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Effective Annealing and Crystallization of Si Film for Advanced TFT System

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Abstract

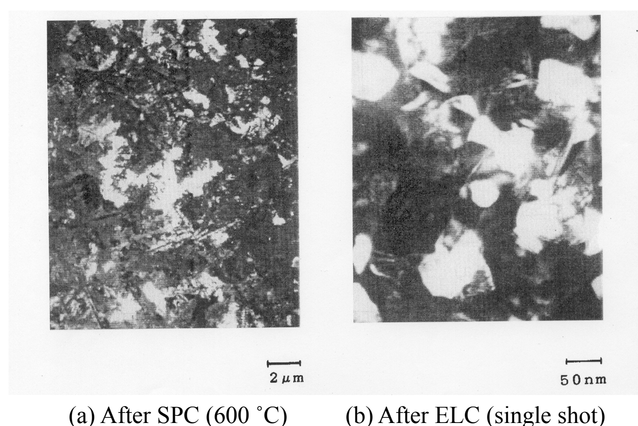
The effect of the crystallization and activated annealing of Si films using an excimer laser and the new CW blue laser are described and compared with furnace annealing for application in advanced TFTs and for future applications. Pulsed excimer laser annealing (ELA) is currently being used extensively as a low-temperature poly-silicon (LTPS) process on glass substrates as its efficiency is high in the ultra-violet (UV) region for thin Si films with thickness of 40-60 nm. ELA enables extremely low resistivity relating to high crystallinity for both the n- and p-type Si films. On the other hand, CW blue laser diode annealing (BLDA) enables the smooth Si surface to have arbitral crystal grains from micro-grains to an anisotropic huge grain structure only by controlling its power density. Both annealing techniques are expected to be applied in the future advanced TFT systems.

Keywords: Poly-Si, Si film, Crystallization, ELA, ELC, BLDA, TFT

1. Introduction

Si TFTs have been developed remarkably in the last 25 years and play an important role for active-matrix flat panel display (AM FPD) application. Poly-Si TFTs are the most reliable devices that can be used to realize a high performance FPD. Poly-Si TFTs have been developed for small-sized high-resolution LCD panels with peripheral circuits on glass substrates. So far, the laser and furnace annealing processes have been studied extensively for the crystallization and activation of thin-Si films. For the realization and further development of an advanced AM FPD system that includes organic light-emitting diode (OLED) driving, laser annealing techniques are effective and are still expected to obtain higher-performance TFTs by adopting an advanced LTPS process on glass and even on a flexible panel.

Solid phase crystallization (SPC) at around 600˚C heating has been actively studied for the Si films as a low-temperature process on glass, before the trial of ELA or excimer laser crystallization (ELC) because it allows large grains to be obtained while maintaining the smoothness of the Si surface [1, 2]. Subsequently, an LTPS TFT on low-cost glass was applied to an LCD panel via the ELC technique, and it is expected to be developed into a highly functional system-on-glass (SoG) [3]. The obtained crystallinity of the poly-Si grains after ELC was much higher than that after SPC, as shown in Fig. 1 and in Table 1 [4]. Following the trend of lowering the voltage and shrinkage of the device size for stacked static random-access memory (SRAM) application in Si LSIs, the uniformity issue for the TFT characteristics has become serious. To improve the uniformity of high performance TFTs, a size-controlled grain growth technique in the low-temperature process has been proposed for small size devices [5]. Currently, AM OLED is expected to be developed into an advanced FPD panel. In



(a) After SPC (600 ˚C) (b) After ELC (single shot)

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

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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℃

this case, micro-poly-Si TFTs with stable characteristics have an advantage in terms of pixel driving [6]. Simple and stable grain-size control is desirable depending on the TFT application. On the other hand, to realize a flexible FPD system such as that on a plastic panel, efforts are being made to further reduce the process temperature for the LTPS process [7, 8].

To realize an advanced FPD panel, although ELC is a powerful and efficient process for high-mobility TFTs with a large grain-structure size, a more stable and higher-power annealing process with highly efficient absorption for thin Si films is required. As the newly developed high-power semiconductor blue-multi-laser diode is stable and as its absorption at the 445 nm wavelength is higher than that at 532 nm for 50-nm-thick polycrystalline thin Si films, as shown in Fig. 2, stable and flexible crystallization or a uniform annealing process of a controllable grain size is expected [9, 10].

