Evaluation of Two Si Layers Simultaneously Crystallized LTPS-TFT Memory by the Green Laser Irradiation

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Abstract: Low temperature polycrystalline Si thin film transistor (LTPS-TFT) used for a liquid crystal display (LCD) is obtained by crystallizing a-Si (amorphous Si). Although excimer laser is commonly used for crystallization, green laser crystallization attracts attention in recent years due to two a-Si layers in stacked substrate (a-Si/SiO₂/a-Si/quartz) are crystallized only by one time of irradiation. In order that this stacked layer structure is the same as the structure of a flash memory, this technology is applied to improvement in a performance of a flash memory. As a result, even when laser irradiation from the back is performed, two Si layers simultaneous crystallization is possible. Compared with the irradiation from front, the field-effect mobilities of the irradiation from the back improved about 10 times. Furthermore, in order that the retention time is improving significantly, it indicated that the quality of the oxide film between two layers improves. This technology is a technology promising for the improvement in a performance of a flash memory.

Key words: Low temperature poly-Si thin film transistor, flash memory, laser crystallization.

1. Introduction

Low temperature polycrystalline Si thin film transistor (LTPS-TFT) has been widely investigated as the switching devices for active matrix LCDs (AMLCDs). Recently, the electron mobility of LTPS-TFT is becoming almost equivalent to Single crystal Si by improvement in a crystallization technology. Therefore, it becomes possible to fabricate an integrated circuit (IC) only with a LTPS-TFT. The fabrication of nonvolatile memory using LTPS-TFT is an important issue for the realization of new devices [1].

On the other hand, flash memory is used to memory device for the mobile phone and digital camera due to high speed and large capacity. Previously, we reported several types flash memory using LTPS-TFT [2, 3]. The quality of the oxide film which an electron

tunnels is important for the memory performance. The conventional memory uses the single crystal silicon substrate, and the highest quality thermal oxidation film is used for the tunnel oxide [4, 5]. In our case, in order that a process maximum temperature is 600 °C, there is a problem that it can not use a thermal oxidation film and a property modification treatment at after deposition lower temperature by chemical vapor deposition (CVD) is needed for requiring good retention time.

Excimer laser is the mainstream of a crystallization technology [6]. However, the crystallization by green laser attracts attention in recent years. It was reported that two a-Si layers of stacked substrate can be crystallized only one irradiation [7]. We applied this technique for high performance LTPS-TFT flash memory as upper and lower Si layers were floating gate and channel layer, respectively. Furthermore, a property modification treatment of a tunnel oxide film is attained with crystallization.

In this study, the layer of a crystallinity which laser

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irradiation corresponds to first is the highest, we compared the influence of performing laser irradiation from a front and the back (laser transmits a quartz substrate) by memory characterization.

2. Experiments

The device structure is shown in Fig. 2. After cleaning step, a-Si (50 nm) as a channel layer on quartz substrate was deposited by Plasma enhanced CVD (PECVD). Next, SiO₂ (5 nm) as tunnel oxide and a-Si (20 nm) as a floating gate were deposited by same PECVD. Two a-Si layers and SiO₂ layer were deposited in the clustered chambers without atmospheric exposure. After formation of a floating gate by wet etching, SiO₂ (20 nm) as control oxide was deposited by PECVD. Both of the a-Si layers were crystallized by irradiation of green laser from front or back. Condition of laser crystallization is shown in Table 1. Next, phosphorus ions with $1 \times 10^{15} \text{ cm}^{-2}$ were doped at 30 keV for the source and drain. After activation anneal at 600 °C for 3 h and fabrication of contact hole by wet etching, aluminum was deposited for gate electrode. Finally, the TFT flash memory was annealed in forming gas (H₂: 15%) at 400 °C for 30 min.

3. Results and Discussion

3.1 TEM Image of Laser Irradiation Form Back to Staked Substrate

Fig. 3 shows Transmission Electron Microscopy (TEM) image of laser irradiation form back to staked substrate. polycrystalline Si and microcrlistaline Si were observed in channel layer and floating layer, respectively. From the this result, even when it irradiates with green laser from the quartz substrate side, a two-layer simultaneous crystallization is possible for stacked a-Si layers.

