50nm thick as-deposited poly silicon as an active layer of TFT for driving AM-OLEDs prepared at low temperature (<200℃) using Cat-CVD

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Abstract

The influence of various process parameters for the as-deposited poly silicon was investigated. The polycrystalline silicon films were successfully deposited on glass substrates at a low-temperature (<200℃) using the catalytic chemical vapor deposition (Cat-CVD). We achieved a low hydrogen content (~0.9%) and a high deposition rate (~35Å/sec). The film is applicable to thin film transistors on plastic substrates.

1. Introduction

Catalytic chemical vapor deposition (Cat-CVD) was utilized recently to obtain device quality thin films at low substrate temperatures without using plasma. Cat-CVD has attracted a great deal of attention as a fabrication technique for silicon thin films such as amorphous silicon (a-Si:H) and as-deposited poly silicon, having advantages of the high deposition rate and the capability to grow high-quality films with low hydrogen content [1,2]. A-Si:H has a capability of deposition in large areas at low costs, retaining its optical and electronic properties that are suitable for driving flat panel display. These facts make it a very promising technique for applications such as thin film transistors (TFTs), solar cells and thin film sensors [3]. However, because of meta-stability in a-Si:H, which deteriorates its properties upon light exposure or bias application, as well as its low carrier mobility, polycrystalline silicon (poly-Si) is currently being investigated as a strong candidate for a next generation material for many of these device applications [4]. Many groups have studied to obtain good quality as-deposited poly-Si films by varying the process parameters such as filament temperature, hydrogen dilution ratio and pressure [5,6]. However,

there are not many reports on very thin (<200nm) layers with minimal incubation layer. The channel layer thickness of thin film transistors (TFTs) is very important because leakage current is proportional to the silicon film thickness [7]. Therefore, we studied the properties of as-deposited poly-Si with various film thicknesses

2. Results

The as-deposited poly-Si films were prepared by using a catalytic chemical vapor deposition (Cat-CVD) system which is schematically illustrated in Figure 1. The tungsten wire was used as a catalyst and placed over the substrate at a distance of 50mm. The temperature of the tungsten wire was measured by a pyrometer. The temperature of the substrate was monitored by a thermocouple (TC) attached on the substrate holder.
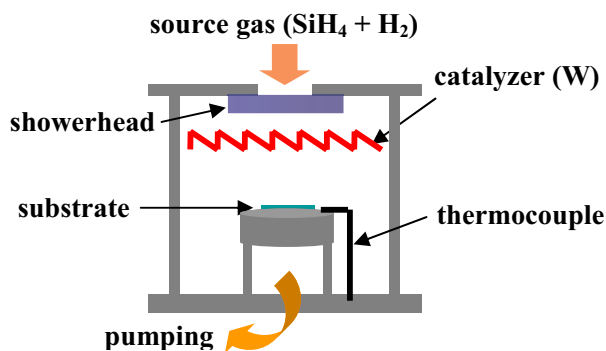

Figure 1 Schematic diagram of the Cat-CVD

First, we performed a series of experiments to clarify the influence of the Cat-CVD process parameters to the formation of crystalline phase in the silicon films. The main process parameters are listed in Table I.

Table I Process parameters for deposition of as-deposited Si films.

Variable parameters	Catalyzer temperature (℃)	1740, 2000, 2200
	Hydrogen dilution ratio (%)	60, 75, 90
	Gas pressure (mT)	20, 40, 60
	Film thickness (nm)	50,100,150, 200
Fixed parameters	Substrate temperature (℃)	190
	Catalyzer-substrate distance (mm)	50

The films were deposited on two kinds of substrates to investigate the characteristics of as-deposited Si films: eagle 2000 glass, for Raman scattering spectroscopy, Transmission electron spectroscopy (TEM), and silicon wafers for Fourier transform infrared spectroscopy (FTIR). The film thickness was determined by a surface profilometer (α-step).

The deposition rate is significantly influenced by both the hydrogen dilution ratio and process pressure. The crystallinity of the as-deposited poly-Si films was investigated by Raman scattering spectroscopy. The crystalline volume fraction (N_c) of the as-deposited poly-Si was estimated as follows:

$$N_c = (I_c+I_i)/(I_c+I_i+I_a)$$

Where I_a, I_i and I_c correspond to the integrated intensities of Raman peaks near 480, 510, 520cm^{-1}, respectively [9].

