Improvement of the Surface Roughness of LTPS Thin Films with Additional Laser Irradiation

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ABSTRACT

A well-known major problem in thin-film transistor (TFT) manufacturing is the protrusions that form on low-temperature polysilicon thin films after excimer laser annealing, which, in turn, induce gate leakage current in the TFTs. In this paper, we report the use of additional laser irradiation to reduce the height of protrusions.

1 INTRODUCTION

Low-temperature polysilicon (LTPS) thin films crystallized via excimer laser annealing (ELA) are used as a channel material for flat-panel-display (FPD) thin-film transistors (TFTs). In recent years, selective laser annealing (SLA) using a microlens array (MLA) has been proposed as a technology that can be applied to large substrates of the G10 generation and beyond. However, irradiation with the fixed optical system of the SLA method has been reported to make the crystal grain size non-uniform, and the TFT characteristics (Vth, mobility) become unstable compared to the conventional scanning method [1]. Previous research has reported that by controlling the beam profile by projecting a dot mask pattern, crystal growth during Si melting and solidification can be suppressed, the uniformity of crystal grains can be improved, and the TFT characteristics can be stabilized [2]. However, for LTPS manufactured using this method, the height of the protrusion formed at the grain boundary is 60–100 nm, which is higher than that through irradiation without a mask. As shown in Fig. 1, the TFT leakage current flows owing to the electric field concentration on the protrusion [3]. The current causes a breakdown, resulting in failure of the TFT. This is one of the causes of defective pixels in FPDs. In the present study, we investigated whether the height of the protrusion formed on the LTPS thin film could be reduced via additional irradiation with an excimer laser without deteriorating the TFT characteristics.

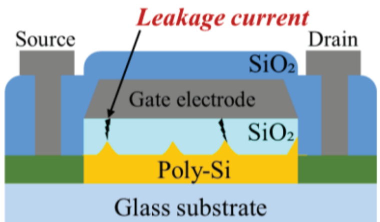

Fig. 1 Schematic of transistor failure owing to protrusions

2 EXPERIMENT

Fig. 2 shows a schematic of the KrF-excimer-laser (Gigaphoton Inc., wavelength: 248 nm, pulse duration (full width at half maximum (FWHM)): ~15 ns) annealing system. An optical pulse stretcher (OPS) can lower the pulse peak and extend the pulse width by generating an optical path delay. The FWHM when using the OPS is approximately 45 ns. The shot repetition rate of the laser is 10 Hz. The beam fluence is adjusted using the attenuator. The irradiated area can be observed with a charge-coupled device camera. A 100 nm amorphous silicon (a-Si) layer is deposited on the quartz substrate via low-pressure chemical vapor deposition at 550 °C.

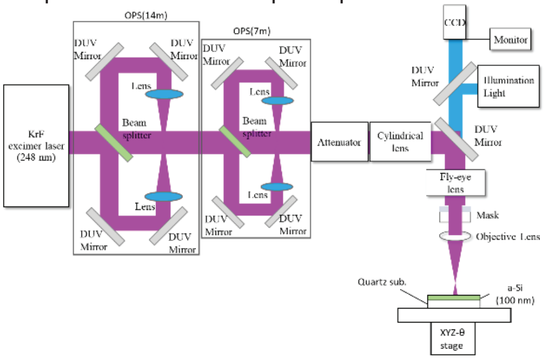

Fig. 2 Schematic of the excimer-laser annealing setup

2.1 Irradiation of Dot Mask Pattern Projection

As shown in Fig. 3, an aluminum mask is used to project a dot pattern for irradiation. The position of the crystal nucleus is controlled by intentionally creating a weak beam profile. With this method, we succeeded in forming square grains with sides of 1.5–2.0 μm. As for the formation mechanism of the protrusions, crystallization progresses rapidly from the crystal nucleus. At this time, protrusions are formed as the volume expansion of Si pushes the protrusions to the boundaries of the crystal grains [4]. An infinitely corrected objective lens with a numerical aperture of 0.36 (20×) was used to reduce and project a dot mask onto a 200 μm × 200 μm area. A laser irradiation fluence of 670 mJ/cm^2 and an irradiation number of 10 shots were used to irradiate the laser to a-Si with a film thickness of 100 nm, and a sample was prepared that had protrusions on the LTPS thin film.

