Effective Annealing and Crystallization of Si film for Advanced TFT System

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Abstract

The crystallization and activated annealing effect of Si films using an excimer laser and a new CW blue laser are described comparing with furnace annealing (SPC) for the application of advanced TFTs and future applications. Currently, pulsed ELA is used extensively as a LTPS process on glass substrates as the efficiency is high in UV region for thin Si film of 40- 60 nm thickness. ELA enables extremely low resistivity for both n- and p-typed Si films. On the other hand, CW BLDA enables the smooth Si surface having arbitral grains from micro-grains to anisotropic huge grain structure only controlling its power density.

1 Introduction

Si TFT has been developed remarkably in the last 25 years and plays an important role for FPD application. To realize a high performance AM FPD, poly Si TFTs are the most reliable device. Poly Si TFTs have been developed for rather small LCD panel of high resolution with periphery circuit on glass substrates. So far, laser annealing as well as furnace annealing have been studied extensively to crystallize and to activate thin-Si films. In order to realize and develop further advanced AM FPD system including OLED driving, laser annealing techniques are effective and are still expected to obtain higher performance TFTs by adopting advanced LTPS process on glass and on flexible panel.

SPC at around 600˚C heating was studied intensively before the trial of ELA or ELC for low temperature process on glass because of the large grains with keeping the Si surface smooth. [1, 2] Subsequently, the LTPS TFT on low-cost glass was applied to LCD panel by adopting ELC technique, and is expected to develop to highly functional SoG (System on Glass). [3] Obtained crystallinity of poly-Si grains after ELC is much higher than SPC as shown in Fig.1 and in Table 1. [4] Following a trend of lowering the voltage and shrinkage of device size for stacked SRAM (Static Random Access Memory) application in Si LSIs, uniformity issue becomes serious. In order to improve the uniformity of TFT performance, size controlled grain growth technique in low temperature process has been designed for the small size device. [5] As an advanced FPD panel, AM O-LED (Organic Light Emitting Diode) is expected. In this case, micro-poly-Si TFTs of stable characteristic have an advantage in pixel driving. [6] Simple and stable grain-size control is wanted depending on the TFT application. On the other hand, in order to realize flexible FPD system, many efforts are being done on further reduction of the process temperature. [7, 8]

In order to realize an advanced FPD panel, although ELC is a powerful and an efficient process for high mobility TFTs having large size of grains, more stable and high power annealing with highly efficient absorption for the thin Si films are required. As newly developed high-power semiconductor Blue-Multi-Laser Diode is stable and the absorption at 445 nm wavelength is higher than at 532 nm for polycrystalline thin Si film of 50 nm thickness as shown in Fig.2, stable and flexible crystallization or uniform annealing process of controllable grain size is expected. [9, 10]

2 Effective crystallization Techniques

2.1 SPC

After furnace annealing of high quality amorphous Si film at about 600˚C, remarkable grain growth occurs. Lower the SPC temperature, larger the grain size as the nucleation is lower. [1] Smooth surface

with dendrite Si grains as large as 1μm can be obtained. By fabricating poly-Si TFT using SPC process at 600˚C, fairly high mobility of 60 cm^2/V.s. was obtained. [11] By performing the subsequent high temperature annealing or thermal oxidation, electronic properties improve as a result of decreasing the defects density in the grain without enlarging the grain size. [2]

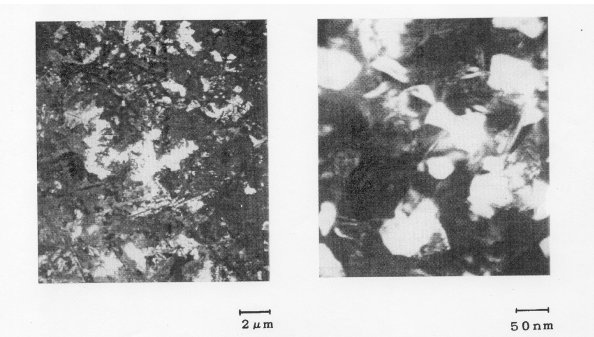
2.2 ELC and ELA

As a result of performing single pulsed ELA onto dendritic poly-crystallized Si films obtained subsequently after SPC, the film properties improves by an instantaneous heating at high temperature as the Si film has a high absorption coefficient in UV region. [12] If the UV pulse beam is irradiated directly onto thin amorphous Si films, drastic crystallization occurs. As the duration time of excimer laser pulsed beam is too short, typically, a few tens of nano-seconds, the under substrate such as glass does not receive any thermal damage. Therefore, ELC or ELA is, practically, a low temperature compatible process. The crystallization behaviour depends on the initial quality of amorphous Si films and on the under layer structure, the reached grain size is influenced not only by the energy density but also by the shots number. [13] Although crystallization of Si film for ELA has been studied intensively [14, 15], further research on the precise mechanism should be explored related to the quality of initial amorphous Si film. In the case of ELC for the Si film with a thermal slope in plane, remarkable lateral growth is occurred. And, in general, the crystallized poly-Si films after ELC receives tensile stress. [16]

