# Low Temperature Processes of Poly-Si TFT Backplane for Flexible AM-OLEDs

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## Abstract
*Low temperature deposition of silicon and silicon nitride films by catalytic CVD technique was studied for application to thin film transistors on plastic substrates for flexible AMOLEDs. The substrate temperature initially held at room temperature, and was controlled successfully below 150ºC during the entire deposition process. Amorphous silicon films having good adhesion, good surface morphology and sufficiently low content of atomic hydrogen were obtained and could be successfully crystallized using excimer laser without a prior dehydrogenation step. $SiN_x$ films showed a good refractive index, a high deposition rate, a moderate breakdown field and a dielectric constant. The Cat-CVD silicon and silicon nitride films can be good candidates for fabricating thin films transistors on plastic substrates to drive active-matrix organic light emitting display.*

## 1. Introduction
Low temperature polycrystalline silicon (LTPS) films are a key component of thin films transistors (TFTs) for driving active matrix organic light emitting displays (AM-OLEDs) due to their high carrier mobility [1,2]. Fabricating good quality LTPS films on plastic substrates has been a big challenge, since the overall process temperature must be limited to the glass transition temperature of the plastic substrates. However, deposition at lowered temperatures often results in reduction in film density, and the related electrical properties, such as mobility, trap density, breakdown voltage, are degraded. As for amorphous silicon films as a precursor for polycrystalline silicon layer, a very low content of atomic hydrogen is desired to prevent damage caused by explosive evolution during crystallization [3]. Therefore, a deposition technique that may produce device-quality films at low (<150ºC) is required for AM-OLEDs on plastic substrates.

Catalytic (Hot-Wire) chemical vapor deposition (Cat-CVD *or* HWCVD) technique has been studied since 1970s [4]. This technique has been reported to be capable of depositing device quality semiconductor and insulator films with much higher decomposition efficiency of the source gas than the plasma-enhanced chemical vapor deposition (PECVD) technique. Very high film growth rate values of a few tens of angstroms per second can easily be obtained due to the high gas utilization. Also, since the source gas is decomposed at the catalyst held at a very high temperature (>1600ºC), films with a low hydrogen content can be obtained by a careful choice of process parameters [5,6].

However, the catalytic CVD technique has a difficulty in depositing thin films on plastic substrates because of the heat radiated from the high temperature filament. The reactor design must then be modified to minimize the radiative heat arriving at the substrate surface. In this study, amorphous silicon and silicon nitride films were deposited by a catalytic CVD technique, and the influence of the process parameters on the various film characteristics were studied.

## 2. Experimental Procedures
The main obstacle to deposition on plastic substrates is the substrate heating due to absorption of the heat that is radiated from the filament. We adopted a custom-designed cooling system to the substrate holder, and the substrate temperature was suppressed successfully to a level below the glass transition temperature (~180ºC) of the polyethersulfone (PES) substrates. Fig. 1 shows a schematic diagram of the Catalytic CVD apparatus used in this experiment.

Amorphous silicon films were deposited from undiluted $SiH_4$ gas, and silicon nitride films were from a mixture of $SiH_4$, $NH_3$, and $N_2$. Three kinds of substrate were used: silicon wafer, Corning 7059 glass, and PES sheets. The thickness values of the

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substrates were 0.6 mm, 0.7 mm, and 0.2 mm, respectively. The temperature of tungsten filament was 1800ºC, and the substrates were initially held at room temperature. The chamber pressure, the gas flow rate, and the spacing between the filament and the substrate were chosen as main process parameters. The film thickness was measured by a piezoelectric profilometer. FTIR spectra were taken and the composition the films was analyzed. The data were analyzed using Minitab® software.

## 3. Results and Discussion

### 3.1 Deposition and Crystallization of Amorphous Silicon Films

Fig. 2 shows the change in temperature on the substrate surface during deposition. The substrate temperature rose almost linearly with time for a period of 1 minute, and was affected mainly by the distance from the filament. We varied the residence time of the source gas inside the reaction chamber, and compared the trend in the temperature change, as shown in Fig. 2. At the spacing of 3 cm, the temperature did not vary with the process condition. Therefore, the temperature rise could be attributed to the radiation from the filament. However, at the spacing of 6 cm, the temperature rose more rapidly when the gas residence time was longer, which corresponded to the gas flow rate of 1 sccm and the chamber pressure of 20 mTorr. This result suggests that as the distance between the substrate and the filament becomes greater, the influence of the radiation becomes smaller, as it is inversely proportional to the square of the distance, and the conduction via gas molecules and ions comes into play.