Crystalline volume fraction is significantly influenced by the filament temperature and the hydrogen dilution ration. Figure 2 shows the effect of filament temperature on the crystalline volume fraction.
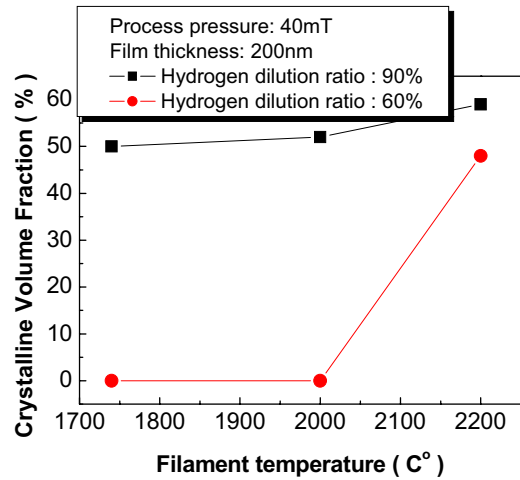

Figure 2 Crystalline volume fraction of the films as function of the filament temperature and the hydrogen dilution ratio.

It shows that crystalline volume fraction was increased with filament temperature. It could be due to the reason that the high filament temperature possibility makes more mono-silicon than the low filament temperature [10]. From the figure 2, it is revealed that crystalline volume fraction was hardly changed when filament temperature increased at hydrogen ratio 90%. The hydrogen dilution ratio had a larger effect on the crystalline volume fraction compared to the filament temperature. More detailed mechanism about the affection of hydrogen dilution ratio to crystalline volume fraction will be showed in figure 4.

Figure 3 shows the dependence of the deposition rate on the hydrogen dilution ratio and process pressure, respectively.
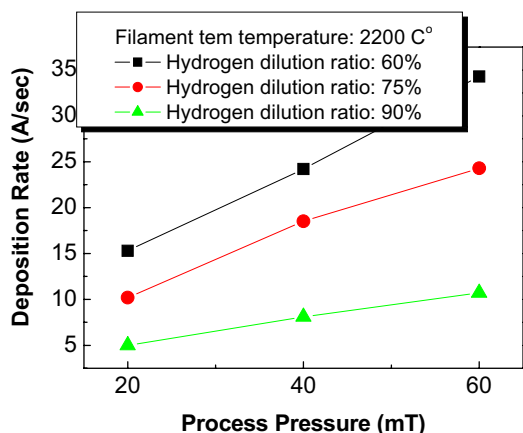
Figure 3 Dependence of deposition rate on the hydrogen dilution ratio and the process pressure

It is found from the figure that the deposition rate is increased by decreasing hydrogen dilution ratio and increasing process pressure. It was assumed that a large number of H radicals have etched the amorphous silicon network, and helped adhesion of fresh radicals in an ordered formation [6].

As the pressure increased, the source gas molecules have an increased probability of decomposition on the tungsten wire. Hence, the concentration of silane radicals has increased with increasing process pressure, leading to the increase in the deposition rate [8]. A deposition rate that was as high as 35Å/sec could be achieved at the hydrogen dilution ratio of 60% and the pressure of 60mT.

Figure 4 shows the crystalline volume fraction of the films deposited from various hydrogen dilution ratio and process pressure.
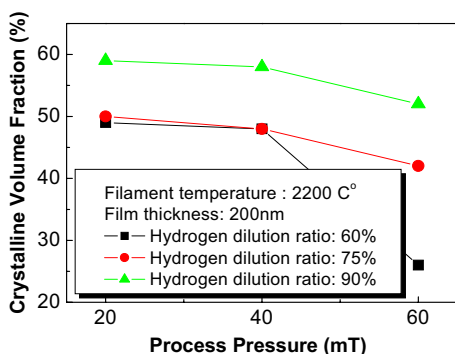

Figure 4 Crystalline volume fraction of the films deposited at 190℃ for various hydrogen dilution ratio and process pressure.

