P-10 Post-Crystallization of Metal-Induced Laterally Crystallized Poly-Si with YAG Laser

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Abstract

Post-crystallization heat-treatment of metal-induced laterally crystallized polycrystalline silicon thin film using YAG solid-state laser is characterized. It is found that both the material quality and the TFT performance are related to the laser-treatment condition. The amorphous silicon fraction remaining in the polycrystalline thin film can be reduced and the performance of the thin-film transistors fabricated on the laser-treated thin film under an optimized condition can be greatly improved.

1. Introduction

With the development of flat-panel display technology and increasing demand for higher information content, active-matrix addressed panel has been widely used in high quality flat-panel displays [1,2]. Low-temperature polycrystalline silicon (poly-Si) thin-film transistor (TFT) technology allows the possibility of integrating peripheral driver circuits with the matrix on the same glass substrate, leading to the realization of systems-on-panels. As a promising poly-Si technology, metal-induced lateral crystallization (MILC) [3] has been intensively investigated for its characteristics of high field-effect mobility and low-fabrication temperature.

Though high performance MILC poly-Si TFTs have been fabricated [4], techniques to further improve the poly-Si material quality and the electrical performance of the resulting TFTs have been investigated. High temperature post-crystallization anneal at 900°C was found to eliminate small a-Si fractions and grain boundaries [5] in MILC poly-Si, but it is not generally applicable to inexpensive glass substrates for active-matrix displays. An alternative low-temperature post-crystallization method is laser annealing [6,7,8]. It has been reported that the minimum leakage current can be greatly reduced and the mobility can be much enhanced for TFTs fabricated on laser annealed metal-induced crystallization (MIC) [6] or MILC [7] poly-Si. Poly-Si film with large grain domain and small misorientation angles can be formed by exposing MILC poly-Si to XeCl excimer laser [8]. However, excimer laser annealing suffers from high initial cost, high variation of device characteristics and narrow process windows. A relatively low cost YAG laser was reported for direct crystallization of a-Si [9], but there are few reports on the application of YAG laser to post-crystallization of MIC/MILC poly-Si.

In this paper, post-crystallization heat-treatment of MILC poly-Si thin film using YAG solid-state laser is characterized. It is found that both the material quality and the performance of TFTs formed on it can be improved with YAG laser exposure.

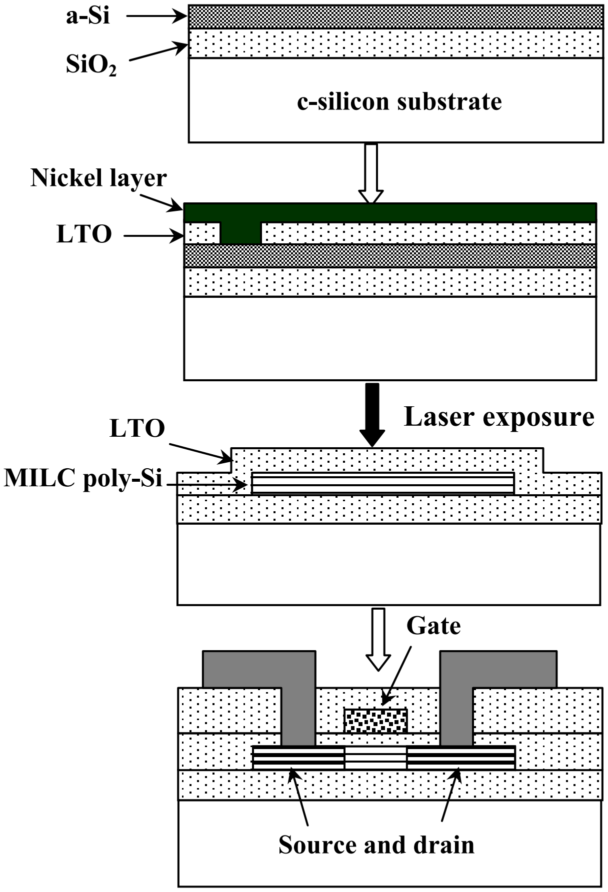

Figure 1. Process flow of MILC-TFTs with YAG laser exposure.

2. Fabrication

The fabrication process (Fig. 1) began with 4-inch, single crystalline silicon wafers covered with 500nm thermal oxide as the starting substrates. 50nm a-Si was formed by low-pressure chemical vapor deposition (LPCVD) at a temperature of 550°C. Following the patterning of the a-Si layer into active islands, 100nm low-temperature oxide (LTO) was formed at 425°C. Crystallization-inducing windows were opened before 3nm nickel was evaporated.

