# Low temperature Aluminum induced crystallization process to get Poly-silicon films for thin film transistor application in active matrix displays

***Hitesh Chelawat, Alka Kumbhar, Subhra Adhikari, Hrishikesk Kelkar, R.O.Dusane***
Semiconductor Thin Films and Plasma Processing Laboratory,
Department of Metallurgical Engineering and Materials Science,
Indian Institute of Technology Bombay, Mumbai, India
rodusane@iitb.ac.in

**Abstract:** *The realization of high information-content active matrix flat-panel displays (FPD's) requires low temperature thin film transistor (TFT) process that is compatible with the thermal constraints imposed by common inexpensive glass panels. Aluminum induced crystallization (AIC) has been researched extensively for producing poly-Si from a-Si. In this paper Aluminum-induced crystallization (AIC) in amorphous silicon films deposited by Hot Wire CVD (HWCVD) on glass has been demonstrated .The samples were annealed at temperatures ranging from 300°C to 400°C.The annealing time and temperature was observed to have significant role in crystallization of the amorphous film. Along with this, it is also shown that it is possible to avoid the post deposition annealing step and it is possible to get crystallization by depositing aluminum at as low temperatures as 200ºC. The results also showed that appreciable crystallization is obtained only for temperatures more than 250ºC.Optical micrographs indicating dendritic growth of c-silicon are also shown.*

**Keywords:** TFT; aluminum; crystallization.

## Introduction

Thin film Transistor's are the key driving elements for high-density electronic displays and are indispensable for any high-end OLED-based display device and active matrix liquid-crystal displays (AMLCD). TFTs made from hydrogenated a-Si can be used as switching elements only in AMLCD because of poor mobility. In comparison TFTs made from poly-Si enable integration of TFTs and IC driver circuits, which is turn reduces the fabrication cost[1]. Different possibilities for fabricating poly-Si films have been look into, which includes direct deposition methods and converting a-Si produced by low temperature CVD into crystalline silicon. This has been accepted now that as-deposited poly-Si does not give films with desired electrical properties. So various possible routes of converting amorphous silicon (a-Si) into poly-Si have been explored like excimer laser annealing (ELA)[2], solid phase crystallization (SPC)[3] and metal induced crystallization (MIC)[4]. In ELA a nano-second-pulse excimer laser transform a-Si to poly-Si without hampering the substrate but it involves problems like high cost and poor uniformity over large areas. In SPC, a-Si is annealed at temperatures of the range of 600 ºC for several hours. Its drawbacks are high temperatures required, large annealing time and poor grain structure. Another relatively new approach used to obtain poly-Si at considerable lower temperatures and anneal times is MIC, where a metal like Pd, Ni, Al, Ag, Au etc. acts as a seed layer for crystallization. Another advantage with MIC is that it gives large c-Si grains of the order of few micrometers. Aluminium induced crystallization (AIC) with a annealing step after depositing a-Si and Al has been researched extensively and it has been shown that the minimum temperature to get any appreciable crystallization is 350 ºC. In this paper, we have shown for the first time the AIC of a-Si:H films without the need of any annealing step after depositing Al on a-Si:H at some higher temperature. Experimental results show that it is possible to get crystallization by depositing Al at 200 ºC without any further annealing. But appreciable amount of crystallization is obtained only when deposition temperature of Al is 250 ºC.

## Experimental

All experiments were done on corning 7059 glass. Glass was first washed in a soap solution followed by subsequent washing in DI water and then methanol in ultrasonic bath. Glass samples were then mounted for depositing a-Si:H by HWCVD at a substrate temperature of 300°C, silane flow of 10 sccm and pressure of 70 mtorr. Aluminum (Al) films of different thicknesses were then deposited on glass/a-Si:H by thermal evaporation at room temperature and at various temperatures ranging from 150 ºC to 300 ºC. In other set of experiments samples were prepared by first depositing Al at room temperature followed by depositing a-Si:H by HWCVD at a substrate temperature of 300 ºC. These samples were then annealed at different temperatures under nitrogen flow. Thickness measurements were done using AMBIOS Technology XP-2 Stylus Profiler. X-ray diffraction spectroscopy (XRD) and Raman spectroscopy (Jobin Yvon HR 800) was done to find the crystal orientation and crystalline fraction of our samples.