The silicon film thickness needed for the TFT channel layer is 500~1000Å. Since the catalytic CVD provides sufficiently high deposition rate to complete the required thickness within a few tens of seconds, the silicon film can be deposited on PES sheets without causing damage to the substrate. A high deposition rate up to 100 Å/sec. was obtained.

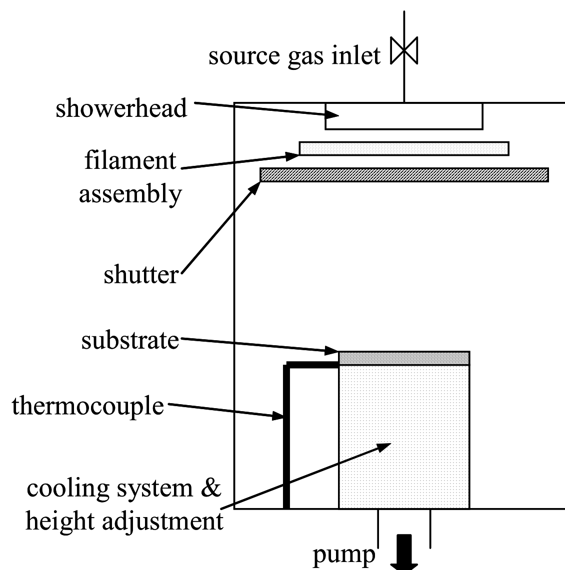



Figure 1 Schematic diagram of the catalytic CVD reactor

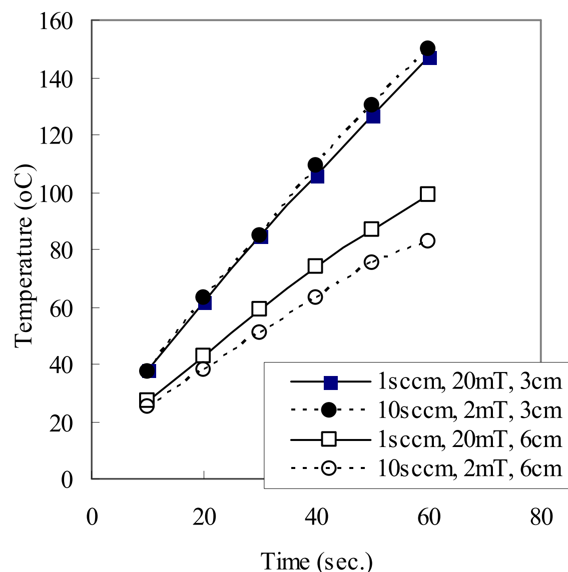



Figure 2 Change in substrate temperature with

Amorphous silicon films were successfully deposited on PES substrates over a wide range of process parameters. As the gas flow rate and the chamber pressure became greater, the deposition rate increased. However, a high deposition rate often resulted in rough surface morphology and poor adhesion. The

adhesion was qualitatively evaluated by applying and detaching a piece of cellophane tape. The surface morphology was characterized by measuring the reflectivity at a wavelength of 200nm of UV reflectance spectra. The result is plotted in Fig.3.

Combinations of the flow rate and the chamber pressure inside the white area resulted in films that fail the tape test, and those inside the gray area passed the test. The combination of process conditions inside the cross-hatched area produced films having reflectance values greater than 50%.

