Poly-Si TFT Fabricated at 170°C Using ICP-CVD and Excimer Laser Annealing for Plastic Substrates

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Abstract

We have fabricated poly-Si TFTs at 170°C using inductively coupled plasma chemical vapor deposition (ICP-CVD) and excimer laser annealing (ELA). A Poly-Si film with large grains exceeding 5000Å and a SiO_2 film with high breakdown field are deposited by ICP-CVD. A high mobility exceeding 100cm^2/Vs with a low sub-threshold swing of 0.76V/dec was obtained.

1. Objectives and Background

Recently, flat panel displays on plastic substrate have attracted considerable attentions due to the robustness, lightweight and flexibility as well as low cost (1). The conventional processes for low-temperature poly-Si (LTPS) TFT (< 450°C) on glass substrate may not be adaptable to plastic substrate because deformation of plastic substrate occurs at 200°C (2). It is rather difficult to fabricate poly-Si film with large grains and silicon dioxide with a flat-band voltage close to 0V when the process temperature is less than 200°C (3)(4).

There are two methods in fabricating precursor Si film of ELA poly-Si film. One is physical vapor deposition (PVD) such as sputter, the other is chemical vapor deposition (CVD) like a PECVD or a inductively coupled plasma chemical vapor deposition (ICP-CVD). The Si film prepared by PVD has merits such as low impurity gas content, which is essential for ELA process. The Si film prepared by CVD may be appropriate for large panel process compared with Si film by PVD. However, CVD precursor Si film has rather high content of H_2 that can be an obstacle during ELA process. So dehydrogenation process is inevitable for precursor Si film prepared by CVD prior to ELA. The Conventional dehydrogenation is performed at the temperature higher than 400°C. In the process for plastic substrates, the conventional dehydrogenation is inappropriate due to its much lower thermal budget. So, dehydrogenation without thermal heating is required to fabricate poly-Si TFT for plastic substrates.

A high density-plasma by ICP-CVD allows a high deposition rate (5). It is also noted that ICP-CVD is a kind of remote plasma and the ion damage on the film-growth zone could be reduced. (6)

The purpose of this paper is to report the characteristics of poly-Si TFT using ICP-CVD and ELA for plastic substrates at 170°C. Step-by-Step excimer laser irradiation (7) is employed for the dehydrogenation/ recrystallization as well as dopant activation.

2. Experiments and Results

2.1 Si film deposition by ICP-CVD

The active layer of the poly-Si TFT is prepared by ICP-CVD with the substrate temperature of 170°C using SiH_4 diluted with He. The pressure is kept at 25mTorr and He/SiH_4 ratio is 10, i.e. 20:2 [sccm]. Raman spectrum of the deposited Si film is shown in Fig. 1. Crystalline structure is successfully formed in our Si film as evidenced by the dominant peak at 520cm^{-1}. We evaluated crystalline volume fraction and crystalline component of about 67% is obtained. The successful formation of polycrystalline Si film by ICP-CVD may be attributed to the reduced ion bombardment at the film growth zone where energetic ions may prohibit the crystalline growth. (8)

The H_2 content in the Si film with He dilution are evaluated by FT-IR. Most of bonding is Si-H_2 (@2090cm^{-1}) rather than Si-H (@1980cm^{-1}) (9) and evaluated H_2 content is 4 at. %. When H_2 dilution is used to deposit Si film, H_2 content is 10 ~ 12 at. %. The reduced H_2 content is due to the effect of inert gas (He) which is known to reduce the energy barrier for surface reaction. (10) And He dilution may be useful to decrease thickness of incubation layer of these microcrystalline(μc) Si film, which is a-Si layer formed at initial stage of μc-Si film deposition. In the case of He dilution the transition point from a-Si to μc-Si is only 20nm from the bottom, while in the case of H_2 that is about 50nm. This result may be attributed to activated He that can easily decompose SiH_4 into SiH_x radicals and H ions. Therefore decomposed H ions are sufficient on the surface of the deposition area and they may assist the crystal growth (11).