## Results and Discussions

*Effect of post deposition annealing time and temperature on crystallization*

Annealing temperature is a process parameter having a strong influence on grain size and annealing time. Sample of type glass/Al/a-Si:H were prepared with Al thickness of 40 nm and Si thickness of 500 nm. After deposition, annealing under different conditions was carried out in $N_2$ atmosphere. Crystallization was

confirmed by Raman spectroscopy and XRD. Crystalline fraction denoted by $X_C$ was calculated using the peak intensities at $I_a$(480 $cm^{-1}$), $I_m$(500 $cm^{-1}$) and $I_c$(521 $cm^{-1}$), indicating amorphous, intermediate state and crystalline state respectively. The crystalline volume fraction $X_c$ can be expressed as [5],

$$X_c=(I_m+I_c)/(I_m+I_c+I_a) \qquad (1)$$

Raman spectroscopy (Figure 1) showed that crystallinity increases with increase in the annealing temperature. The reason is the dependence of nucleation rate as well as diffusion of Si and Al atoms on temperature, which are crucial for this process. It was also observed that for lower annealing temperature larger annealing time was required to obtain similar amount of crystallization. XRD data as shown in Figure 2.was used to calculate the grain size. For sample annealed at 350 ºC for 5 hours crystallization extent was 73% and grain size was 48 µm where as sample annealed at 400 ºC for 4 hours crystallization extent was 80 % with grain size of 55 µm. Annealing at 300 º C even for 4 hours did not show any crystallization.

*Comparison of crystallization for glass/a-Si:H/Al and glass/Al/a-Si:H samples*

Position of aluminum layer in the samples was found to affect the extent of crystallization. Figure3. shows that there is a considerable difference in extent of crystallization for samples with aluminum at different positions with respect to silicon layer and glass substrate.

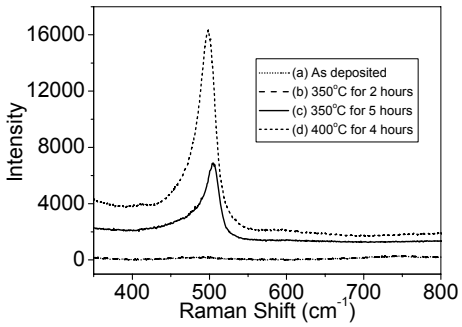


**Figure 1.** Raman Spectra for samples glass/Al(40 nm)/a-Si:H(500 nm) with different annealing time and temperatures(a) As deposited (b) Annealed at 350 ºC for 2 hours (c)Annealed at 350 ºC for 5 hours (d) Annealed at 400 ºC for 4 hours

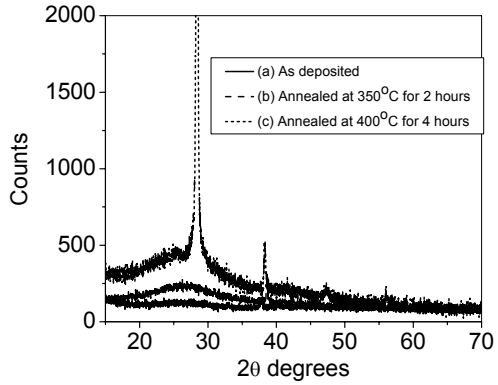


**Figure 2.** XRD data for glass/Al(40 nm)/a-Si:H(500 nm) annealed at (a) As deposited (b) 350 ºC for 2 hours (c) 400 ºC for 4 hours

