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Rapid Thermal Annealing Technique for Poly-Si TFTs

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The fundamental characteristics of a rapid thermal annealing (RTA) technique that has been applied to poly-Si TFTs have been investigated and short channel poly-Si TFTs have been achieved. The annealing characteristics of a thin silicon film on a transmissive substrate is entirely different from that of a Si wafer. An arc lamp for a light source of RTA is essential. A self-controlled effect in activation annealing was observed. Size and pattern density of silicon islands affect the uniformity of annealing. An absorption layer of a silicon film makes the use of RTA practical. A shift-register circuit composed of short channel TFTs was also evaluated.

1. Introduction

Poly-Si TFTs fabricated on quartz are playing an important role in small LCDs, but further improvements are desirable. Small LCDs such as viewfinders and light valves are still low resolution^{1,2)}. The higher the resolution of small panels, the wider the field of applications. The key to increasing the number of pixels, enlarging the aperture ratio, and reducing costs is the reduction of TFT size. Based on this requirement this paper introduces rapid thermal annealing (RTA), which is already used in LSI technology³⁾, to poly-Si TFTs. RTA is used in order to obtain shallow lateral junctions in the TFTs, an essential condition for scaling down TFTs.

Recently RTA using a halogen lamp has been applied to poly-Si TFTs for crystallization with low thermal budget^{4,5)}. In this paper, first, it was necessary to confirm the degree to which thin silicon films on transparent substrates absorb light irradiation. Annealing characteristics which primarily depend on an absorption coefficient of a thin silicon film and an intensity spectrum of light sources are discussed. The difficulty of uniform annealing is disclosed in application of RTA to practical devices at the activation step. An absorption layer is required to avoid this difficulty. Finally, short channel TFTs were developed and the performance of shiftregister circuits was evaluated.

2. Annealing Characteristics

The absorption coefficient of silicon film depends not only on wave length but also on its crystallinity. Figure 1 shows the absorption coefficients of silicon films and intensity spectra of the light sources, an arc lamp and a tungsten halogen lamp. The silicon films were deposited



Fig. 1 Absorption coefficients of 100nm-Si films deposited by LPCVD, and spectra of a arc lamp and a tungsten halogen lamp.

by LPCVD at deposition temperatures of 510, 550, 600 and 630 °C. A thickness of the films was 100nm. The films deposited at 510 and 550 °C were amorphous and the films deposited at 600 and 630 °C were polycrystalline. The former two films look darker because of higher absorption coefficient in the range of visual wave length. But the higher absorption range is less than 400nm, so the source lamp for RTA needs intensive spectrum which meets the absorption characteristics of silicon films. An arc lamp is preferable, while a tungsten halogen lamp is undesirable for RTA of thin silicon film.

Figure 2 shows the activation annealing by the broad beam arc lamp. A 100nm-thick poly-Si film deposited at 600 °C was followed by phosphorous implantation at a dose of 1x10¹⁵ /cm². Successive annealing was 45 seconds irradiation time. The maximum temperature of the film rose gradually with the lamp power until activation occurred, but once the activation occurred the temperature failed to rise as high as before despite even higher lamp power. The sheet resistance of the silicon film was too high to measure until activation, but it remained constant during higher power successive annealing. Figure 3 shows the rising temperature of implanted silicon film during irradiation. The rate that the temperature rose ' slowed down just after activation. According to these figures, the activation annealing by RTA is characteristic of a self-controlled annealing which is a desirable feature in mass production.



Fig. 2 Successive annealing of a 100-nm Si film implanted phosphorus at a dose of 1×10^{15} /cm².

3. RTA for Practical TFTs

The annealing characteristics of RTA described in the previous section, however, are limited to a blanket silicon film. There are many silicon islands in actual devices at the activation annealing step. And furthermore, the size and density of islands vary. Figure 4 is a photograph of a driver circuit just after RTA irradiation for activation annealing of implanted ions. In the photograph, the central region, or the higher density pattern region looks annealed; on the other hand, the edge region, or the lower density pattern region, looks unannealed. When a irradiation power is increased, the edge region can be annealed but the central region will be damaged because of excessively high temperature.