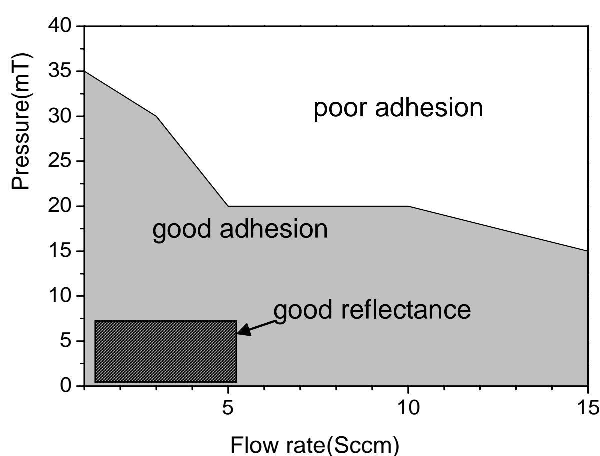



Figure 3 Process window diagram for films having good adhesion and surface morphology

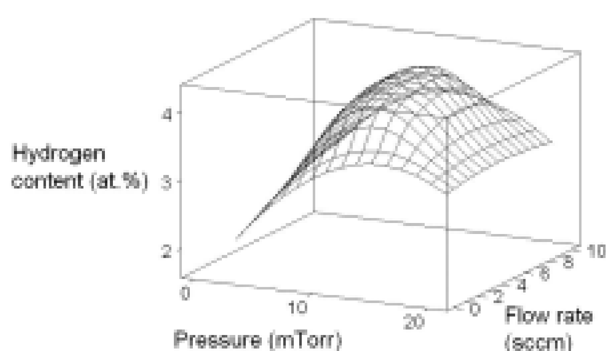



Figure 4 Response surface plot of the variation in hydrogen content with the gas flow rate and the chamber pressure

Fig. 4 shows a 3-dimensional plot of the variation in the hydrogen content with the gas flow rate and the chamber pressure. The hydrogen content varied in rather a complicated way with pressure and flow rate. The hydrogen content increased with the $SiH_4$ flow rate the low pressure regime, but did not change in the high pressure regime. In the mid pressure regime, the hydrogen content increased first, reached a maximum, and then decreased as the flow rate increased. With the $SiH_4$ flow rate held constant, the hydrogen content always showed the highest value in the mid pressure range. This result implies that the content of atomic hydrogen in the film is determined by the competition between the supply of hydrogen radicals and the evolution of molecular hydrogen via surface reaction.

The maximum content of atomic hydrogen with which the laser crystallization could be performed without preliminary dehydrogenation process was estimated to be 2%. The process window that could produce films having less than 2% of hydrogen was calculated by extrapolating the response curve shown in Fig. 4. The chamber pressure and gas flow rate must be lower than 10 mTorr and 5 sccm, respectively, to ensure sufficiently low hydrogen content. This process window was confirmed by the FTIR analysis of the films prepared under such conditions. Also, the process region of good reflectance, which is shown in Fig. 3, matches closely with this process range.

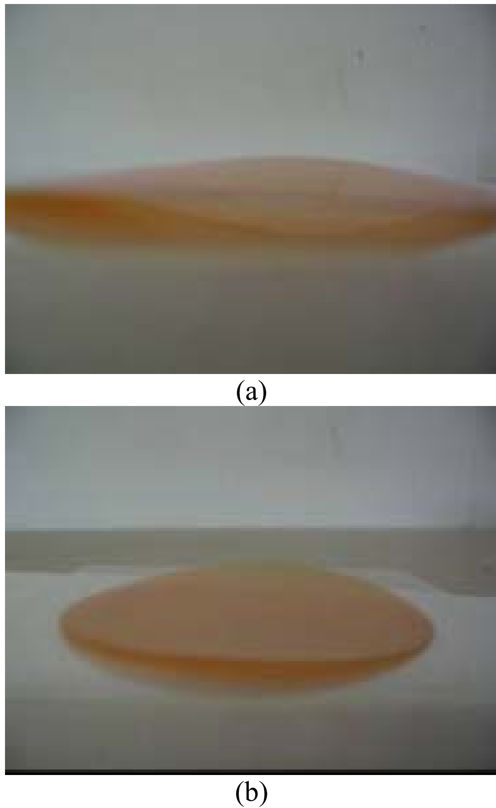
The films of low hydrogen content were crystallized with XeCl excimer laser without the preliminary dehydrogenation process. Formation of crystalline phase was confirmed by characteristic peaks near 280 nm and 370 nm of the UV reflectance spectra. Crystallization could be completed at a laser energy density that is as low as 90 $mJ/cm^2$.

