Improvement in Characteristics of Thin Film Transistors by High Pressure Steam Annealing

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Abstract

High Pressure Annealing System was developed to improve the characteristics of low-temperature poly-silicon thin film transistors (TFTs). The high-pressure steam annealing was applied to the poly-silicon film made by rapid thermal annealing method. The carrier lifetime was investigated by Microwave detection of the Photo-Conductive Decay and the increase of carrier lifetime which indicates the reduction of the defect was observed by high-pressure steam annealing of 1MPa 600C 1hour.

1. Introduction

In recent years, development and mass production of low-temperature poly-silicon TFTs are progressing. In order to expand the application and product market, it is necessary to realize such a new advanced display as OLED in addition to LCD. For this purpose, not only the transistor performance of low-temperature poly-silicon (LTPS) TFTs but also the uniformity of the performance should advance.

As the improvement in the transistor performance is represented by high mobility, threshold voltage reduction and sub-threshold swing reduction, the uniformity is more important than the absolute value in particular in OLED. Although the drive circuit operation performance depends on the transistor of the worst performance, the individual TFT performance in pixel visually effects much more in OLED than in LCD.

In the present LTPS TFTs formation, a excimer laser anneal system is usually used. Generally, as irradiation energy density increases, the TFT performance of the poly-silicon film is getting better. However, the film quality is quite sensitive for the changes in irradiation energy density. In fact, the superposition of the linear excimer laser beam forms the thin poly-silicon film on a glass substrate. The quality of the film is affected by the fluctuation of the laser pulse shot by shot and the inhomogeneity of the optics at the same time. Actually, it is very difficult to achieve the uniformity that satisfies the quality of manufacturing level in an OLED large-sized glass substrate.

Against a background of these situations, solid phase crystallization (SPC) has been reconsidered in stead of laser crystallization. Rapid thermal annealing (RTA) technology is one of the SPC solutions for a large glass substrate because it is expected to solve such issues as long process time and glass damage in manufacturing. We have developed a high-pressure anneal system (HPA) for reduction of defects in p-Si [1,2] and a rapid thermal annealing system(IHI-RTA) for a large glass substrate [3]. In this paper we report HPA effect in p-Si crystallized by RTA.

2. Equipment

The experimental sample was prepared by using IHI-RTA in crystallization and then annealed by HPA.

2. 1 Rapid thermal annealing system

IHI-RTA consists of anneal chamber and shutter module.

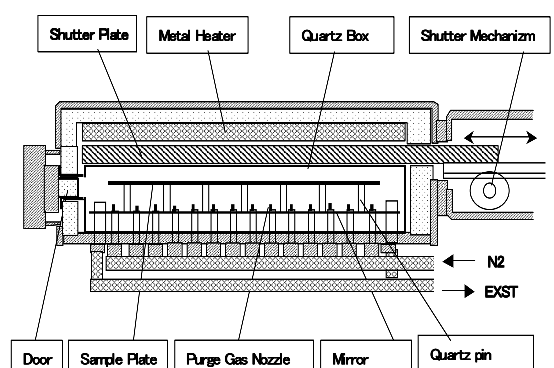

Fig.1 Outline drawings of Rapid Thermal Anneal system

An annealing chamber is composed mainly of metal heaters and quartz chamber modules. Heater modules are located upside of the annealing chamber and the heater gives heat radiation to a glass substrate through the cap plate of the quartz box. Heat insulation materials crowds round a quartz box. A substrate is loaded and unloaded from the quartz door left side made by quartz. The inside of the quartz box is filled with N2 gas that is purging from the bottom side of the chamber during annealing.

The glass substrate receives not only anneal-heat topside from heaters but also reflection heat bottom side from mirror plates. The both sides of heating make high annealing efficiency and a small temperature uniformity error for the actual annealing performance. In case of normal annealing like activation, the glass substrate is supported from the bottom side by quartz pins of which spacing is optimized to minimize the glass deformation by the annealing impact. In this experiment, an additional quartz setter plate is used to support the glass substrate for the prevention from glass deformation by high temperature conditions as 680-750C.