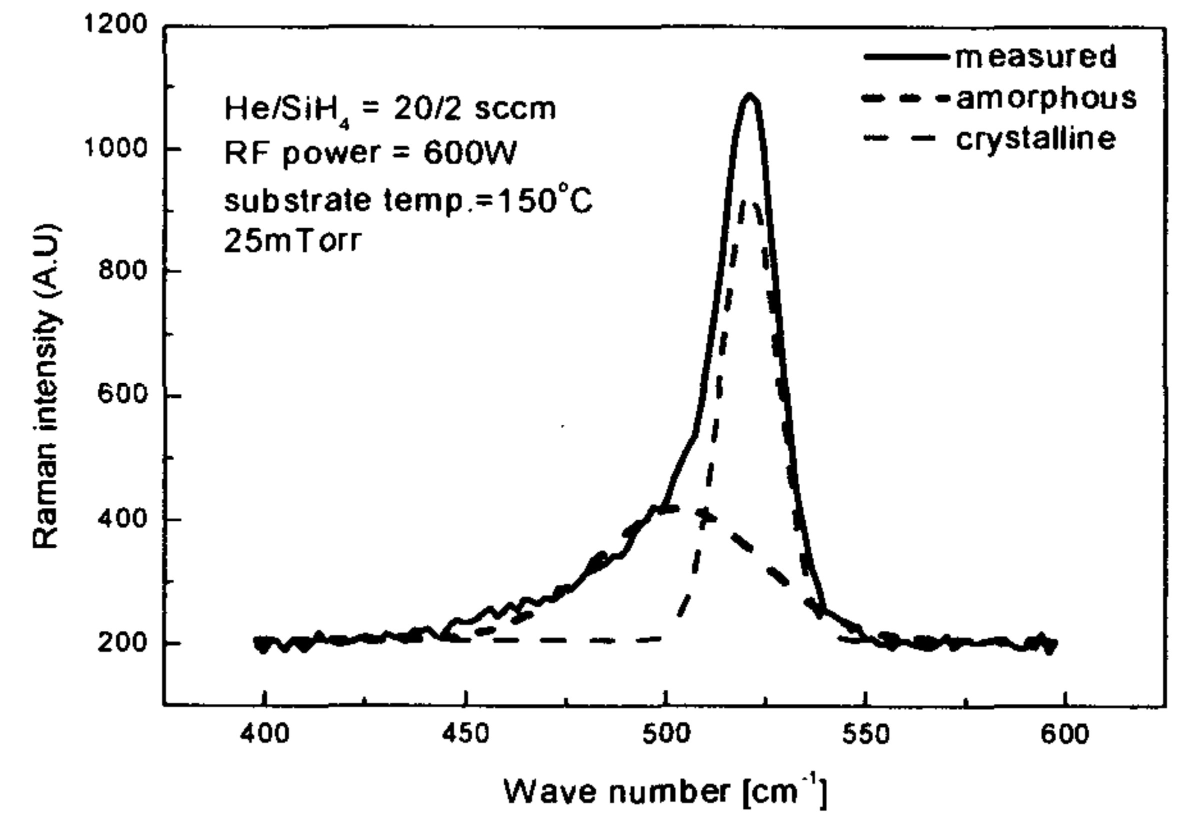


Fig. 1 Raman spectrum of the ICP-CVD Si film

2.2 Step-by-Step excimer laser annealing

The Si film deposited by ICP-CVD is annealed by XeCl (λ=308nm) excimer laser. In order to avoid abrupt effusion of H_2 (4 at.%), step-by-step excimer laser irradiation (7) is employed with increasing energy densities from low energy density (100mJ/cm^2) to high energy density (210mJ/cm^2). The increasing energy step is 10mJ/cm^2 and the number of shot at each energy density is 10. By step-by-step excimer laser irradiation, dehydrogenation is simultaneously carried out with recrystallization. Fig. 2 shows the excimer laser annealed poly-Si film with large grains. The grain size is larger than 5000Å when the final energy density was 210mJ/cm^2. Fig. 3 shows the cross-section of the excimer laser annealed poly-Si film. The poly-Si film is fully crystallized and grain boundary formed by ELA is obviously observed.