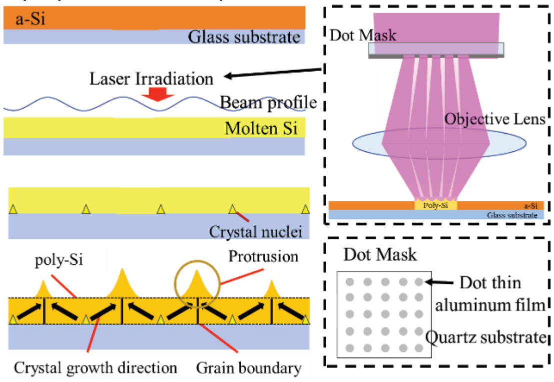

Fig. 3 Schematic of the crystallization process of poly-Si using ELA

2.2 Additional Irradiation of the Sample

We attempted to reduce the height of the protrusions by additionally irradiating the sample on which the regular dot protrusions were formed. The samples with regular dot projections were subjected to additional irradiation, with an irradiation fluence of 520–700 mJ/cm^2 and an irradiation number of 1–10 shots/loc. The TFT was prepared, and the electrical characteristics were evaluated.

3 RESULTS AND DISCUSSION

Fig. 4 shows (a) an optical microscope image and (b)–(d) scanning electron microscope (SEM) images of the LTPS thin films with and without additional irradiation conditions. The LTPS thin films were crystallized using a dot pattern mask with the following irradiance conditions: fluence of 670 mJ/cm^2, 10 shots, and an area of 200 × 200 μm^2. Subsequently, additional irradiation was performed under the following irradiance conditions: fluence of 600 mJ/cm^2, 10 shots, and an area of 150 × 150 μm^2. The additional irradiation was conducted with a flat beam without using a dot mask. As depicted by the red frames in Fig. 4 (b) and (d), the crystal grains were squares with a side of approximately 2 μm, and the size and position of the crystal grains did not change with and without the additional irradiation.

The white dots in the SEM image of Fig. 4 (b) indicate the protrusions and have a height of 60–100 nm. Furthermore, protrusions are formed at the corners of the crystal grains. By contrast, in the additional irradiation spot, the white dots in Fig. 4 (d) disappeared, possibly owing to the decrease in the height of the protrusions.

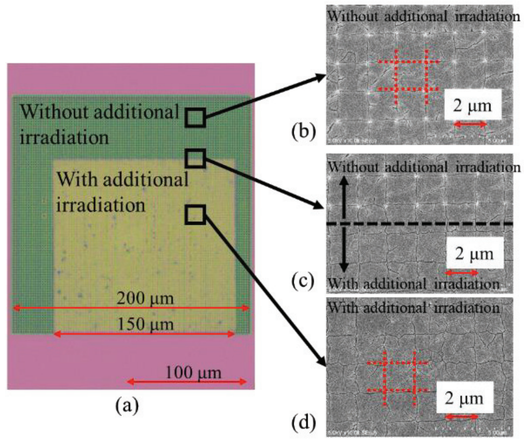

Fig. 4 (a) Optical microscope image and (b)–(d) SEM images (b: without additional irradiation, c: boundary without and with additional irradiation, d: with additional irradiation)

Fig. 5 shows the change in the arithmetic mean roughness (Ra) with additional irradiation, which is measured using a 3D laser microscope. The irradiation fluence was 520, 600, and 700 mJ/cm^2, and the irradiation number was 1, 5, and 10 shots. The Ra surface roughness of the LTPS thin film without additional irradiation was approximately 14.4 nm; subsequently, for the additional irradiation of 600 mJ/cm^2 and 10 shots, the Ra surface roughness was reduced to 4.79 nm, which is a reduction of 70%. By contrast, there was almost no change in the Ra surface roughness at 520 mJ/cm^2. At 700 mJ/cm^2, a sharp drop can be observed at 1 shot; moreover, the effect of reducing the protrusion can be observed.

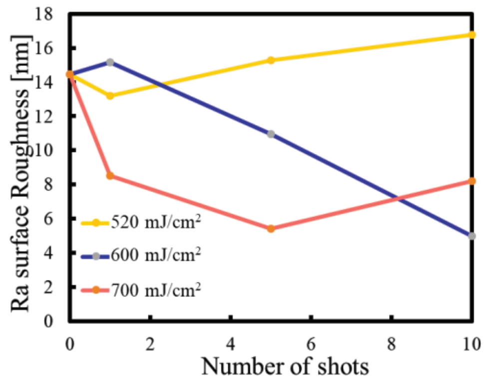

Fig. 5 Arithmetic mean roughness of LTPS-TFT irradiated with 1, 5, and 10 shots with irradiation fluence of 520, 600, and 700 mJ/cm^2

Fig. 6 shows the mobility (μ_{FE}) of the fabricated TFT. At 520 mJ/cm^2 and 600 mJ/cm^2, there is no significant change, even with the additional irradiation. By contrast, at 700 mJ/cm^2, the mobility decreased, and the electrical characteristics of the TFT deteriorated. Fig. 7 shows the SEM images of 10 shots with irradiation fluences of 600 mJ/cm^2 and 700 mJ/cm^2. In Fig. 7 (b), the crystal grains are disturbed by the additional irradiation. Therefore, the mobility decreased owing to random crystal growth. Therefore, by additionally irradiating LTPS with protrusions under appropriate conditions, the surface can be made flat without deteriorating the electrical characteristics of the TFT.