IHI-RTA uses a shutter plate to rise up and cool down the chamber quickly in annealing cycles. The shutter plate is located between heater modules and the top of the quartz box. The shutter plate prevents from the heat radiation of the heaters when the substrate is not in heating. The temperature rise started when the shatter plate move out of the anneal chamber, and the cool down started when the shutter plate move into the anneal chamber.

IHI-RTA can provide the step-wise temperature profile inside chamber. Figure 2 shows typical temperature profile of 2-step function.

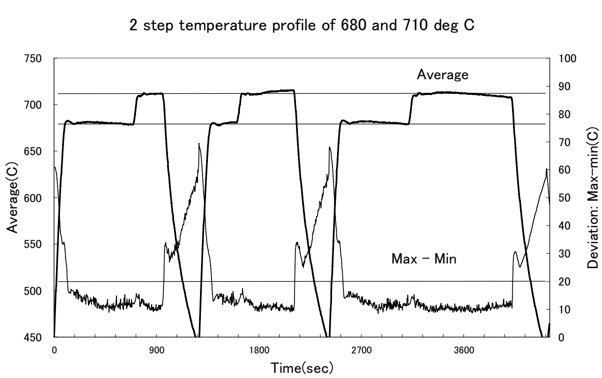

Figure 2 Typical temperature profile of IHI-RTA

2. 2 High-pressure annealing system

The outline figure of HPA is shown in Figure 3, which is developed using the principle that the oxidization speed rises in proportion to pressure. The system is a vertical type furnace arranged in a metal Pressure Vessel, and consists of a double structure of the Pressure Vessel and a reaction chamber made from quartz (Quartz Vessel). Steam or nitrogen is charged into the Quartz Vessel to apply pressure up to 2MPa, and air into the outer portion of Quartz Vessel to apply same pressure to reduce the stress of the vessel. The glass substrate is set on the cassette made from quartz (Quartz Cassette) in Quartz Vessel, and has structure in which metal impurities cannot contaminate during anneal process.

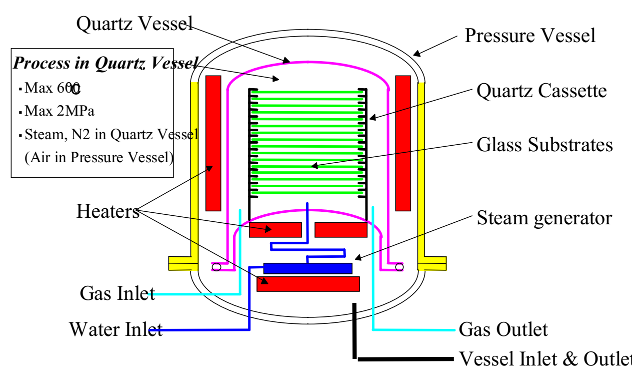

Figure 3 Outline drawings of High Pressure Anneal system.

A typical process chart is shown in Figure 4. The system performs heating and pressuring to 600C and 2Mpa, holding the state during a predetermined constant, cooling with nitrogen substitution after processing, and finally depressurizing.

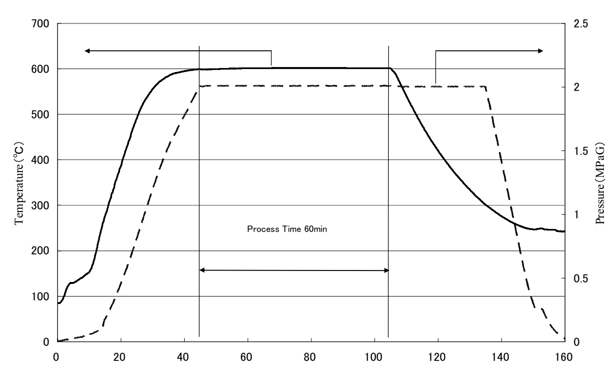

Figure 4 Typical process chart of HPA

3. Results and discussions

The initial poly-silicon film was investigated before HPA treatment. The rapid thermal annealing method by IHI-RTA was used for SPC to reduce the glass damage in poly-silicon formation. The best SPC condition for HPA treatment was chosen after the crystallinity evaluation.