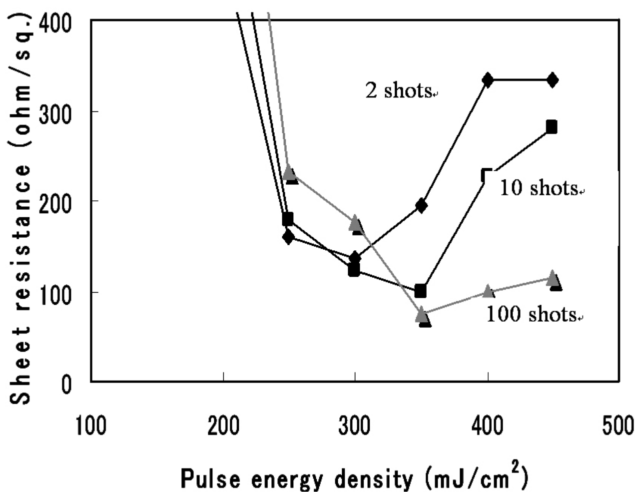


Fig. 2. Dependence of sheet resistance on pulse energy density for various laser shot numbers (phosphorus was doped at a dose of $2x10^{15}$ cm^{-2}) [19].

Table 2. Sheet resistance obtained via four-point probe for the doped Si film after BLDA (phosphorus dose: $2x10^{15}$ cm^{-2})

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

2. Effective Crystallization

2.1 SPC

After the furnace annealing of a high-quality amorphous Si film at about 600˚C, remarkable grain growth occurred based on the homogeneously suppressed nucleation in the thin film. It was found that the lower the SPC temperature is, the larger the grain size, as the nucleation is lower [1]. A smooth surface with dendrite Si grains as large as 1μm in diameter can be obtained. Moreover, by fabricating a poly-Si TFT through the SPC process at 600˚C, a fairly high mobility value of over 60 cm^2/V.s. can be obtained [11]. By performing subsequent high-temperature annealing or thermal oxidation for the films with dendrite grains, the electronic properties were further improved as a result of the decrease in the defects density of the grains, without enlarging the grain size [2].

2.2 ELC and ELA

As a result of the performance of single-pulsed ELA onto dendritic poly-crystallized Si films obtained after SPC, the film properties improved through instantaneous heating at a high temperature as the Si film has a high absorption coefficient in the UV region [12]. The absorption coefficient of the Si film in the UV region is as high as 10^6 cm^{-1}. If the UV pulse beam is irradiated directly onto thin amorphous Si films, drastic crystallization will occur. As the duration of the pulsed excimer laser beam is very short, typically a few tens of nanoseconds, the substrate, such as glass, under the films does not receive any thermal damage. Therefore, ELC or ELA is a practical low-temperature and compatible process. The crystallization behavior depends on the initial quality of the amorphous Si films and on the

under-layer structure, and the maximum attainable grain size, is influenced not only by the energy density but also by the number of shots [13]. Although the crystallization of the Si film via ELA has been studied intensively [14, 15], further research on its precise mechanism should be conducted particularly with regard to the quality of the initial amorphous Si film. In the case of ELC for the Si film with a thermal slope in a plane, remarkable lateral growth occurs, and, in general, after ELC, the crystallized poly-Si films receive tensile stress [16].

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

2.3 BLDA

In Fig.3, the absorbance spectra are shown for the 50-nm-thick Si films before and after BLDA [9]. With assistance given to the interference effect, the absorbance at 445 nm became fairly high both for the amorphous and poly-crystallized films, as well as at 308 nm (for the XeCl excimer laser). Therefore, due to the irradiation of the laser beam with controlled power and a beam-shape at this wavelength, the amorphous Si films should be poly-crystallized efficiently and stably, as in the ELA case.

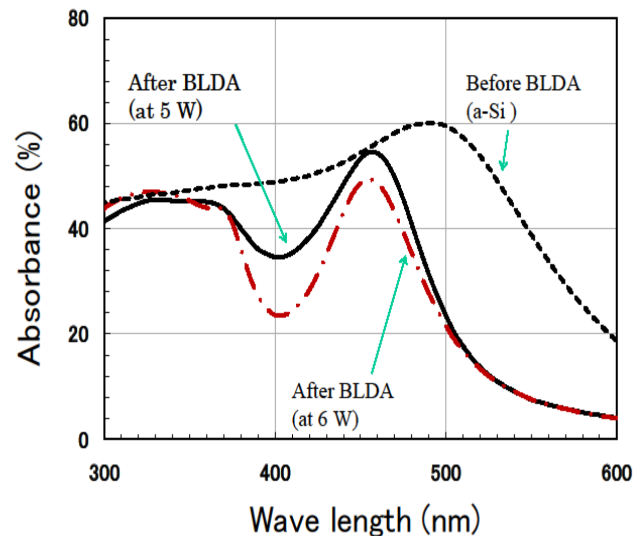
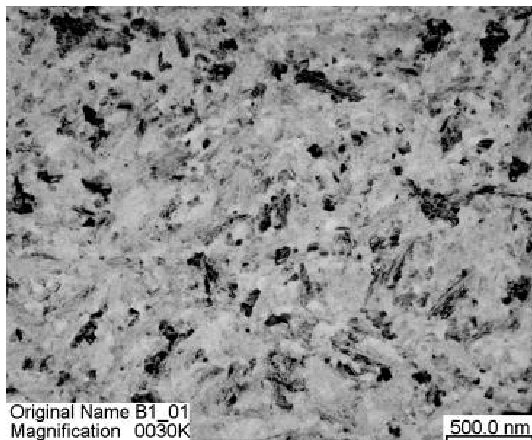