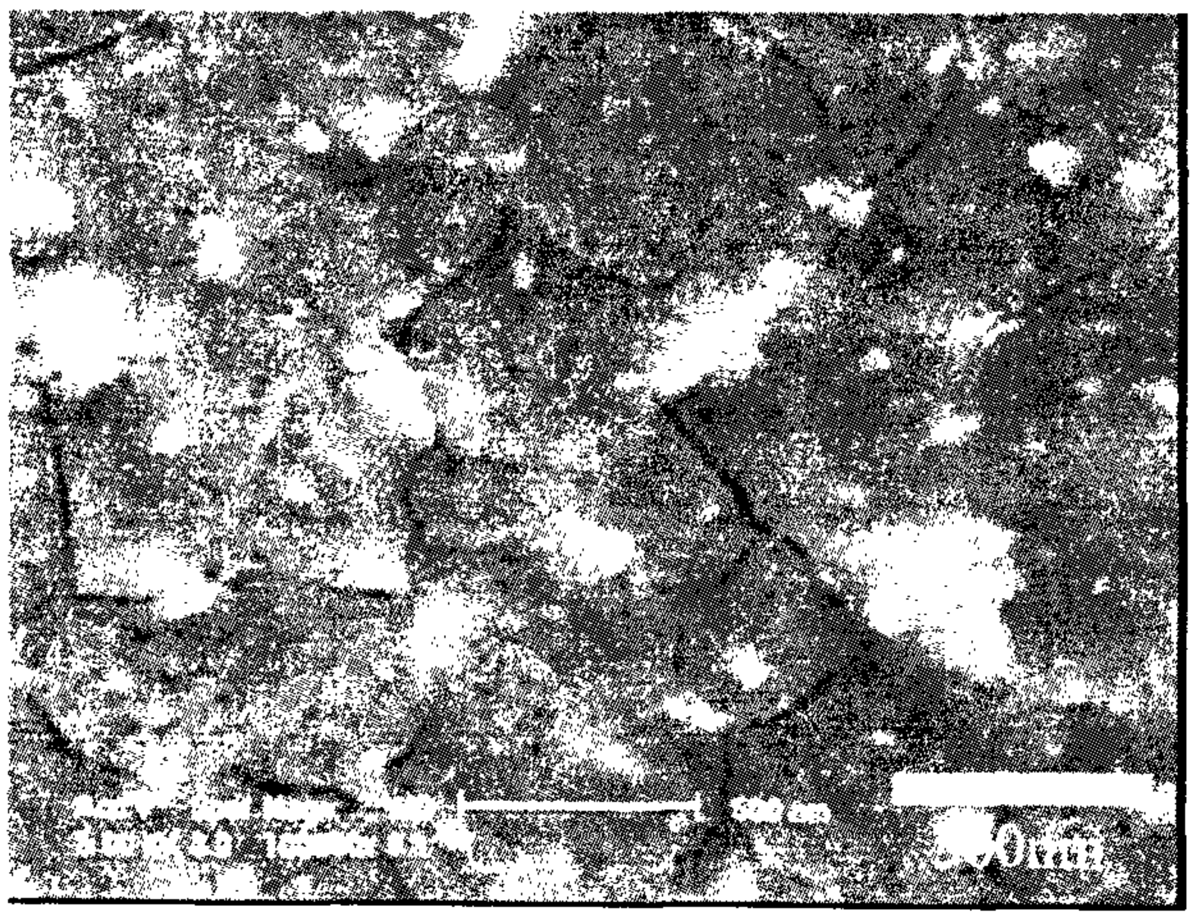


Fig. 2 The SEM image of the excimer laser annealed poly-Si film with large grains. Film thickness = 800Å