At the beginning Raman scattering spectroscopy is observed for the evaluation for SPC. Figure 5 shows Raman spectrum sample of amorphous silicon deposited on the glass substrate after annealed by IHI-RTA. In this case the annealing temperature is fixed at 730C and the annealing time at fixed temperature was changed from 1min to 10min. Comparing to the film as deposited, a peak signal in wave number of 518 cm-1 increases with the annealing time. Contrary, a peak signal in wave number of 480 cm -1 decreases with time. The peak counts of 518cm-1 and that of 480cm-1 are considered to represent the fraction of the generated poly-silicon and the residual amorphous silicon respectively. Thus it is confirmed that the peak ratio of 518cm-1 to 480cm-1 is one of the measures to evaluate the crystallinity in the poly-silicon film. The ratio of poly-silicon to amorphous silicon refers to p-Si/a-Si.

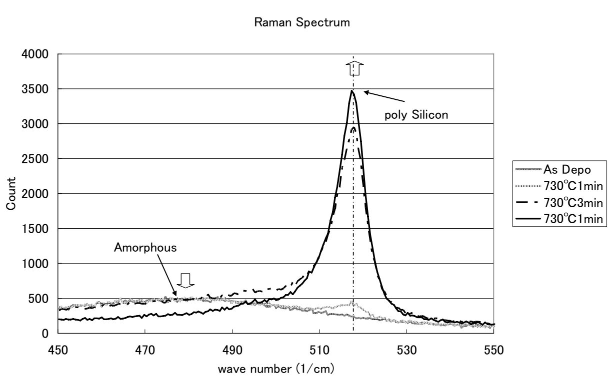

Figure 5 Raman scattering spectrum of amorphous-silicon after IHI-RTA

As the temperature of 730C is considerably high for glass deformation, the realistic annealing condition in manufacturing should be applied for this experiment. We have provided poly-silicon samples of the several conditions by changing the annealing temperature, time and method to prove the SPC conditions before HPA treatment. Figure 6 shows the annealing conditions and the p-Si/a-Si ratio calculated by Raman spectrum. The amorphous silicon of 50nm thickness is used as precursor. As shown in the figure, the ratios of 3 conditions of 710C-15min, 730C-10min, and step-wise annealing of 680C-10min and 710C-10min have reached almost same value so that the fraction of poly-silicon is considered to be saturated by this SPC method. After visual checking of glass edge, the step-wise annealing of 680C-10min and 710C-10min is the best annealing condition of glass deformation in this experiment.

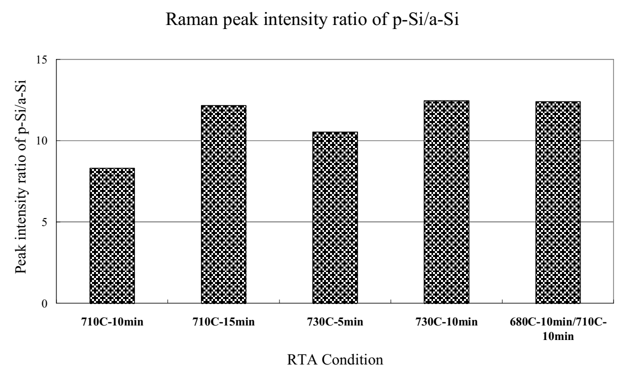

Figure 6 Peak intensity ratio of p-Si/a-Si of RTA

Secondary, all samples have been measured by Microwave detection of the Photo-Conductive Decay: μ-PCD for the evaluation of the carrier lifetime that is inversely proportional to defect density in the film. Figure7 shows μ-PCD signal intensity which is proportional to the carrier lifetime of the film.

