Characteristics of Poly-Si TFTs Fabricated on Flexible Substrates using Sputter Deposited a-Si Films

Y. H. Kim, D. G. Moon, W.K. Kim J. I. Han
Information Display Research Center, Korea Electronics Technology Institute,
Seongnam, Gyeonggi. 463-816, Korea

Abstract
The characteristics of polycrystalline silicon thin-film transistors (poly-Si TFTs) fabricated using sputter deposited amorphous silicon (a-Si) precursor films are investigated. The a-Si films were deposited on flexible polymer substrates using argon-helium mixture gases to minimize the argon incorporation into the film. The precursor films were then laser annealed by using a XeCl excimer laser and a four-mask-processed poly-Si TFT was fabricated with fully self-aligned top gate structure. The fabricated pMOS TFT showed field-effect mobility of 32.4 $cm^2/V{\cdot}s$ and on/off ratio of 10^6.

1. Introduction
Polycrystalline silicon thin-film transistors (poly-Si TFTs) are currently used in active-matrix flat panel displays (FPDs) as pixel switching devices and also as peripheral drive circuit elements [1,2]. The monolithical integration of drive circuits into the panels will reduce the external interconnection to the panels and improve the form/factor of the displays [3].

In general, the poly-Si TFTs are fabricated on glass or quartz substrates using amorphous silicon (a-Si) films formed by plasma-enhanced chemical vapor deposition (PECVD). However, the a-Si films deposited at low temperature by PECVD contains considerable amount of hydrogen atoms (10 ~ 20 at%) and the incorporated hydrogen atoms cause ablation of Si films during the laser annealing process. To remove the hydrogen atoms, thermal dehydrogenation process (>400℃) is carried out before the laser annealing process. However, most of polymer substrates have glass transition temperatures range from 120℃ to 320℃, limiting the conventionally used processes. In contrast, sputter deposition a-Si films can be carried out at room temperature and by optimizing the process conditions, very low concentration of impurities can be achieved.

In present work, a-Si precursor films were deposited by sputtering and laser annealed by using a XeCl excimer laser (?=308 nm). Then, a four-mask-processed pMOS TFTs were fabricated with fully self-aligned top gate structure.

2. Experimental Details
The direct fabrication of poly-Si TFTs onto polymer substrates encounters several obstacles during the fabrication process. In particular, mechanical stresses are induced in inorganic layers due to dimension changes of the polymer substrate during the thermal cycling. This indeed generates cracks in the inorganic layers resulting in failure of the device. To minimize the dimension changes of polymer substrate during the thermal cycling, polyarylate substrate was annealed at 250℃ for 60 hours before the buffer layer deposition. The annealed substrate showed shrinkage rate less than 2 ppm/K. The a-Si film was deposited on a 600-nm-thick SiO_2 buffer layer using rf-magnetron sputtering system with argon-helium mixture gases. The a-Si film was then laminated onto a glass substrate using a thin adhesive film and irradiated by XeCl excimer laser with energy densities ranged from 200 to 400 mJ/cm^2. The pulse duration and final beam size of the laser were 35 ns and 45 **x** 0.2 mm^2, respectively. After defining Cr or AlNd gate electrode (200-nm-thick) and gate insulator (SiO_2, 200-nm-thick), source-drain region was formed by ion shower process and laser activation. Then 400-nm-thick interlayer dielectric was deposited and contact hole was defined. Finally, 300-nm-thick AlNd source and drain electrode was deposited and patterned.

3. Results and Discussion
One of the disadvantages of using polymer substrates instead of glass is the large dimension changes during thermal cycling procedure. Upon heating a polymer material, structural changes take place which can be divided into a reversible part controlled by coefficient of expansion (CTE) and an irreversible part given by

coefficient of shrinkage [4]. Although the CTE mismatch between the polymer and inorganic films induces considerable stress in the film-substrate system, the shrinkage of polymer may also give a critical limitation to TFT fabrication since it is an irreversible process. In order to reduce the effect of irreversible shrinkage during TFT fabrication, the substrates must be annealed before the process starts as mentioned above. Figure 1 shows the shrinkage rates of PAR and PES substrates with various annealing conditions. The shrinkage rates were noticeably decreased with annealing time more than 60 hours. For PAR substrates, the rates decreased from 30 ~ 50 ppm/K to less than 2 ppm/K and for PES, the rates decreased from 180 ~ 200 ppm/K to 2 ppm/K, which are in the acceptable range for TFT fabrication.

