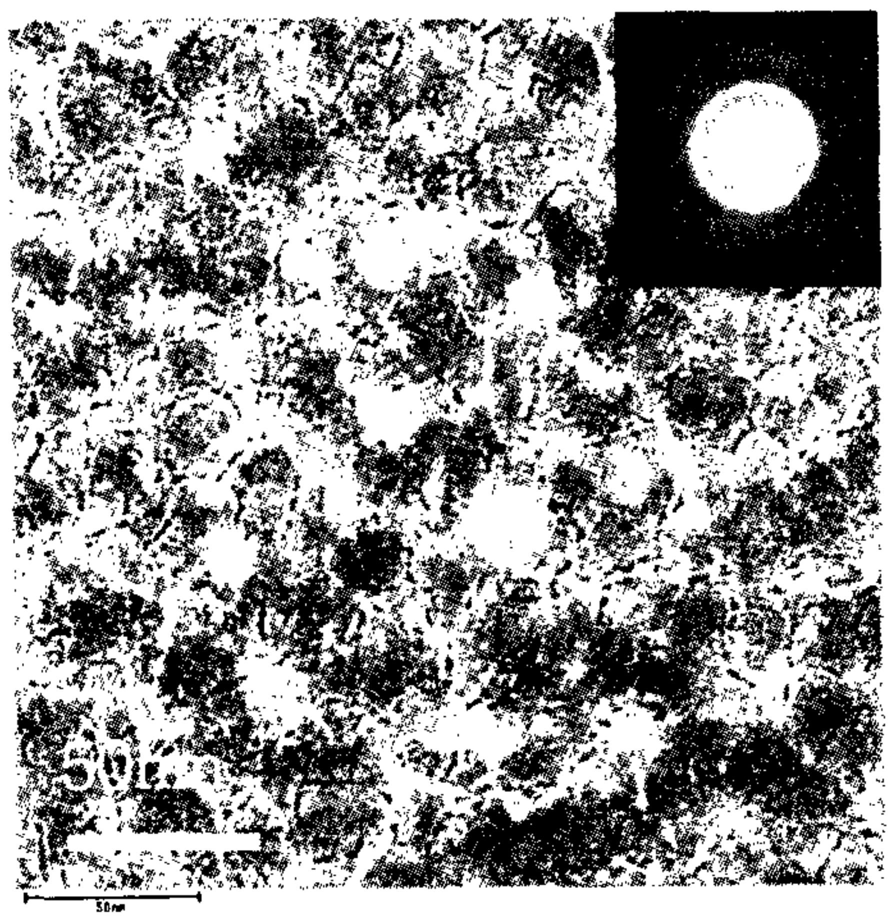

Figure 4. Plan-view TEM image of as-sputtered a-Si film, revealing non-uniform morphology. Inset: Electron diffraction pattern.

3. Results and Discussion

As shown in Figure 1, when the underlying buffer layer consisted only of SiO_2, damage of the film due to delamination occurred at excimer laser irradiation at energy densities of less than 100mJ/cm^2, which is significantly smaller than the optimal laser energy density for laser crystallization, which is the near complete melting regime [6]. However, the inclusion of a 100nm thick AlN film under the SiO_2 layer increased the energy density at which the sputtered a-Si film survives during ELC, and expanded the ELC process window as a result. The a-Si films sputtered on substrates that included an AlN layer in the buffer survived ELC at energy densities up to 170mJ/cm^2 (Fig.2 and 3), which is closer to the laser energy density at which optimum crystallization is expected to occur, based on studies of ELC of a-Si films on glass substrates. SEM analyses reveal that under optimal ELC conditions, poly-Si films were obtained which had grain sizes on the order of 100nm on plastic substrates using AlN layers in the buffer (Fig.2). The microstructure of films irradiated multiple times (Fig. 3) appears to be more uniform and smooth.

There is a significant difference in the survivability of the Si film based on the plasma source gas used to sputter the film. In general, films sputtered with Xe gas survived ELC performed at higher energy densities than films sputtered with Ar gas. This may be due to the difference in the amount of residual sputtering gas trapped in the deposited film depending on the gas species, which were measured by RBS to be 1.1% for Ar sputtered films and 0.39% for Xe sputtered films.

In general, the microstructure of a-Si film sputtered at low temperature is thought to be porous or less dense than films deposited at higher temperatures or films that were annealed after deposition. Plan-view TEM images of the as-sputtered a-Si films (see Fig. 4) confirm this, as it shows a columnar, cracked morphology for the as-deposited film, which is not observed in films deposited at higher temperatures.

Also, inherent stresses are thought to exist in the a-Si film and between the several thin film layers, which were deposited at different temperatures. Therefore, thermal stress caused by ELC-induced rapid heating may be the cause of the delamination of the a-Si film during ELC. The improvement in the survivability of the a-Si film during ELC when AlN is included in the buffer layers could be attributed to the high thermal conductivity of AlN (260 W/mK), by which the laser-induced heat in the a-Si film could rapidly be redistributed to the underlying buffer layers and substrate, relieving the thermal gradient, and therefore, the stress. In comparison, the thermal conductivity of SiO_2 is only 14 W/mK. We propose that the thermal stresses in the film may be reduced significantly in comparison with the case of a purely SiO_2 buffer layer, even during the short period in which laser-induced melting and cooling occurs (~200 nsec).

4. Conclusion

This study shows that by using appropriate buffer layers on the substrate, it is possible to apply excimer laser crystallization to a-Si films deposited by sputtering, with a process window large enough to allow the manufacture of poly-Si TFTs at low temperatures throughout the manufacturing process. The inclusion of a high thermal conductivity layer in the buffer layer stack is thought to increase the laser energy density that is tolerated by the a-Si film by alleviating thermal interlayer stress, among the various mechanisms that possibly contribute to the film delamination during ELC.

5. Acknowledgements

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