So as to achieve uniform annealing, some absorption layer is required. In this paper a silicon film deposited by LPCVD on interdielectric SiO_2 was used for a absorption layer as shown in Fig. 5. An amorphous silicon film deposited by PECVD or a thicker film deposited by LPCVD for an absorption layer was likely to be cracked because of hydrogen evaporation and/or thermal stress



Fig. 3 Temperature profile of implanted Si film.



Fig. 4 Photograph of a driver region just after RTA activation anneal.



Fig. 5 Cross-sectional view of a TFT with absorption layer.

during RTA. A 100nm-thick silicon film deposited by LPCVD is sufficient for the absorption layer.

4. Performance of TFTs and Driver Circuit

Thanks to the absorption layer, TFTs and driver circuits work reasonably well. Channel silicon film of TFTs was deposited by LPCVD at 550 °C. A 120nmthick gate oxide was formed by thermal oxidation at 1000 °C. N⁺ poly-Si was used for gate electrodes. Phosphorus and boron ions were implanted for p-channel and n-channel TFTs at a dose of 1×10^{15} /cm², respectively. 100nm-thick silicon film for the absorption layer was deposited on interdielectric SiO₂ by LPCVD. Then the substrate was scanned under a focused line beam from an

arc lamp. This beam irradiated the substrate at 44 -57kW of power, 2 seconds of resident time and 900 -1000 °C of maximum temperature. After RTA the absorption layer was etched off with a wet solution. Reference samples were annealed in furnace at 1000 °C 20 min. Figure 6 shows the short channel effect of nchannel poly-Si TFTs. The gate width is fixed at 10 µm and the gate length is 2 - 20 µm. The extrapolated threshold voltage of furnace annealed TFTs drops rapidly at around 4 μ m of gate length. On the other hand, the threshold voltage of RTA annealed TFTs drops more slowly. Short channel TFTs with 2 or 3 µm of gate length can be practical by RTA activation annealing. Lateral junction depths were determined from the relation between channel resistance (1/IoN) and gate length. Lateral junction depths of RTA samples were 0.2 - 0.3 μ m for PMOS and 0.4 - 0.5 μ m for NMOS. While those of conventional furnace annealed TFTs were about 1 µm for both PMOS and NMOS.

Performance of shift-register circuits was also evaluated. Two kinds of CMOS TFTs which compose the circuit were fabricated. The only difference between the two is the gate length. The gate length of the one, conventional-sized TFTs, is 4 μ m for PMOS and 5 μ m for NMOS; that of the other, short channel TFTs, is 2 μ m and 3 μ m for PMOS and NMOS, respectively. Furnace annealed samples and RTA annealed samples of both kinds of circuit were compared. The maximum frequencies of the circuits are shown in Fig. 7. The operation speed of RTA annealed samples with short channel TFTs was about tripled compared with that of samples with conventional-sized TFTs. The furnace annealed circuit with short channel TFTs did not work because of large leakage current.



Fig. 6 Extrapolated Vth of NMOS vs. gate length. Gate width is $10 \,\mu$ m.



Fig. 7 Maximum frequencies of a CMOS shift-register. Gate lengths are $4/5 \mu m$ for PMOS/NMOS, and $2/3 \mu m$ for short channel PMOS/NMOS.

5. Conclusion

The fundamental characteristics of a rapid thermal annealing (RTA) technique that has been applied to poly-Si TFTs have been investigated. The annealing characteristics of a thin silicon film on a transmissive substrate are entirely different from those of a Si wafer. An arc lamp for a light source of RTA is essential. A self-controlled effect in activation annealing was observed. Since the size and pattern density of silicon islands affect the uniformity of annealing an absorption layer is required at activation annealing step. Thanks to RTA, the short channel effect was improved and a shiftregister circuit operated at higher frequency.

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7. References

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