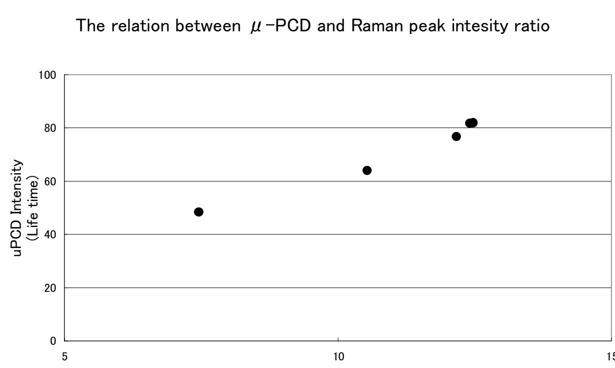

Figure 7 Relation between μ-PCD and Raman peak intensity ratio of p-Si/a-Si

The x-axis shows p-Si/a-Si ratio of all SPC samples and the y-axis the intensity of μ-PCD. The figure indicates the carrier life time correlates with the fraction of poly-silicon represented by p-Si/a-Si ratio and it is confirmed that μ-PCD is one of the good measures for the crystallinty evaluation.

Finally the poly-silicon samples are applied by HPA treatment. Both Raman scattering spectrum and μ-PCD were measured after HPA treatment. No significant change in p-Si/a-Si ratio of Raman spectrum was shown but all the signal intensity of μ-PCD was observed to change triple or more after HPA treatment. This result indicates the fraction of poly-silicon in the film has not changed but the amount of defect in the film decreased.

Figure 8 shows the change of μ-PCD intensity of the step-wise annealing of 680C-10min and 710C-10min of IHI-RTA by HPA treatment of 3 conditions. The HPA conditions are 2MPa 600C of 10%steam in nitrogen, 1MPa 600C and 1MPa 580C steam of 1 hour annealing. The signal was measured twice after HPA treatment. The change was compared before and after silicon oxidation stripping by HF.

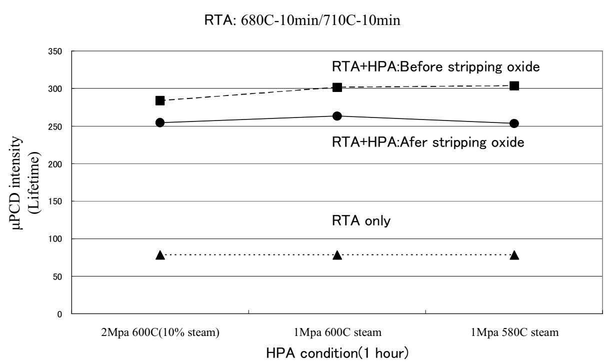

Figure 8 Evaluation result of μ-PCD after HPA treatment

As the signal was reduced by oxidation film stripping, the signal was weakened by the defects of the surface. This indicates the carrier life time was increased as HPA inactivates the defects by forming the oxidation film on the surface of poly-silicon and the interface inside poly-silicon. The effect of signal enhancement remains after oxidation stripping. The reduction of the signal is around 20% or less in 3 HPA conditions. This suggests HPA reduces the defects not only on surface but also inside the poly-silicon film. As comparing to the HPA conditions, the signal of 1MPa 600C steam pressure is slightly higher than that of 2MPa 600C 10% steam and that of 1MPa 580C steam after HF etching. The difference is considered more, if the reduction of the film thickness is taken into account. The reduction of poly-silicon film is estimated 15-20% and 10-12% at 1MPa 600C, 580C steam annealing of 1 hour respectively. Since the film thickness correlates with μ-PCD signal intensity, the signal of 1MPa 600C should be interpreted as the longest carrier life time of these 3 conditions.

3. Conclusion

The crystallinity of the poly-silicon crystallized by rapid thermal annealing of IHI-RTA and HPA treatment was investigated by Raman scattering spectrum and Microwave detection of the Photo-Conductive Decay. The increase of carrier life time was observed after high-pressure steam annealing. This indicates that the defects in the poly-silicon were reduced by steam annealing. High-pressure steam annealing is expected to be one of the effective solutions for the improvement of TFT transfer characteristics.

4. References

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