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MILC heat-treatment was carried out at 550°C in atmospheric-pressure nitrogen for 20hrs with the formation of ~100μm long laterally crystallized poly-Si. After the heat-treatment, the remaining nickel on the samples was removed in a solution of H_2SO_4 and H_2O_2 at 120°C.

Post-crystallization of the MILC poly-Si film was performed using solid-state frequency-tripled YAG laser at a series of energy densities of 40.8, 66.2, 112 and 132.5mJ/cm^2. The wavelength of the YAG laser is 355nm, the pulse frequency is 10Hz, the pulse width is 2-3ns, the diameter of the light beam is 5mm and the scan speed is 0.5mm/s.

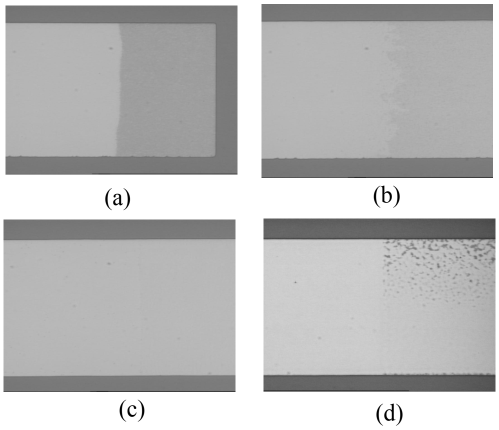

(a) (b)
(c) (d)

Figure 2. Morphology of MILC poly-Si and a-Si regions after exposure to laser at energy density of (a) 40.8, (b) 66.2, (c) 112 and (d) 132.5mJ/cm^2.

After laser scanning, the LTO cover layer was removed in a buffered hydrofluoric acid. This was followed by sequential depositions of 50nm LTO layer and 280nm LPCVD poly-Si at 620°C. The poly-Si layer was patterned into the gate electrodes before self-aligned ion implantation of phosphorus and boron at a dose of 4x10^{15}/cm^2 to form source and drain regions of the n- and p-type TFTs, respectively. Dopants were activated at 620°C for 3hrs in nitrogen after the deposition of 500nm LTO isolation layer. Contact holes were opened before 500nm aluminum-1%Si was subsequently sputtered and patterned. Contact sintering was performed in forming gas at 420°C for 30mins.

3. Results and Discussion

The surface morphology of the MILC poly-Si and the adjacent a-Si regions after the laser exposure was studied under an optical microscope. The corresponding photographs are shown in Figure 2. It can be seen that there is no observable morphology change in the MILC region (left-hand side) when the energy density changes from 40.8 to 132.5mJ/cm^2, but the a-Si region (right-hand side) is partially crystallized with 66.2mJ/cm^2 laser exposure (Fig. 2b) and fully crystallized when the energy density increases to 112mJ/cm^2 (Fig. 2c). At an energy density of 132.5mJ/cm^2 (Fig. 2d), small grains with darkened regions appear. This is similar to that observed after excessive exposure of a-Si to excimer laser [10].

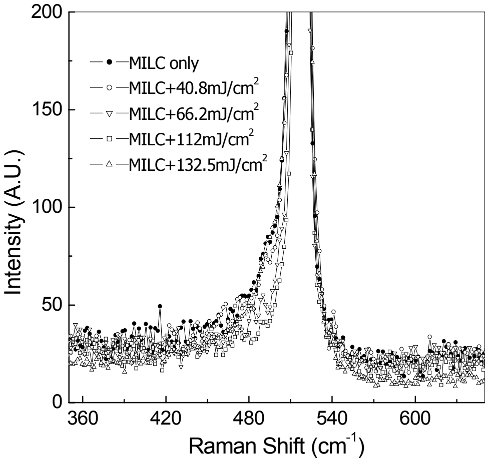


Figure 3. Micro-Raman spectra of MILC poly-Si without and with exposure to laser at different energy density.

Amplified Raman spectra taken in the MILC poly-Si regions are shown in Figure 3. It can be seen that there are obvious “peak” centered at 480cm^{-1} and “shoulders” at 510cm^{-1} for the poly-Si without any laser exposure and that exposed to laser at 40.8mJ/cm^2 and 132.5mJ/cm^2. However, there are no obvious “peak” at 480cm^{-1} for the MILC poly-Si exposed to laser at energy densities of 66.2mJ/cm^2 and 112mJ/cm^2. The “shoulders” at 510cm^{-1} are also significantly decreased.