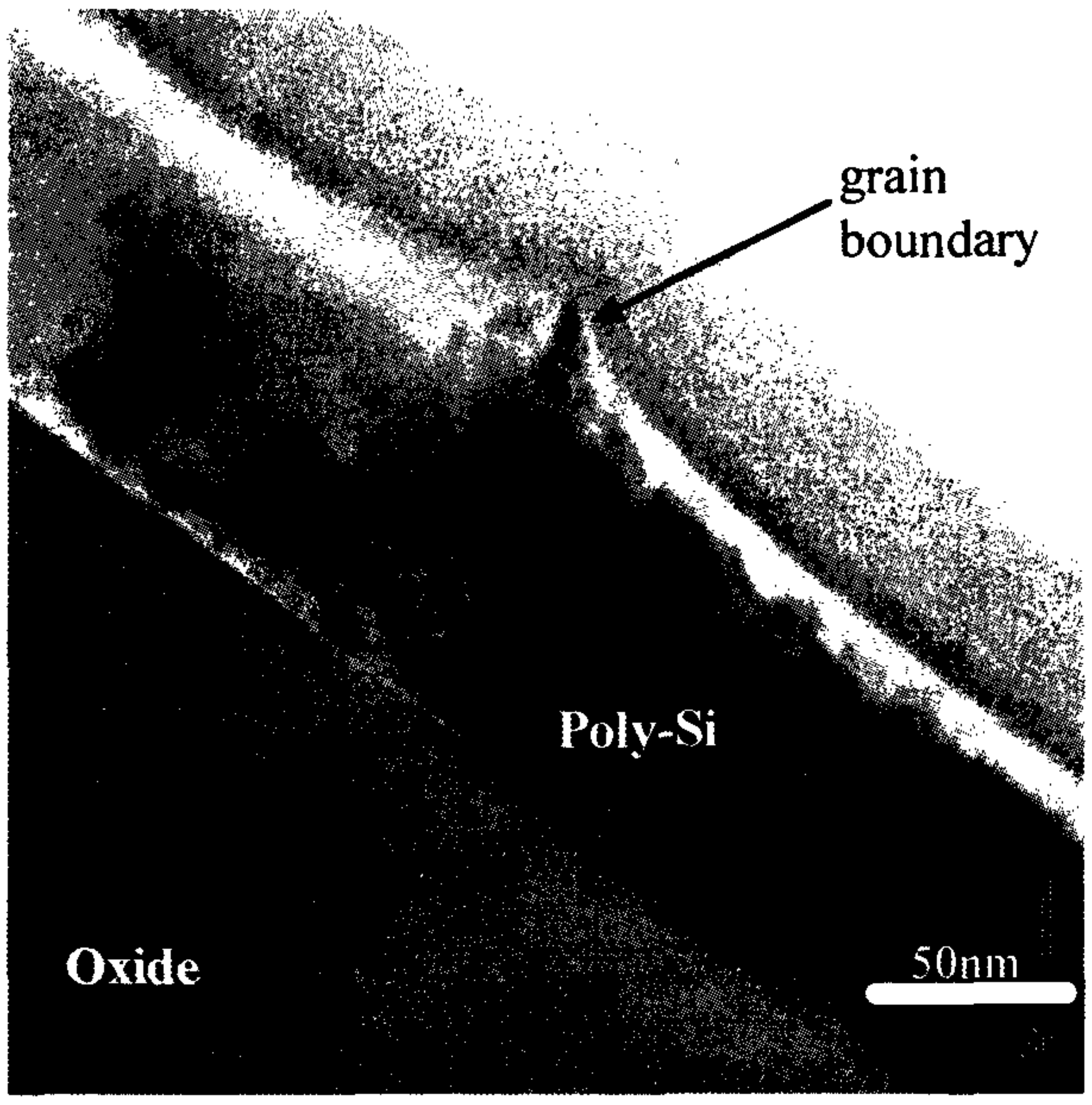
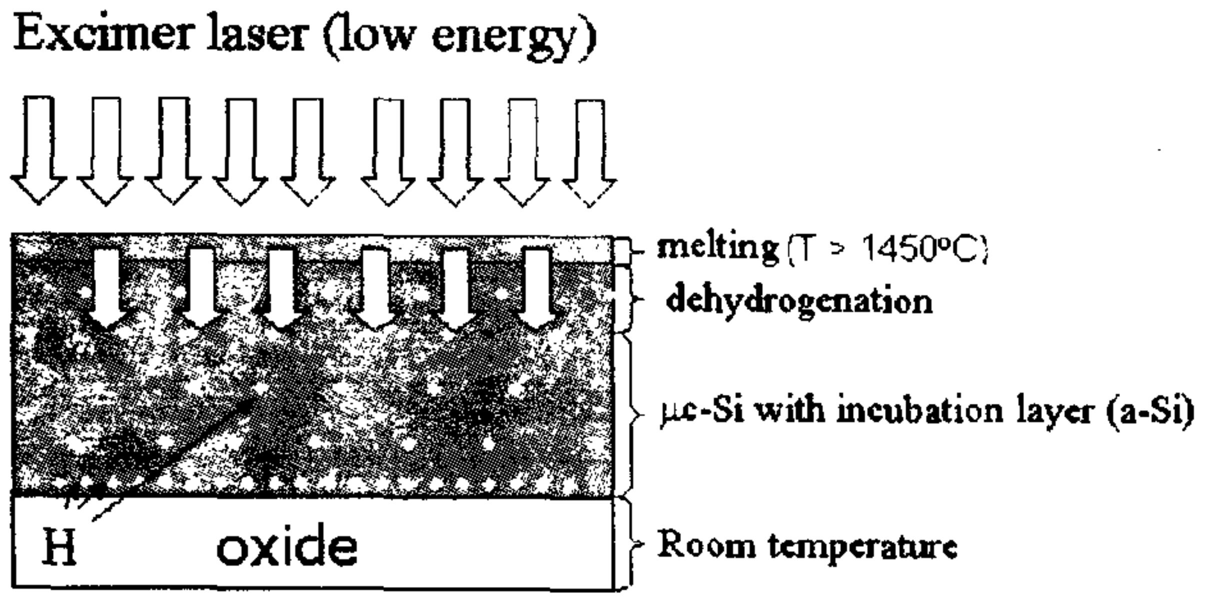