Fig. 5 shows photographs of the silicon films deposited on PES substrates. Since the PES substrates have a very low mechanical stiffness, even a thickness of a few thousand angstroms can cause substrate bending, as shown in Fig. 5(a). Applying 2000Å of PECVD silicon nitride coating on both sides of the substrate can improve the stiffness, as shown in Fig. 5(b)

## 3.2 Deposition of Silicon Nitride Films

Silicon nitride thin films deposited by LPCVD or PECVD films are usually silicon-rich. These films usually exhibit a low refractive index and low electrical resistivity than those of the stoichiometric silicon nitride [7]. Atomic concentrations of nitrogen and silicon in the films deposited at various conditions

were estimated from the FTIR spectra, and the atomic ratio of nitrogen to silicon atoms (x = N/Si) of



(a)

(b)

Figure 5 Photographs of 1000Å-thick amorphous silicon films on PES substrates: (a) Si film on bare surface, (b) Si film on 2000Å-thick $SiN_x$ buffer layer

selected films are plotted in Fig. 6. The deposition parameters of the films shown in this plot are summarized in Table I. The Cat-CVD $SiN_x$ films are silicon-rich, but are closer to the stoichiometry than typical PECVD films.

Fig. 7 shows the relationship between the refractive index and the N/Si ratio in the Cat-CVD $SiN_x$ films. As the film composition becomes closer to stoichiometry, the refractive index also approaches to the tabulated value (2.01) of the stoichiometric compound. For comparison, the refractive index of the PECVD silicon nitride film prepared at 150°C was only 1.92 [8]. Data in Fig. 6 and in Table I also suggest that addition of nitrogen is critical to obtain a good N/Si ratio and refractive index.

PECVD silicon nitride used in semiconductor processing contains 20 to 25% hydrogen [7]. Usually, too much hydrogen in the deposited film reduces the film density and dielectric strength. Hydrogen content of the Cat-CVD films was estimated to be lower than 20%.

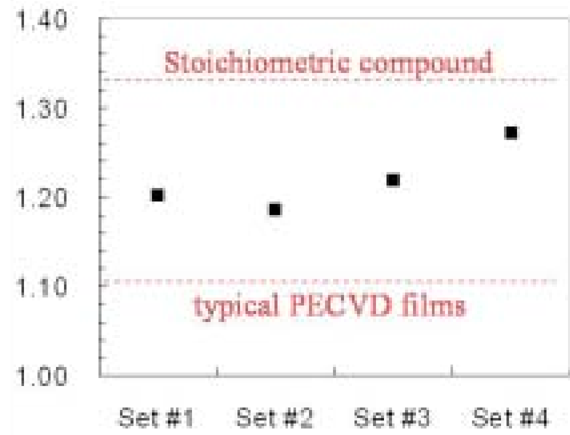



Figure 6 Atomic ratio of nitrogen to silicon (x = N/Si) in the deposited films

Table I Deposition parameters for Films in Fig. 6

| | $SiH_4$ (sccm) | $NH_3$ (sccm) | $N_2$ (sccm) | Pressure (mT) |
|---|---|---|---|---|
| Set #1 | 1.5 | 20 | 0 | 40 |
| Set #2 | 1 | 30 | 0 | 40 |
| Set #3 | 1.5 | 20 | 40 | 200 |
| Set #4 | 1.5 | 10 | 50 | 150 |