3.2 Improvement of Initial Characteristics by Green Laser Irradiation

Figs. 4a and 4b show comparison of initial transfer

Fig. 1 The direction of laser irradiation.

Fig. 2 Device structure of TFT flash memory.

Table 1 The irradiation conditions of the green laser for a crystallization.

Parameter	Values
Wavelength	532 nm
Frequency	4 kHz
Scan pich	2 $\mu\text{m}/\text{pulse}$ (8mm/s)
Irradiation energy	439 mJ/cm^2

Fig. 3 Cross section TEM image of two Si layers.

curves and output curves of TFT flash memory, respectively. Laser irradiation from front and back applying the gate voltage from -5 V to 10 V and drain voltage is 1 V. Although the drain current at the gate voltage 10 V was $5.3 \times 10^{-8} \text{ A}$ when laser irradiation from the front. However, drain current was $3.6 \times 10^{-7} \text{ A}$ when laser irradiation from the back. Drain current

Fig. 4 (a) transfer curve (b) output curve of TFT flash memory. Laser irradiation from front and back.

Fig. 5 The memory property characteristics of TFT flash memory. Laser irradiation from (a) front and (b) back.

was markedly improved in transfer curves and output curves due to increase in crystallinity of channel layer by laser irradiation. Compared with the irradiation from a front, the field-effect mobilities of the irradiation from the back improved about 10 times. The threshold voltage and S value were improved 2.8 V to 1.4 V and 1.3 V/dec to 0.4 V/dec, respectively. Negative fixed charges in SiO_2 were decreased. We considered that it was annealed by heat of fusion in laser crystallization. These result suggested that not only crystalline but quality of tunnel oxide (SiO_2) were improved.

3.3 Memory Properties of TFT Flash Memory

Figs. 5a and 5b show the memory property characteristics from transfer curve of laser irradiation from front and back under applying the gate voltage

from 10 V to -5 V after application from -5 V to 10 V and drain voltage is 1V, respectively. Hysteresis was observed in both TFT flash memory. The threshold voltage shift suggests electron confinement in the floating gate. Hysteresis with a large memory window was clearly observed for gate voltage sweep in the LTPS-TFT flash memory laser irradiation from back. It proved that the memory characteristic improves by the laser irradiation from the back. For the various sizes (W/L) of TFT flash memory were measured, large memory window was also obtained.

3.4 Retention Time Characteristics of TFT Flash Memory

We evaluated the retention time by monitoring the drain current at a reading voltage of 0.5 V. After writing ($V_g = 10$ V) and erasing ($V_g = -5$ V), the

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Fig. 6 Retention time characteristics of TFT flash memory.

change in the drain current was measured, as shown in Fig. 6. Memory window disappeared after approximately more than 1,000 s. Thus, retention time is 1,000 s. Although drain current changes a lot in a few seconds at the laser irradiation from a front, the case from the back changes in about 100 s. Retention time is related to quality and thickness of tunneling oxide. This is due to improvement of tunneling oxide quality. The results suggest that this technique is effective method to improve the memory properties.

4. Conclusions

LTPS-TFT flash memory was fabricated by green laser irradiation. Effect of laser irradiation was clearly observed by initial transfer and output curve characteristics. Drain current was markedly increased due to increase in crystallinity of channel layer. And threshold voltage was shifted from 5.6 V to 3.4 V due to increase quality of tunneling oxide. Charging and discharging effect were confirmed by the transfer curve. The width of hysteresis in LTPS-TFT flash memory was larger than a-Si TFT flash memory. Large hysteresis was observed when the slower gate sweep rate. Especially, retention time was markedly improved. This is promising technique for improvement of memory properties. High performance LTPS-TFT flash memory fabrication

technique using 3-dimensional substrate is promising for the realization of nonvolatile memory for system on panel.

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