Fig. 3 The cross-section of the excimer laser annealed poly-Si film

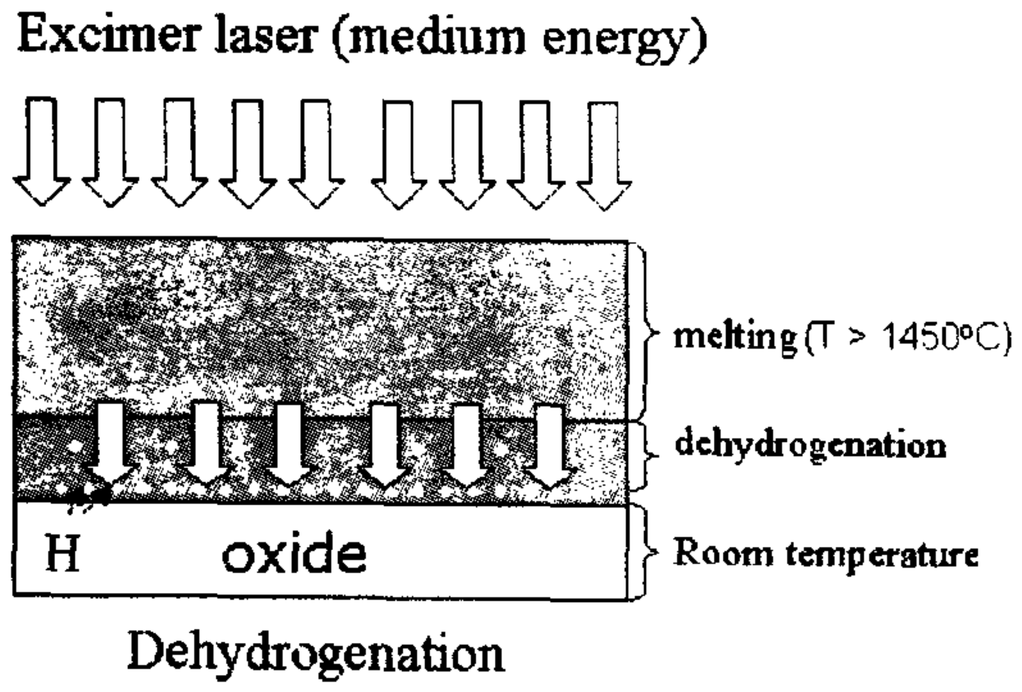
As mentioned above, the μc-Si deposited by ICP-CVD is successfully annealed by step-by-step ELA. Different from a-Si film deposited by PECVD using H_2 diluted SiH_4 at the deposition temperature less than 200℃, μc-silicon film deposited by He diluted SiH_4 has a reduced H_2 concentration less than 4 at. % which allows a successful laser dehydrogenation without an abrupt hydrogen eruption. Furthermore, μc-Si film has inherently higher thermal conductivity (13 ~ 25W/cm·K) than a-Si film (less than 5W/cm·K) (12) and thermal conductivity in the direction of the columnar grains is about 60% greater than that perpendicular to the columnar grains (13). High thermal conductivity in μc-Si may assist the dehydrogenation process through step-by-step ELA. Because μc-Si film has a greater thermal conductivity than a-Si film, latent heat provided from the surface melting may propagate through underlying μc-Si film or incubation layer (a-Si film) which is not molten by given laser energy density. In our experiment, dehydrogenation process was cumulatively performed by multiple shots of excimer laser at each energy density, so that the dehydrogenation was more effective.

Fig. 4 shows the mechanism of dehydrogenation and grain growth. At the stage of low energy density, the dehydrogenation in μc-Si happens and melting depth increases as the energy density increases. At the medium energy density, melting depth reaches near the transition region from incubation layer to μc-Si and dehydrogenation in the incubation layer happens gradually. Further increase of laser energy density would melt most of Si film without ablation and super lateral growth may occur as shown in Fig. 4 (c). The grain growth starts from some seeds which survive in the molten Si, and grains larger than film thickness grow from seeds. By the step-by-step ELA on μc-Si thin film deposited by ICP-CVD, grain size greater than 1000Å is feasible and fabrication of high performance poly-Si TFT is also achievable.

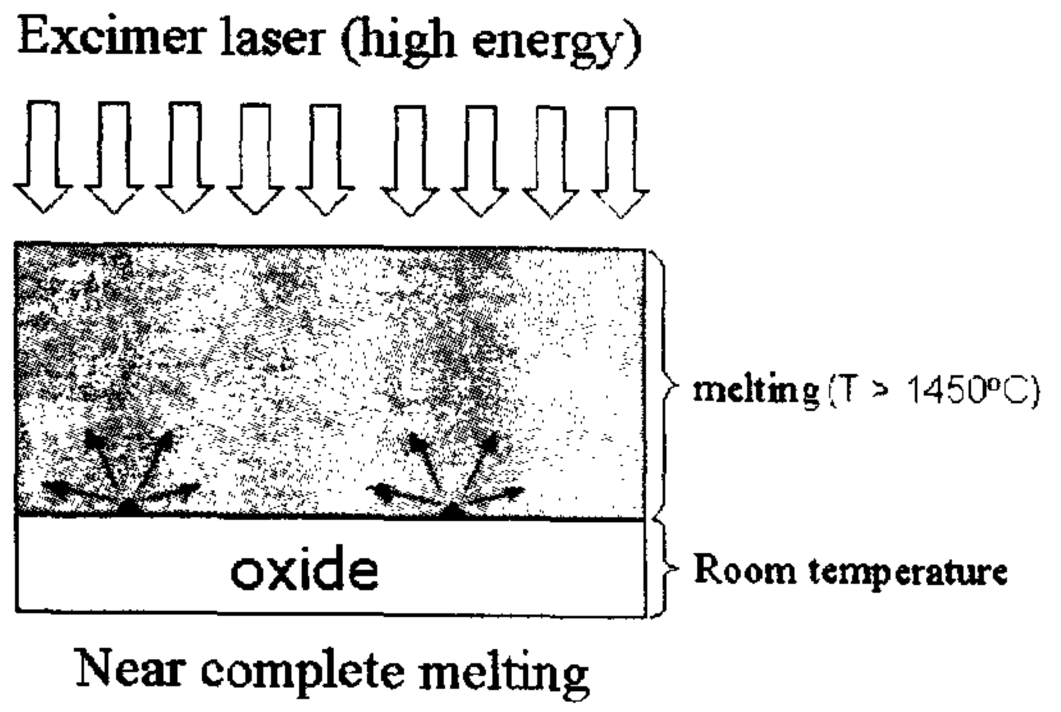
In step-by-step ELA process, the thickness of incubation layer is important. As the incubation layer is thin, the effect of ELA is maximized. Therefore He diluted Si film has advantage over H_2 diluted Si film in terms of the incubation layer that be intimately associated with the effectiveness of step-by-step ELA.