For a self-aligned formation of S/D (Source and Drain) through gate, low resistance is required to realize high performance TFTs and for fine patterned MOS FETs. Efficient activation of doped Si film can be attained by SPC, RTA (Rapid Thermal Annealing) or by adopting excimer laser processing. [17, 18] In particular, ELA is expected as a promising technique for dopant activation. Electrical activation of Si film, which was performed ELA subsequently after impurity doping using ion shower, was evaluated. With the increase in the pulse energy density and in the shot number, the extremely low sheet resistance can be obtained both for heavily doped n-type (phosphorus), and for p-type (boron) case, respectively, as shown in Fig. 3. [19, 20] In the lower pulse energy condition, although a segregation at the grain boundaries or other phenomena peculiar to highly-doped poly-Si film after thermal annealing should be taken into account for the higher shot number, precise study is required. [21] Above the pulse energy density of 350 mJ/cm^2, the resistivity decreased by an increase in the shot number. [19] In this condition, the growth is speculated to be accelerated by a surface energy-driven-like grain growth. It was found that the decrease in resistivity corresponds to the improvement of crystallinity by using Raman scattering and by S.E. (Spectroscopic Ellipsometry) analysis. The high activation efficiency in laser annealed poly-Si film of heavily doped case is comparable to the result of doped single-crystalline bulk-Si in the thermally equilibrium condition.

Table 1 Comparison of Effective Crystallization (O: Good, X: Poor)

	SPC	ELC	(MIC)
Grain size	O	Δ	O
Crystallinity	Δ	O	Δ
Flatness	O	Δ	
Uniformity	O	Δ	
Throughput	X	O	Δ
Growth model	O	Δ	
Process temperature	~600℃	<400℃	~500℃



(a) SPC (600℃) (b) ELC (Single shot)

Fig.1 Comparison of grain structure in Si films after two crystallizations. (TEM images) [4]

2.3 BLDA (Blue-Multi-Laser Diode Annealing) [9,10]

In Fig.2, the absorbance spectra are shown for the Si films of 50 nm thickness before and after BLDA. By assisting the interference effect, the absorbance at 445 nm is fairly high both for amorphous and poly-crystallized films as well as at 308 nm. Therefore, as a result of irradiating the laser beam of controlled power and beam-shape, the amorphous Si films are poly-crystallized efficiently and stably.

Images of the grain structure observed by TEM for the each controlled laser power are seen in Fig. 4. For the films annealed by lower power of 5W, rather small crystallized grains are observed as is shown in Fig. 4 (a). If the power is controlled below 5W, micro-poly

Si films of uniform grain size, which is required to TFTs for Organic Light Emitting Diode (OLED) driving, are expected [6]. Crystallized Si films of micro-grains are considered to be superior in term of reliability than those obtained by direct deposition as the grain structure including grain boundaries should be improved by heating at high temperature. If the laser power is increased up to 6W, drastic isotropic grain growth occurred as shown in Fig. 4 (b). By using the large poly Si films, high performance TFTs of high mobility are expected.

In the case of fairly higher laser power condition, the crystallized Si films have anisotropic structure of large grains as shown in Fig. 4 (c). The grains seem to be expanded along the beam scanned direction similar to the result by using CW green laser (532 nm) crystallization [22]. In this advanced grain structure, much higher mobility is expected if TFTs are fabricated along the longer grain direction for an application to peripheral circuits as SoG. As the blue laser (455 nm) has a higher absorbance than green laser for a-Si film as well as for poly-Si, efficient crystallization for the Si films can be realized with effective heating and much higher crystallinity is expected.

For the doped Si films, result of the sheet resistance is shown in Table 2. As the exposed power is increased, i.e. as higher the crystallinity or larger the grain size, the resistance decreases. For the 8W annealing case, extremely low value as low as 84 ohm/□ is obtained. In the case of 8W case, the sheet resistance value is close to the value by optimizing the shot condition by pulsed ELA. (Fig. 3) In this case, the activation ratio for the annealed film is close to the case of bulk single-crystalline Si. The behavior of the electrical data corresponds to the crystallinity.