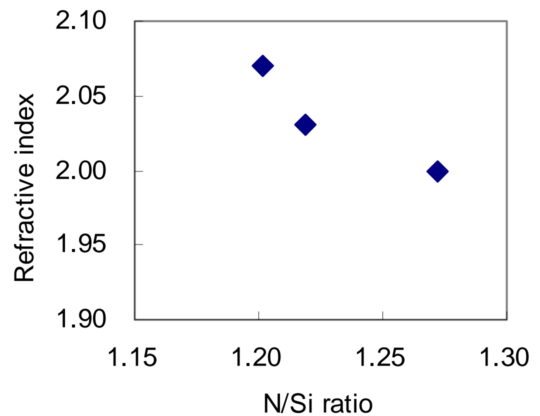



Figure 7 Change in the refractive index with the

composition of the deposited films

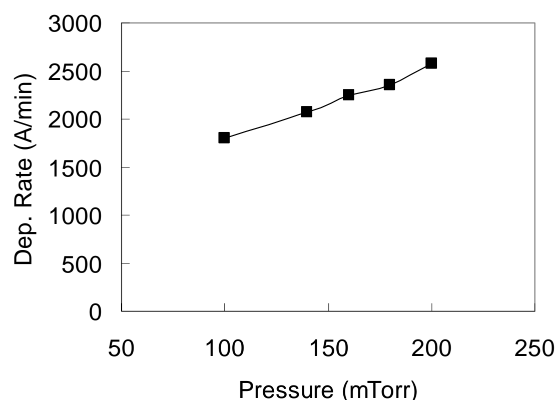



Figure 8 Change in the deposition rate with chamber pressure

I-V and C-V measurements were performed for a 1000Å-thick film deposited on a high-conductivity silicon wafer. A gold dot of 300 microns in diameter was used as the top contact. The breakdown field was determined to be 3 MV/cm. The C-V measurement showed that the relative permittivity ($\varepsilon_r$) of this film was ~5. These values are comparable to those of the films prepared at a substrate temperature of 250°C [9,10].

Fig. 8 shows the change in the deposition rate with chamber pressure. A deposition rate as high as 2500 Å/min. could be obtained, which is much faster than that of the PECVD.

## 4. Summary

Amorphous silicon films were deposited on plastic substrates by using the catalytic CVD technique at temperatures below 150°C. A very high deposition rate (~100Å/sec) was achieved, and the hydrogen content could be controlled effectively in the range of 1 ~ 5 %. Films having good adhesion, good surface morphology and sufficiently low content of atomic hydrogen could be obtained at process parameters of low chamber pressure and low gas flow rate. The resulting films were successfully crystallized using excimer laser without a prior dehydrogenation step.

$SiN_x$ films having good refractive index and N/Si ratio were successfully deposited by Catalytic CVD technique at substrate temperatures below 150ºC. The films also showed high deposition rates and a moderate breakdown field. The breakdown field is expected to be improved by optimizing the process parameters at the expense of the deposition rate. The Cat-CVD silicon and silicon nitride films can be good candidates for fabricating thin films transistors on plastic substrates to drive active-matrix organic light emitting display.

## 5. Acknowledgements

This work was supported by the 21c Frontier R&D Program, Korean Ministry of Science and Technology, under grant number M102KR010001-04K1801-01111. The authors thank Dr. Young-Soo Park at SAIT for valuable discussions and support.

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## 6. References

[1] R.M.A.Dawson, Z.Shen, D.A.Furst, and S.Conner, in *Society for Information Display/1999*, pp. 438 (1999)

[2] C.W.Han, S.J.Bae, J.Y.Lee, J.Y.Park, W.S.Choi, H.S.Soh, in *International Display Manufacturing Conference: Eurodisplay '99*, pp.27 (1999)

[3] R. Morimoto, A. Izumi, A Masuda, H. Matsumura, *Jpn. J.Appl. Phys.*, **41** 501 (2002)

[4] H.Wiesmann, A.K.Ghosh, T.McMahon, M.Strongin, *J.Appl.Phys*., **50** 3752 (1997)

[5] A.H. Mahan, J. Carapella, B.P. Nelson, R.S. Crandall, I.Balberg, J. *Appl. Phys.*, **69** 6728 (1991)

[6] A.Gallagher, *Thin Solid Films*, **395** 25 (2001)

[7] R.C.Jaeger, Introduction to Microelectronic Fabrication, 2nd Ed., Prentice Hall, pp.140 (2002)

[8] M.P.Hong, S.H.Yang, J.H.Seo, I.V.Nikulin, H.I.Jeon, W.J.Lee, S.I.Kim, K.Chung, The Proceedings of the 1st International TFT Conference, p.2 (Seoul, Korea, March 2005)

[9] S.B.Patil, A.Kumbhar, P.Waghmare, V.Ramgopal Rao, R.O.Dusane, *Thin Solid Films*, **395** 270 (2001)

[10] Y.Uchiyama, A.Masuda, H.Matsumura, *Thin Solid Films*, **395** 275 (2001)