Enhancement of the crystalline volume fraction was observed as the hydrogen dilution ratio increased and process pressure decreased. It is hypothesized that the high hydrogen dilution ratio breaks silicon-hydrogen weak bonding, low process pressure forms stronger silicon-silicon bonding effectively. They increase the number of nucleation site for crystalline growth. In consequence, nucleation of small crystallite occurs directly on the substrate [10, 11].

H-content (C_H) of the films deposited for various hydrogen dilution ratio and pressure was also investigated by FTIR measurement [12]. C_H was in inverse proportion to crystalline volume fraction. We expected that these facts make the possibility to obtain high crystallinity even in silicon films that are thinner than 200nm.

Figure 5 shows the crystalline volume fraction for the samples deposited as a function of film thickness. Figure 6 shows TEM images of the silicon films having various thicknesses, which were plotted in Figure 5.
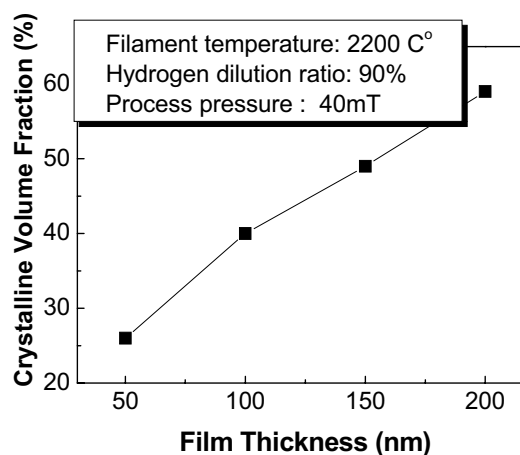

Figure 5 Crystalline volume fraction of the films deposited at 190℃ for various film thickness.

The crystalline volume fraction has been enhanced from 26% to 59% when the film thickness increased from 50nm to 200nm. Selected area electron diffraction (SAD) pattern and cross-sectional TEM images in Figure 6 show that the as-deposited Si films have the long columnar grain and the very thin incubation layer (~5nm) on the glass substrate. From Figure 6, it is considered that the thickness of incubation layer shows little change even though the total thickness of silicon film increased. It makes the overall crystallinity increase with the film thickness

increased. 50nm thick as-deposited Si films having a crystalline volume fraction of 26% has been successfully deposited at a low substrate temperature (<200℃) to apply to thin film transistors on plastic substrates.
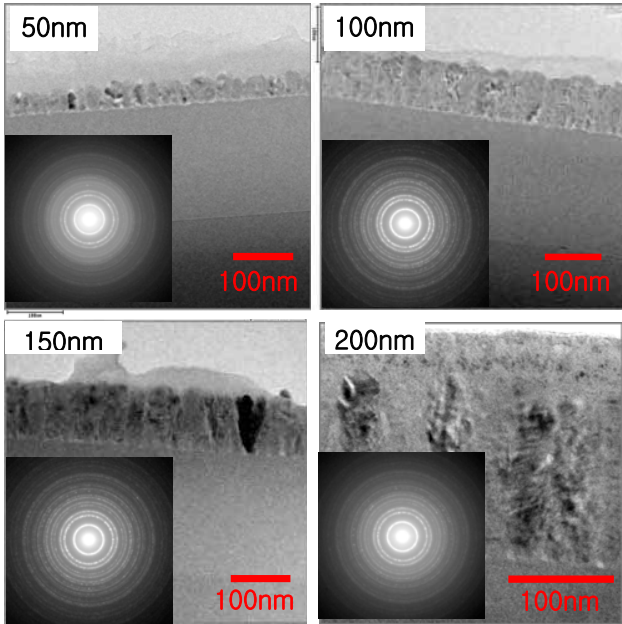

Figure 6 SAD pattern, cross-sectional TEM image of the films deposited at low temperature (<200℃).

3. Conclusion

As-deposited poly-Si films were prepared successfully at a high deposition rate (~10Å/sec) at process parameters of a high filament temperature, a high hydrogen dilution ratio and a low chamber pressure. The average grain size is 30 nm, and the grains in the films are very uniform (standard deviation: ~6%). The as-deposited film showed polycrystalline phase even as the thickness was reduced to 50 nm. The thin poly-Si layer is expected to result in a low leakage current, making itself a promising material as an active layer of thin film transistors for driving active matrix organic light emitting displays (AM-OLEDs) on plastic substrate.

4. Acknowledgements

5. References
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