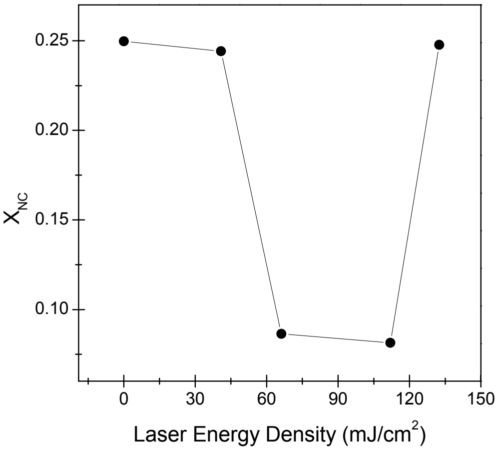


Figure 4. Ratio (X_{NC}) of areas under peaks at 480cm^{-1} and 510 cm^{-1} to areas under peaks at 480cm^{-1}, 510 cm^{-1} and 520cm^{-1} after Gaussian-fitting to the Raman spectra.

Three-peak (480cm^{-1}, 510cm^{-1} and 520cm^{-1}) based Gaussian-fitting to the Raman spectra was performed. Shown in Figure 4 is the ratio (X_{NC}) between $I_{480} + I_{510}$, the sum of the areas under the peaks at 480cm^{-1} and 510 cm^{-1}, and $I_{480}+I_{510}+I_{520}$, the sum of areas under peaks at 480cm^{-1}, 510cm^{-1} and 520cm^{-1}, versus laser energy density. It can be seen that X_{NC} is almost the same as that of poly-Si without laser exposure when the energy density is 40.8mJ/cm^2 and decreases abruptly when the energy density is increased to 66.2mJ/cm^2 and gradually saturates at 112mJ/cm^2. However, when the energy density increases to 132.5mJ/cm^2, X_{NC} increases to a high level similar to that of the poly-Si without laser exposure.

Combining the results on the morphology change and the Raman spectroscopy measurement results, it is concluded that the defects and the a-Si fractions remaining in the MILC poly-Si grain boundaries can be reduced or crystallized after laser exposure at an appropriate energy density such that the material quality can be improved. However, excessive laser exposure introduces damage to the poly-Si material rather than improves the material quality.

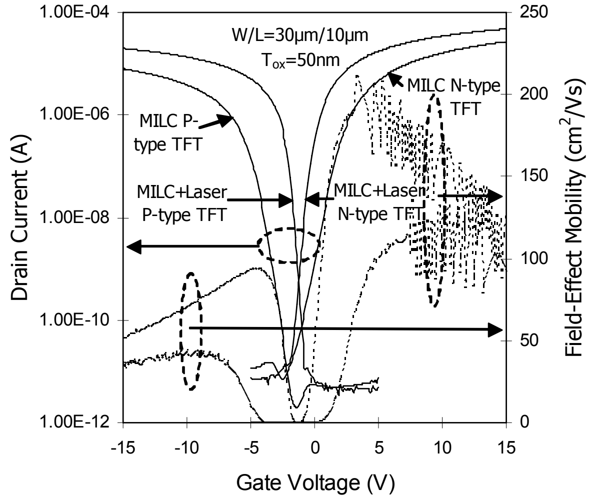
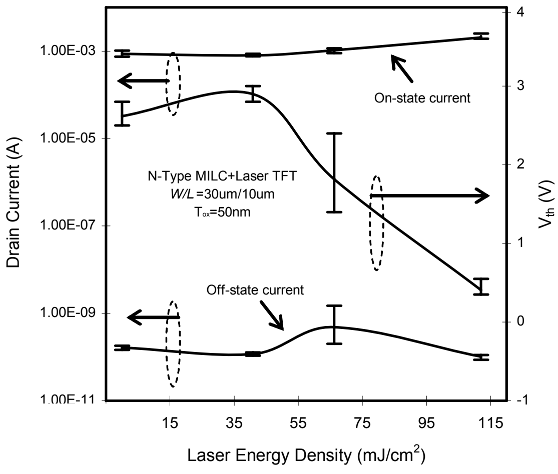


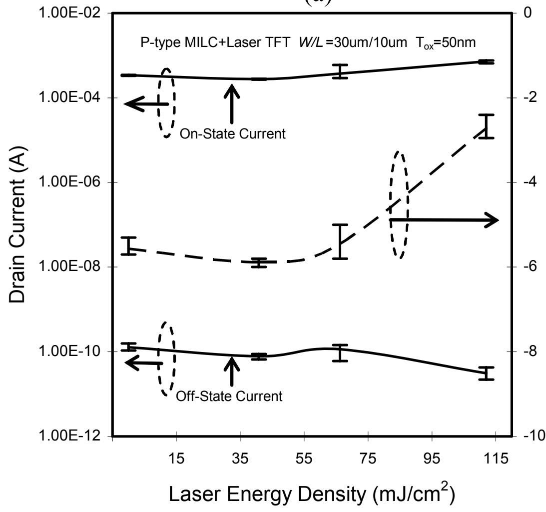
Figure 5. Drain current and field-effect mobility *vs.* gate voltage of n-and p-type MILC-TFTs with and without laser exposure at an energy density of 112mJ/cm^2