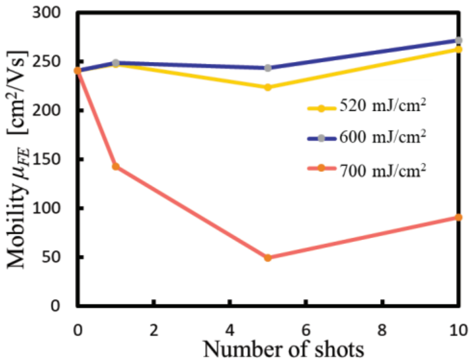

Fig. 6 Mobility of LTPS-TFT irradiated with 1, 5, and 10 shots with irradiation fluence of 520, 600, and 700 mJ/cm^2

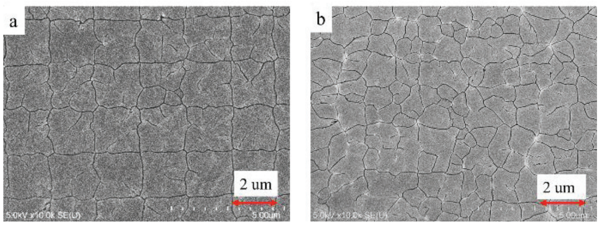

Fig. 7 SEM images with additional irradiation (a: 600 mJ/cm^2; b: 700 mJ/cm^2)

We consider why protrusions have decreased. As shown in Fig. 3, it is reported that the mechanism of protrusions formation is such that when melted Si is rapidly crystallized from crystal nuclei, the volume expansion of Si pushes the protrusions to the boundary between crystal grains [4]. This protrusion has poor crystallinity, and by additionally irradiating a laser to cause an electric field to concentrate at the protrusion, the protrusion is selectively heated and re-crystallized. It can be inferred that low-height protrusions with improved crystallinity are formed.

4 CONCLUSIONS

To reduce the height of protrusions on the LTPS thin film, we performed additional irradiation using a KrF-excimer laser. The experiment confirmed that protrusions were minimized by the additional irradiation of 10 shots of 600 mJ/cm^2.

The protrusions were reduced owing to the recrystallization of the surface of the Si thin film when the electric field was concentrated, and the energy was selectively applied to the protrusions. Therefore, by performing additional irradiation at the optimal fluence for the LTPS where protrusions have formed, the height of the protrusions can be reduced, and the surface can be flattened. The reduction of protrusions through additional irradiation can contribute not only to improved TFT characteristics but also to improved yield. It is a process that has good compatibility with SLA using an MLA, which has recently been attracting attention. Therefore, we believe that this technology will contribute to the development of ELA in the future.

REFERENCES

[1] T. Goto, K. Saito, F. Imaizumi, M. Hatanaka, M. Takimoto, M. Mizumura, J. Gotoh, H. Ikenoue and S. Sugawa, “LTPS Thin-Film Transistors Fabricated Using New Selective Laser Annealing System,” IEEE Trans. Electron. Devices, Vol. 65, pp. 3250-3256 (2018).

[2] K. Imokawa, T. Yamda, K. Saito, J. Gotoh, T. Goto, D. Nakamura and H. Ikenoue, “Grain Growth Control with a Dot Mask in Selective Laser Annealing for Stable LTPS Thin Films Transistors Fabrication,” Proc. SSDM’19, pp. 313-314 (2019).

[3] P.-T. Liu, H.-Y. Lu, Y.-C. Chen, and S. Chi, "Degradation of Laser-Crystallized Laterally Grown Poly-Si TFT under Dynamic Stress," IEEE Electron. Device Lett., Vol. 28, No. 5, pp. 401-403 (2007).

[4] D.K. Fork, G.B. Anderson, J.B. Boyce, R.I. Johnson and P. Mei, "Capillary waves in pulsed excimer laser crystallized amorphous silicon," Appl. Phys. Lett., Vol. 68, pp 2138 (1996).