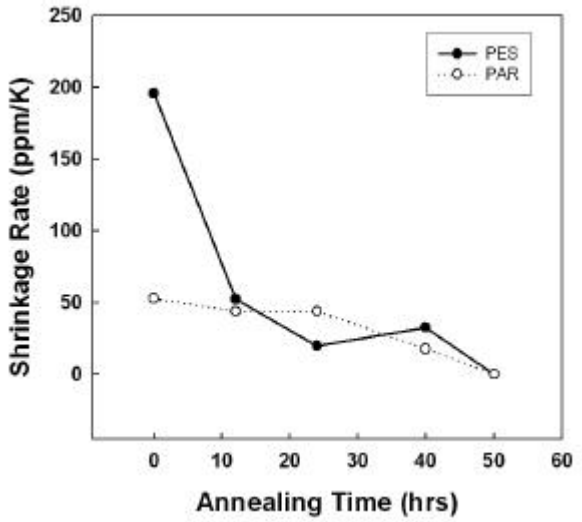


Figure 1. Shrinkage rate changes of PES and PAR substrates as a function of annealing time.

The argon concentrations of sputter deposited a-Si films were analyzed by Rutherford backscattering spectrometry (RBS). The random RBS spectra were obtained using 2.003MeV He^{++} beams with incident beam charge and current of 20 μC and 20 nA, respectively. The measured spectra were simulated to evaluate the argon concentrations in the Si films. Figure 2 shows the measured RBS spectra with different argon-helium mixture ratios. With argon-helium ratio of 2:20, the argon concentration in the film was determined as 1.5 at%, whereas with argon-helium ratio of 2:5, the in-film argon concentration was 6.0 at%.

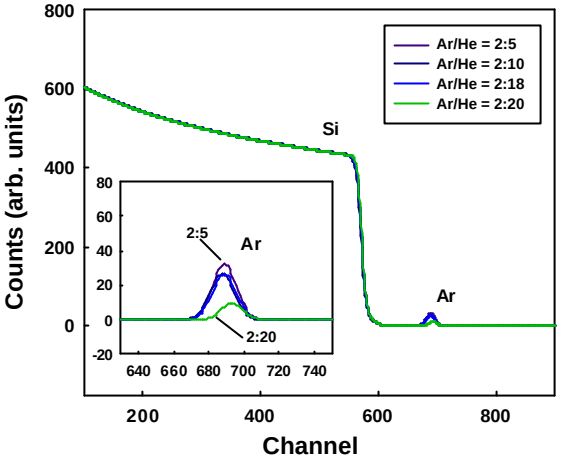
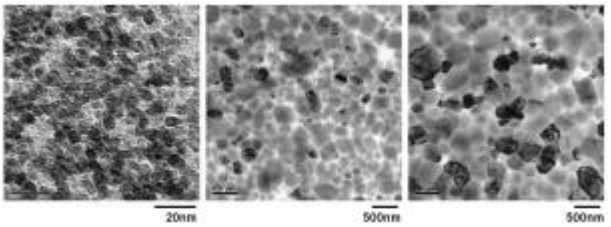


Figure 2. RBS spectra of sputter deposited a-Si films with different argon-helium mixture ratios

Sputter deposited a-Si films were laser annealed by using a XeCl excimer laser system. The laser annealing process was done in vacuum or nitrogen atmosphere at room temperature. Laser annealed films were observed by transmission electron microscopy (TEM) to evaluate the grain size of resulting poly-Si films. Figure 3 shows the TEM images of poly-Si films irradiated with various energy densities and the average grain size was 400 nm when the energy density was 289 mJ/cm^2.

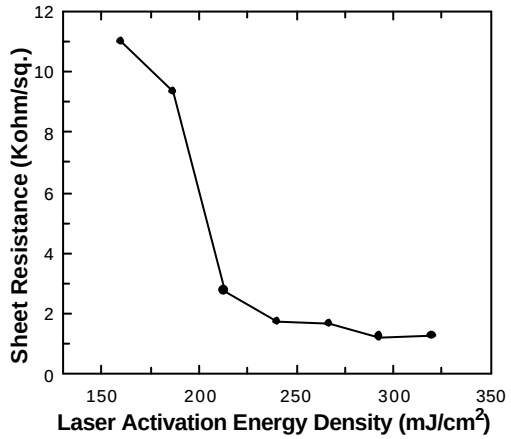


(a) (b) (c)

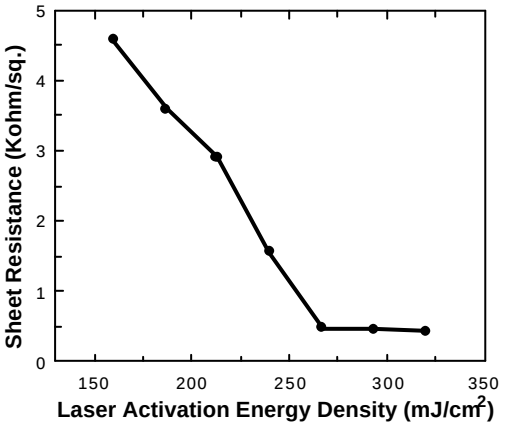
Figure 3. Transmission electron microscopy (TEM) images of poly-Si films irradiated with laser energy densities of (a) 200 mJ/cm^2, (b) 267 mJ/cm^2, and (c) 289 mJ/cm^2.