The electrical characteristics of TFTs with and without laser exposure were measured using an HP4156 semiconductor parameter analyzer. Electrical parameters including I_{on}, I_d at $|V_{ds}|=5V$ and $|V_{gs}|=15V$; minimum drain current I_{off} at $|V_{ds}|=5V$; threshold voltage V_{th}, gate voltage to provide a drain current of 100nA/μm at $|V_{ds}|=5V$, μ_{FE} extracted from maximum trans-conductance at $|V_{ds}|=0.1V$ and $V_{g\text{-}m\mathrm{gm}}$, gate voltage corresponding to μ_{FE} were extracted. Typical I_d~V_{gs} transfer characteristic curves for MILC-TFTs with and without laser exposure at 112mJ/cm^2 are shown in Figure 5. Figure 6 shows the distributions of average I_{on}, I_{off} and V_{th} and their errors for n- (Fig.6a) and p-type (Fig.6b) TFTs.

With the increasing of laser energy density, there is almost no performance improvement after 40.8mJ/cm^2 laser exposure, which implies that laser annealing at this density is not able to reduce defects in MILC poly-Si with the consequence that no improvement on TFTs performance was observed. When the laser energy density increases to 66.2mJ/cm^2, V_{th} is significantly reduced and I_{on} increases slightly. What is most obvious is the scattering degree, especially for I_{on} and I_{off}, which indicates that the grain boundaries and micro-defects in some TFT channels were remedied, while not in others. When the laser energy density increases further to 112mJ/cm^2, I_{off} reduces, V_{th} is reduced and I_{on} becomes much larger than the original one.



(a)



(b)

Figure 6. Distributions of the average I_{on}, I_{off} and V_{th} for n- (a) and p-type (b) MILC-TFTs exposed at different laser energy density.

Parameters distributed in a more uniform manner, which implies that the grain boundaries and micro-defects in different TFT channels were reduced, as it can crystallize the a-Si fully while maintaining the main grain structure of MILC poly-Si (Fig.2c). So we can see that the performance of MILC-TFTs were improved step by step when the laser energy density increases from 40.8mJ/cm^2 to 112mJ/cm^2 and the distribution of the characteristic parameters exhibits a process of tight-loose-tight.

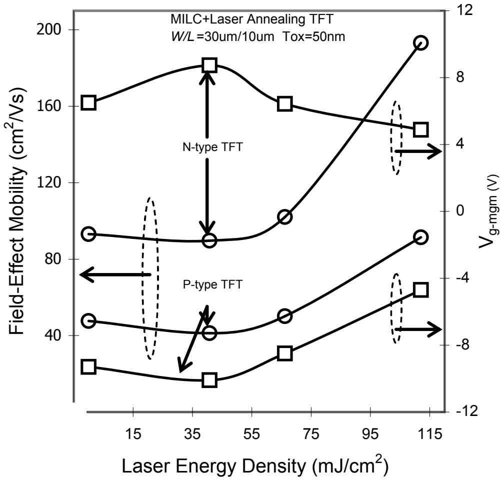


Figure 7. Plots of μ_{FE} and the $V_{g\text{-}mgm}$ *vs.* laser energy density for n-and p-type MILC-TFTs.

Figure 7 shows μ_{FE} and the $V_{g\text{-}mgm}$, versus laser energy density for n- and p-type TFTs. For n-type TFTs, μ_{FE} increases from original 92cm^2/Vs to 102 cm^2/Vs and further to 193cm^2/Vs when the energy density increases to 66.2 and 112mJ/cm^2. And $V_{g\text{-}mgm}$ reduces from 6.5V down to 6.4V and further to 4.9V. For p-type TFTs, μ_{FE} increases from 48cm^2/Vs to 50cm^2/Vs and further to 92cm^2/Vs, and $V_{g\text{-}mgm}$ improves from -9.3V down to -8.5V and further to -4.7V. So the MILC-TFTs with 112mJ/cm^2 YAG laser exposure are suitable for fabrication of poly-Si TFTs based driving circuits working at 5-8V, and this technology can be employed to realize fully-integrated active-matrix addressing circuits for flat-panel displays, though disadvantages including long crystallization time and one more lithography step to open crystallization-inducing windows remain to be solved.

4. Conclusion

YAG laser exposure to metal-induced laterally crystallized poly-Si is proposed and characterized. It is found that both the poly-Si material quality and performance of the resulting TFTs formed on it improve much at an energy density of 112mJ/cm^2. This technology is a promising one to realize fully-integrated active-matrix addressed flat-panel displays.

5. Acknowledgement

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6. References

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