(a) At low energy density (step by step ELA)



(b) At medium energy density (Step-by-step ELA)



(c) At high energy density (Step-by-step ELA)

Fig. 4 The process of dehydrogenation and recrystallization by step-by-step ELA of μc-Si film.

2.3 SiO_2 film deposited by ICP-CVD as a gate insulator

The silicon dioxide film as a gate insulator is deposited by ICP-CVD using N_2O and SiH_4 gas at 170°C. The process pressure is 30mTorr and substrate temperature is 170°C. When the RF power is 400W, the breakdown field is 6.2MV/cm. In our experiment, the increase of RF power is desirable to increase the breakdown field.

The effective oxide charge density is in the order of $10^{11}/cm^2$. In order to improve the poly-Si TFT characteristics, the annealing of oxide film is needed without the deformation of plastic substrate.

We conducted excimer laser annealing on the SiO_2 film deposited on the Si wafer instead of thermal heating in order to improve C-V characteristics. The flat-band voltage is shifted by 1.4V as shown in Fig. 5 when $430mJ/cm^2$ of excimer laser was irradiated on SiO_2 deposited on Si wafer. This result indicates that the laser irradiation on gate insulator deposited at low temperature could reduce the oxide charges in the interface or in the film.

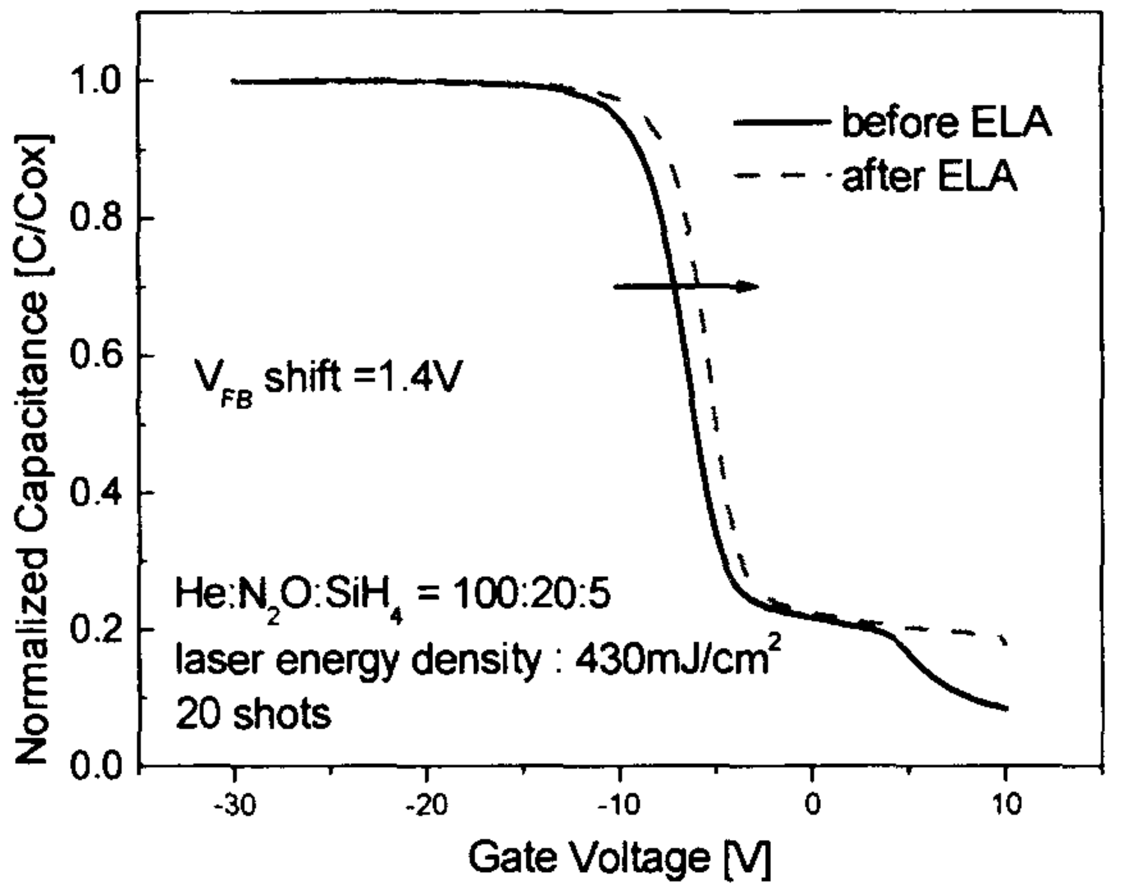


Fig. 5 C-V measurement of silicon dioxide before and after ELA. Flat-band voltage was shifted by 1.4V positively. Oxide film was deposited on Si wafer for C-V measurement. (Freq.= 1MHz)

2.4 Poly-Si TFT fabrication and characteristics

We have successfully fabricated conventional top-gate poly-Si TFTs at 170°C. The process sequence is listed in Fig. 6. Laser irradiation on the gate insulator was added before Al gate layer deposition. Source/drain doping was done by ion-implantation and ELA activation.

Fig. 7 shows the poly-Si TFT characteristics with a high mobility larger than $100cm^2/Vs$ (typically). The electrical characteristics of fabricated TFTs are summarized in Table 1. It should be noted that no thermal treatment or post-annealing was carried out.