3 U-LTPS as a reduction of process temperature for plastic panel

By reducing the process temperature down to 200°C or below and by improving the fabrication process as a U-LTPS process, stable TFT characteristic is obtained on PES (Poly-Ether-Sulphone) plastic substrate. In this case, initial amorphous Si was deposited by using r.f. sputtering. By selecting the sputter gas of Xe (or He) in place of Ar, high purity (low impurity) amorphous Si film was obtained at R.T. (Room Temperature), as a result, subsequent ELC can be performed stably. [7, 19] A direct fabrication of poly Si TFTs for AM-OLED FPD by using U-LTPS by laser crystallization is expected on flexible panel. [23]

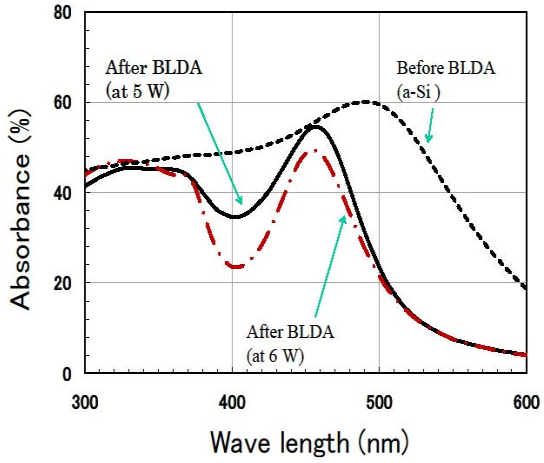


Fig. 2 Absorbance for the Si film of 50 nm thickness before and after BLDA. [9]

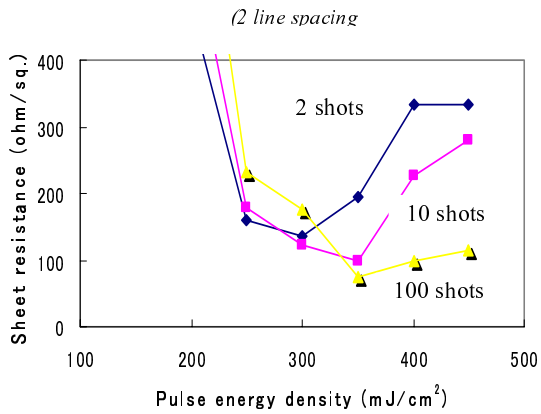


Fig. 3 Dependence of sheet resistance on pulse energy density for various laser shot number.
(Phosphorus doped at a dose of 2E15 cm^{-2}) [19]

4 Summary

The effective crystallization results of Si films were briefly described. Current ELA or ELA is an efficient and powerful tool of LTPS applicationsusing high performance TFTs. Also, stable BLDA is expected to be developed to future applications. In order to develop the advanced SoP (System on Panel), uniform and smooth Si films having arbitral grain size from micro-poly-crystalline to single-cystalline phase are expected.

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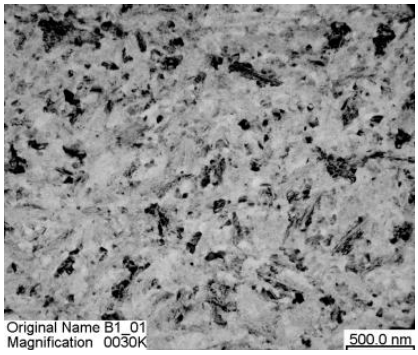
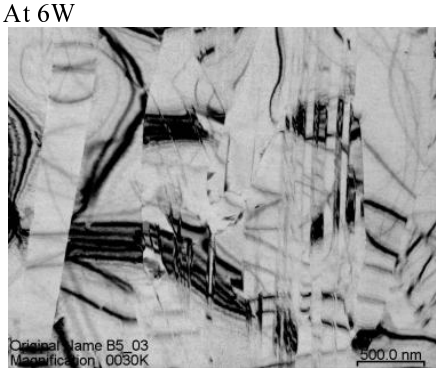


(a) At 5W

(b) At 6W



(c) At 8W

Fig. 4 Plan view of TEM image for the controlled power of blue laser. [10]

Table 2 Sheet resistance obtained by four-point probe for doped Si film after BLDA ($_{Phos.\ dose:\ 2\ x10^{15}\ cm^{-2}}$)

Laser power (W)	Sheet resistance (ohm/□)
5	260
6	108
8	84

5. References

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