Ion implantation or ion shower doping is widely used for the low-temperature poly-Si TFT fabrication [5]. Although the ion shower doping without mass

separation has problems of reproducibility and controllability in low-dose doping, the ion implantation also has a problem in throughput for high-dose doping [5,6]. In this research, ion shower doping method was used to dope the Si films. The doping temperature and acceleration voltage were room temperature and 10 kV, respectively. The sheet resistances of 470 Ω/sq. for boron doping and 1200 Ω/sq. for phosphorus doping were successfully obtained on polymer substrates and these values are low enough for the source and drain formation in poly-Si TFTs (Fig. 4).



(a)



(b)

Figure 4. Sheet resistance of laser activated samples with (a) phosphorus doped, (b) boron doped.

After the laser activation, a four-mask-processed poly-Si TFTs were fabricated with fully self-aligned top gate structure. Figure 5 shows the optical image of poly-Si TFT device fabricated on a polyarylate substrate. Also in Fig. 6, the transfer characteristics of pMOS TFT are shown. Here, the channel width (W) and length (L) were 20 μm/20 μm. The fabricated pMOS TFT showed field-effect mobility of 32.4 $cm^2/V \cdot s$ and on/off ratio of 10^6.

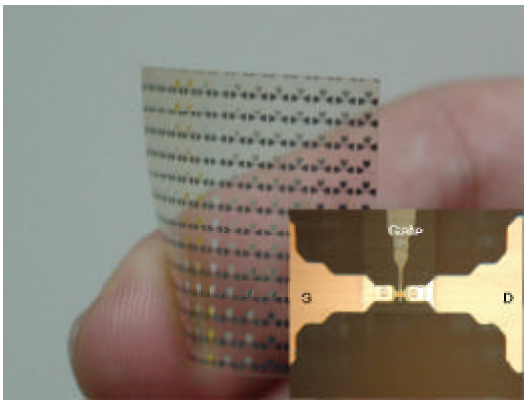


Figure 5. Poly-Si TFT fabricated on a polyarylate substrate.

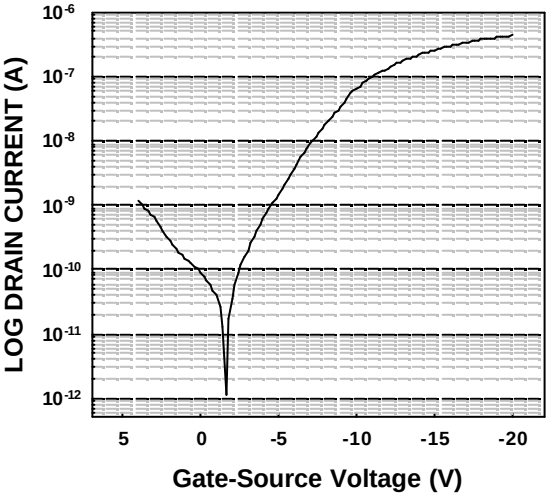


Figure 6. Transfer characteristics of fabricated pMOS (W/L=20/20μm) poly-Si TFTs.

4. Conclusions

This paper reports the fabrication of poly-Si TFTs using sputter deposited a-Si precursor films. The sputter deposition has the advantages of low process temperature and low impurity concentration, suitable for the fabrication of flexible active-matrix type displays with integrated driving circuits.

5. References

[1] C. Yi, P. M. Choi, U. S. Kim, D. B. Kim, C. W. Kim, K. Chung, *SID Digest*, p. 229 (2004).

[2] J. Y. Yang, S. H. Kim, Y. I. Park, K. M. Lim, C. D. Kim, SID Digest, p. 224 (2004).

[3] A. T. Voutsas, A. Limanov, J. S. Im, J. Appl. Phys. **94**, 7445, (2003).

[4] R. Riesen and J. E. K. Schawe, J. Therm. Anal. Cal., vol. 59, p. 337 (2000).

[5] J. R. Ayres, S.D. Brotherton, C. A. Fisher and D. J. McCulloch, Proceedings of International Display Workshops, p. 127 (1998).

[6] K. Sera, F. Okumura, S. Kaneko, S. Itoh, K. Hotta and H. Hoshino, J. Appl. Phys., vol. 67, p. 2359 (1990).