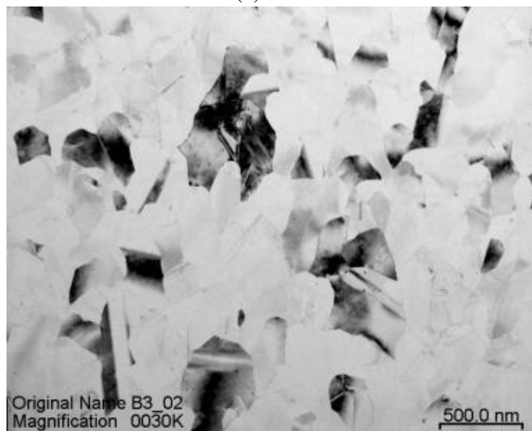
Fig. 3. Absorbance spectra for the 50-nm-thick Si films before and after BLDA [9].

Images of the grain structure in Si films observed via TEM for each controlled laser power as a result of BLDA are shown in Fig. 4. [9] For the films annealed by a lower power of 5 W, small crystallized grains were observed, as shown in Fig. 4(a) [10]. If the power is controlled below 5 W, micro-poly Si films of uniform grain size, which are required for TFTs for organic OLED driving, are expected to be realized [6]. Crystallized micro-grain Si films are considered superior in terms of reliability than those obtained via direct deposition as the grain structure, including the grain boundaries, should be improved by heating a at high temperature. When the laser power was increased to 6W, drastic isotropic grain growth occurred, as shown in Fig. 4 (b). The use of poly-Si films of large grain size is expected to yield high-performance TFTs with high mobility.

In the case of the fairly higher laser-power condition, the crystallized Si films showed an anisotropic structure of large grains as can be seen in Fig. 4(c). The grains seem to have expanded along the beam scanned direction, similar to the result of the use of CW green laser (532 nm) crystallization [22]. Moreover, the resultant surface after BLDA was fairly smooth. In this advanced grain structure, a much higher mobility is expected applicable to advanced peripheral circuits as SoG systems if the channels of TFTs will be fabricated along the longer grain direction As blue laser



(a) 5 W



(b) 6 W

(c) 8 W

Fig. 4. Plane view of the TEM images for the controlled power of the blue laser [9].

(455 nm) has a higher absorbance than green laser for a-Si films and poly-crystallized Si, the efficient crystallization of Si films can be realized with effective heating and a much higher crystallinity is expected.

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

2.4 U-LTPS as a reduction of the process temperature for plastic panels

By reducing the process temperature down to 200˚C or below and by improving the fabrication process to make it an ultra-LTPS (U-LTPS) process, stable TFT characteristics were obtained on the poly-ether-sulphone (PES) plastic substrate. In this case, initial amorphous Si was deposited via r.f. sputtering. By optimizing the deposition condition, such as by incorporating the sputter gas of Xe or He in place of Ar, a high-quality or desirable amorphous Si film was obtained at room temperature. As a result, subsequent ELC can be performed stably [7, 19]. The direct fabrication of poly-Si TFTs for the AM-OLED FPD using U-LTPS via laser crystallization is expected to be done for flexible panels as well as for glass panels [23]. By further improving the process conditions including the laser crystallization, a simpler and more stable process is expected to be developed.

3. Summary

The effective crystallization results of Si films were briefly described and discussed. Currently, ELA or ELC is the most efficient and powerful tool of LTPS applications using high-performance TFTs. On the other hand, stable BLDA is also expected to be developed for future applications. To realize an advanced system-on-panel (SoP), uniform and high-quality Si films with micro-grains to larger grains should be studied in detail and are expected to be applied based on the powerful, stable and reliable laser annealing techniques.

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