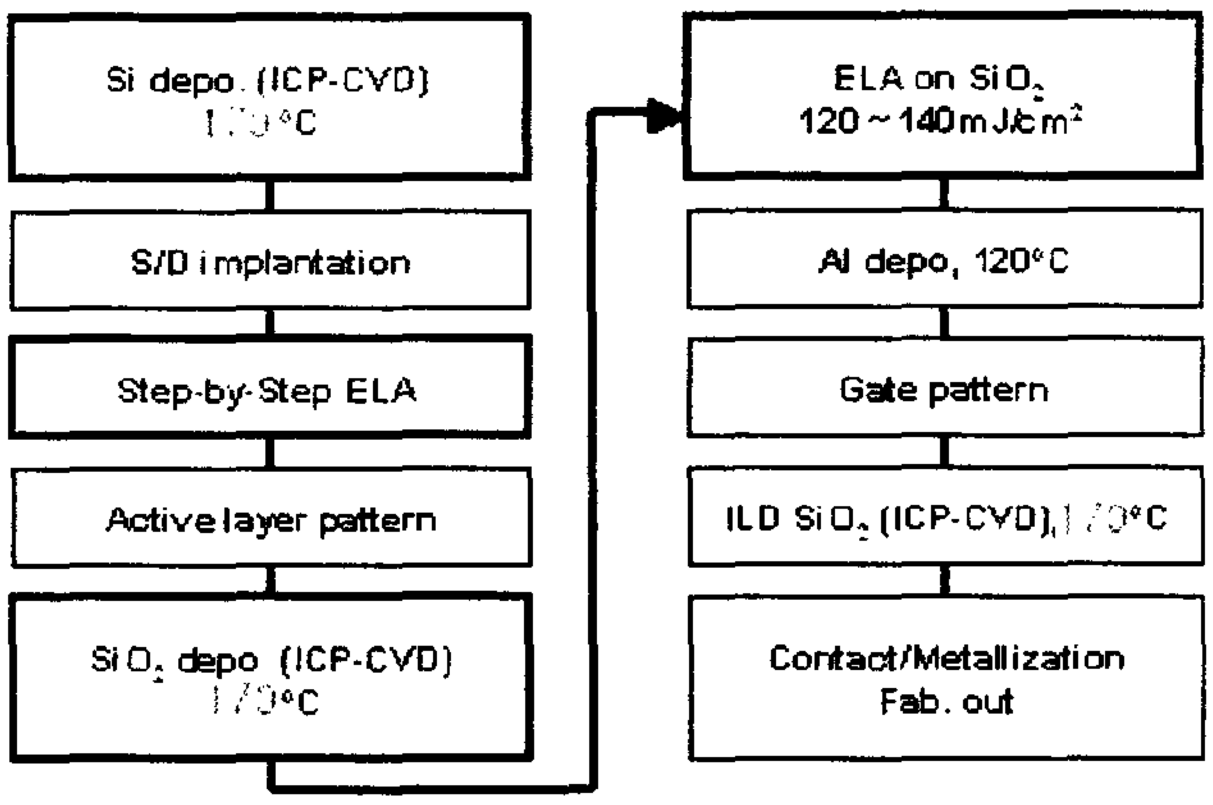


Fig. 6 Fabrication flow of poly-Si TFT

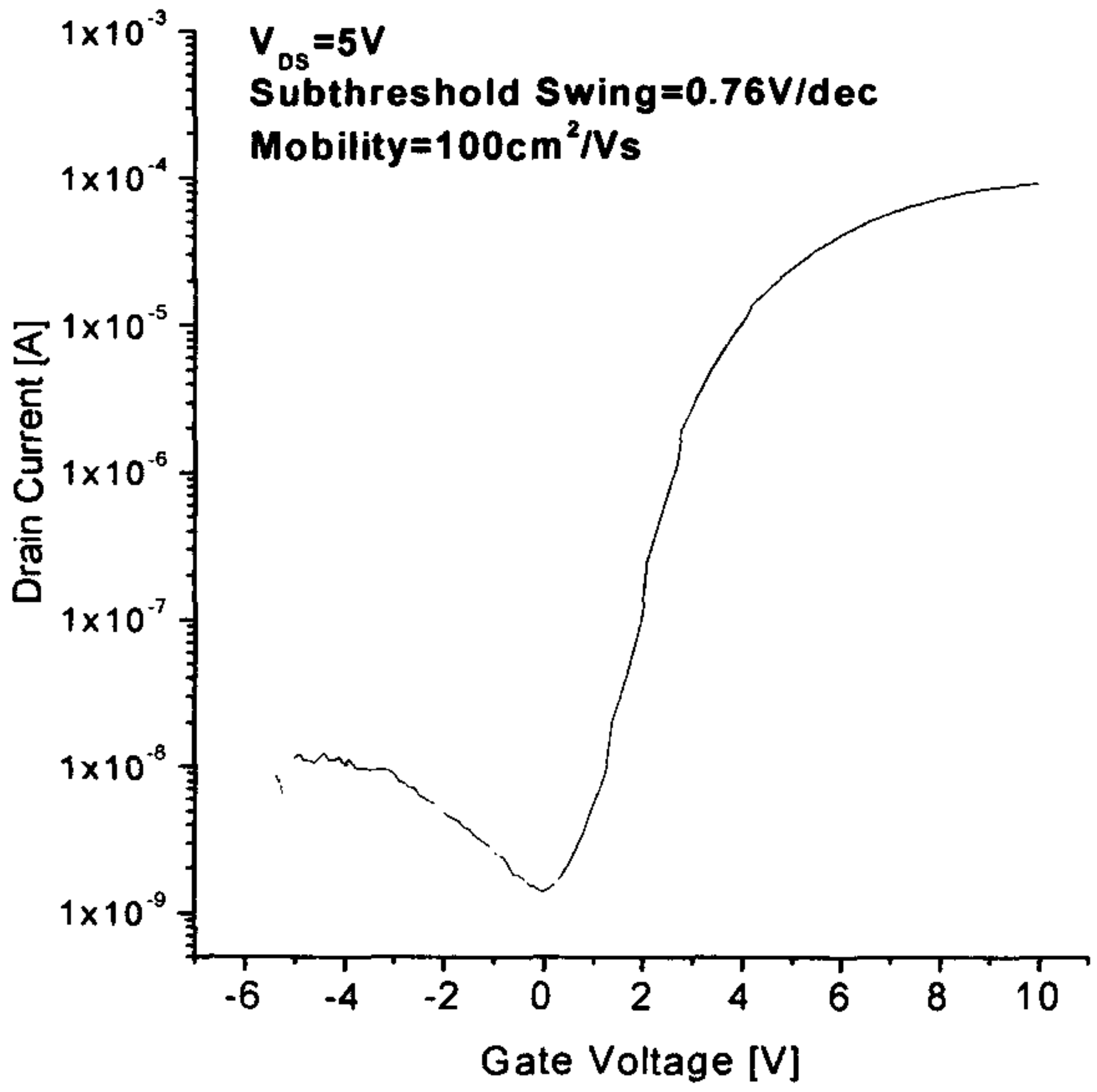


Fig. 7 The transfer characteristics of the fabricated poly-Si TFT. The width/length of gate is 20μm/10μm.

Table 1 Poly-Si TFT parameters (W/L = 20μm/10μm)

TFT parameters	Value
Ion (@ V_{GS}=10V, V_{DS}=5V) [μA]	88
Mobility [cm^2/Vs]	100
Minimum off current [nA] (@ V_{DS}=5V)	1.4
Subthreshold Swing [V/dec]	0.7
On/off current ratio	6.3X10^4

3. Conclusion

We have successfully fabricated poly-Si TFT using ICP-CVD and ELA for plastic substrate. The maximum process temperature was 170°C. A high mobility exceeding 100cm^2/Vs with low sub-threshold slope was obtained without any post-annealing. Though the process temperature is very limited, TFT with remarkable electrical characteristics was fabricated. There are many things to be improved such as off current and subthreshold swing and so on.

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