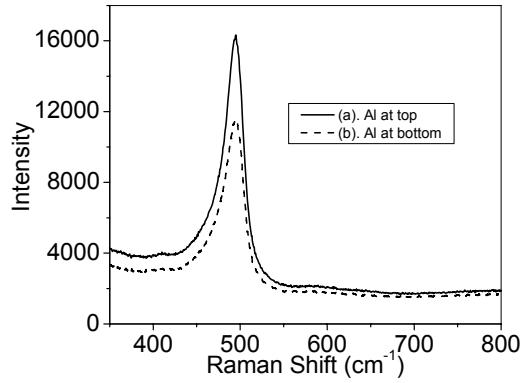


**Figure 3.** Raman Spectra for samples with (a) glass/a-Si:H (500 nm)/Al (40 nm) (b) glass/ Al (40 nm)/a-Si:H (500 nm) showing higher crystallization for former one

Samples with aluminum layer above silicon layer showed a higher extent of crystallization. This is possibly because in samples which had Al layer below a-Si:H , native $Al_2O_3$ layer was formed on the exposure to air during sample transfer from one chamber to another before silicon deposition. This layer acts as a diffusion barrier, thus reducing the number of nucleation sites. Whereas when Al layer is present above silicon layer, $SiO_2$ layer is formed which is not as good a diffusion barrier as $Al_2O_3$ [6]. Hence, the number of nucleation sites is higher as compared to the former case and thus the higher extent of crystallization.

*AIC without post deposition annealing step -In-situ annealing only*

In this set of experiments, samples were prepared by first depositing a:Si:H on glass at 300 ºC. It was followed by depositing Al of various thicknesses at different temperatures. The crucial point to note here is that there was no annealing done after deposition and whatever

crystallization was obtained was because of the effect of depositing Al at temperatures higher than room temperature. Aluminum was deposited at temperatures of 150 ºC, 200 ºC, 250 ºC and 300 ºC.

*Effect of Thickness of Al on in-situ annealing during AIC*

Al of varying thicknesses of 30 nm, 60 nm and 90 nm were deposited at 300 ºC on glass/a-Si:H substrate with a-Si:H thickness constant as 60 nm. Raman spectroscopy was done to observe the crystallization. Optical micrographs of the samples were also taken to see the growth pattern of silicon grains. It was seen that with increase in Al/a-Si:H thickness ratio crystallization percentage increases. This may be attributed to the variation in stresses in the film with varying thickness.

Optical micrograph (Figure 5.and Figure 6.) showed the dendritic growth of c-Si grains. Dependence on thickness of Al layer is clearly observed in the micrographs. With higher Al thickness, we obtain a higher crystallization fraction.

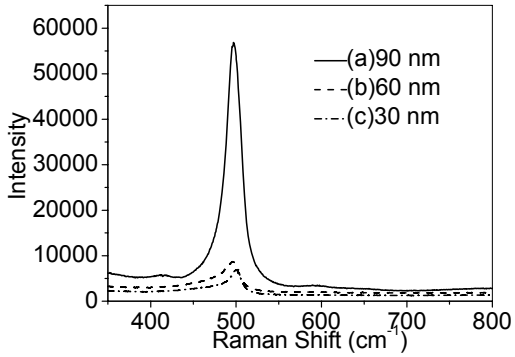


**Figure 4.** Raman spectra of glass/a-Si:H (60 nm)/Al samples with different aluminum thicknesses of (a)90 nm (b) 60 nm (c) 30 nm

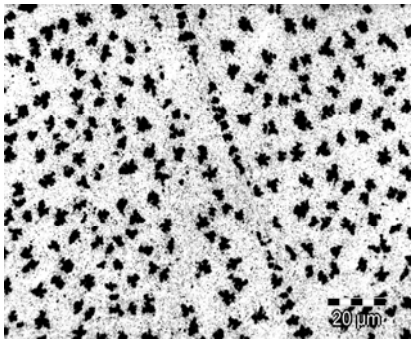


**Figure 5.** Optical Micrograph of glass/a-Si:H (60 nm)/ Al (90 nm) sample in which aluminum was deposited at 300 ºC. Dendritic Si grains can be seen

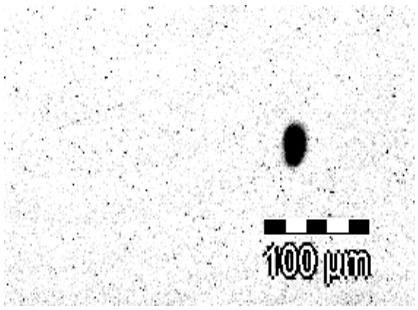


**Figure 6.** Optical Micrograph of glass/a-Si:H (60 nm)/ Al (30 nm) sample in which aluminum was deposited at 300 ºC. Very less nucleation density can be seen

*Effect of deposition temperature of Aluminum*

90 nm thick Aluminum layer was deposited on 60 nm a:Si:H at different temperatures to study its effect on crystallization and grain size. At 150 ºC no crystallization was observed. At 200 ºC weak crystallization was observed in Raman spectroscopy but substantial crystallization was obtained only at temperature of 250 ºC and higher. The increase in crystallization with increase in temperature as shown in Figure 7 can be attributed to higher diffusion rates of Si and Al at higher temperature that controls the crystallization rate.

Optical micrographs of the samples where aluminum was deposited at 150ºC (Figure. 8.) and 300 ºC (Figure. 5.) on glass/a-Si:H show higher nucleation density at higher temperature. The thickness of a-Si:H (60nm) , Al (90 nm) and other conditions were same for the two cases.

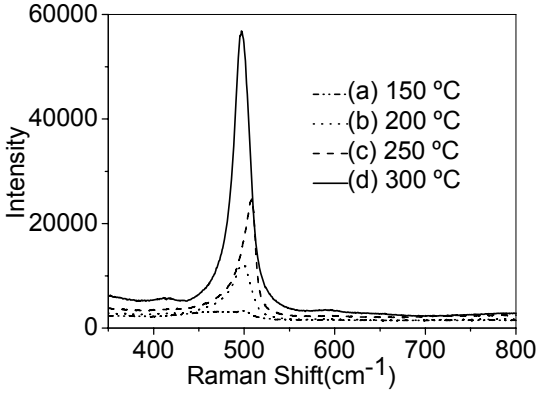


**Figure 7.** Raman spectra of glass/ a-Si:H(60 nm)/ Al (90 nm) samples deposited at Al deposition temperature of (a) 150 ºC (b) 200 ºC (c) 250 ºC (d) 300 ºC. With increasing temperature increase in Raman peak intensity can be seen

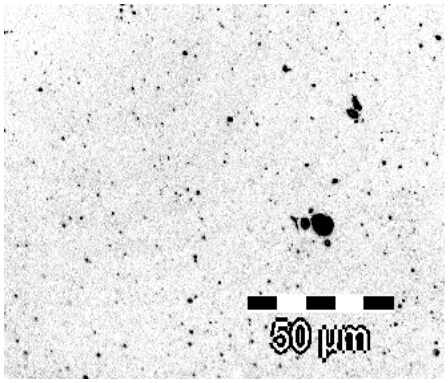


**Figure 8.** Optical micrograph of glass/a-Si:H (60 nm)/Al (90 nm) sample in which Al was deposited at 150 ºC. Low nucleation density in comparison to Fig. 5 can be seen

## Conclusion

AIC of a-Si:H films can be achieved both either by in-situ process during the deposition of Al or by the conventional post-deposition annealing. By AIC it is possible to get large grain sizes suitable for electronic devices. Effect of annealing time and temperature on crystallization are illustrated. The in-situ way of obtaining ALC will not only reduce the process time but through this approach it possible to achieve crystallization at lower temperatures. We have shown crystallization by depositing Al at temperature as low as 200 ºC without any annealing step. However significant approach crystallization was observed at 250ºC. Optical micrograph shows the dendritic growth pattern of c-Si.

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