Chapter 3

Crystallization in Different Laser Annealing Conditions

3.1 Introduction

Among the nowadays crystallization technologies, excimer laser annealing crystallization (ELA) had attracted much attention due to the superior properties of the uniform poly silicon thin films. ELA of amorphous silicon (α-silicon) thin films was a crucial step for the manufacturing of high-performance low-temperature poly-silicon (LTPS) TFTs. The grains of the ELA poly-silicon thin films could be grown as large as several micrometers if the laser conditions were well controlled. In addition, because of the solidification from the molten phase, the intra-grain defects, such as stacking faults and micro-twins, in the ELA poly-silicon thin films were also reduced. Poly–silicon thin films with excellent crystallization could be acquired by optimization ELA process condition. ELA LTPS TFTs with electron mobility higher than $150cm^2/V\text{-}s$ had been manufactured at process temperature below 500 ^{o}C, without causing any thermal damages in the glass substrates [17-20].

The variation parameter of excimer laser was included the laser frequency 0~300Hz, laser energy 850~1000mJ, laser energy density 330~480mJ/cm^2, scan pitch 0.004~0.1mm and scan speed 1~30mm/sec. The poly-crystallization was influenced by different frequency and energy conditions would be studied.

3.2 Experimental Procedure

3.2.1 Modification Parameter of Excimer Laser with Different Frequency Conditions

A buffer layer of 50nm/150nm thickness of SiNx/SiOx were deposited by plasma enhanced chemical vapor deposition (PECVD) means at 500°C on glass substrate. Amorphous silicon film of a 50nm thickness was deposited on buffer layer as the active layer by PECVD at 500°C with SiH_4 gas source then was heated at 500°C for one hour to remove the incorporated hydrogen in the film. After dehydrogenation, first procedure was prior clean treatment with HF 1% for 30seconds then O3 20ppm for 100seconds. The laser frequency was adjusted for every parameters of experiment. It was included the 100, 200, 300Hz. The laser energy was fixed at 950mJ. Crystallization was carried out by the excimer laser anneal in N2 ambiance at room temperature. Top-gate, poly-Silicon TFTs were fabricated with excimer laser annealing (ELA). The process flow was depicted in Fig.4-1. (Just replaced the CW laser by excimer laser). The polycrystalline layer was tailored into active islands. Next, PR coating and patterned then n+ ion doping of PH_2^+ ion implantation with the concentration of 6×10^{14} cm^{-2}, then 1000Å TEOS gate oxide was deposited using PECVD, then PR coating and patterned, then LDD ion doping of PH_2^+ ion implantation with the concentration of 2×10^{13} cm^{-2} was carried out to form the n-type source and drain region, then PR coating and patterned, then p+ ion doping of BF_2^+ ion implantation with the concentration of 1×10^{15} cm^{-2} was carried out to form the p-type source and drain region, than rapid thermal annealing was performed to activate the implanted dopants and recrystallize the source and drain region at temperature 350°C. 2000Å Mo gate electrode was deposited using PVD. Then, a 3000Å/500Å PECVD SiOx/SiNx was deposited as passivation layers. After contact holes opening, Ti/Al/Ti was deposited by thermal evaporation and patterned to form the electrical connecting pads. Finally, the devices were passivated by NH_3 plasma

The transfer characteristics of the poly-Silicon TFTs were measured by HP4156 semiconductor parameter analyzer. The device parameters including the field-effect mobility, the threshold voltage, the subthreshold swing, the OFF current and the ON/OFF current ratio were extracted from the measured characteristics.

3.2.2 Modification Parameter of Excimer Laser with Different Energy Conditions

The frequency of excimer laser was fixed at 300Hz and the laser energy was adjusted for every parameters of experiment. It was included the laser energy range from 850 to 950mJ. After laser irradiation, top-gate, poly-silicon TFTs was fabricated with conventional processing flow was same as different frequency condition.

3.2.3 Variation Excimer Laser Ambiance with Different O2 Concentration

A buffer layer of 50nm/150nm thickness of SiNx/SiOx were deposited by plasma enhanced chemical vapor deposition (PECVD) means at 500˚C on glass substrate. Amorphous silicon film of a 50nm thickness was deposited on buffer layer as the active layer by PECVD at 500°C with SiH_4 gas source then was heated at 500˚C for one hour to remove the incorporated hydrogen in the film. After dehydrogenation, first procedure was prior clean treatment with HF 1% for 30seconds. The crystallization ambiance was in the different O2 concentration. It was included the concentration of 100, 500, 1000, 2000 and 5000ppm. Top-gate, poly-Silicon TFTs was fabricated with conventional processing flow was same as different frequency condition.

3.3 Results and Discussion

3.3.1 Physical Characterizations of Poly-Silicon Thin Film

The Fig. 3-1 was shown the average grain size distribution of different frequency condition after laser irradiation, it could be separated three regions of energy density, it was included the high energy density region, middle energy density region and low energy density region, the high energy density region was 400~430mJ/cm², the middle energy density region was 360~400mJ/cm², the low energy density region was 330~350mJ/cm², every frequency had same trend in average grain size distribution. Only the high energy density region with frequency of 200Hz condition was larger grain size than other conditions in energy density 430 mJ/cm². In the middle energy density region, which was the transition region between the partial melting and complete melting that could induce larger grain with any condition of frequency so the minimum grain size distribution had the larger grain size in this region, as shown in the Fig. 3-2. The maximum grain size distribution always had larger grain size in high energy density region, as shown in the Fig. 3-3. As a result of different frequency condition was less relation with grain size, only the energy density was relation with grain size. If the laser frequency was 300Hz the scan speed was higher, because of the scan speed equal to frequency (Hz) multiplied by pitch (mm), owing to the running throughput was considered the frequency was set 300Hz always. The Fig. 3-4~3-9 were shown the SEM micrographs of the ELA poly-silicon film after Secco etching for 60seconds. The excimer laser energy densities were adjusted from 330 to 430 mJ/cm². The grain structure was same each other in any laser frequency condition, and optimum grain size was about 0.3um.

In the Fig. 3-10~3-12 the different laser energy condition could be separated three regions of energy density also, owing to the trend of every laser energy condition was similar each other in average and minimum grain size distribution, although the maximum grain size distribution had some different in the high energy density region but this situation had more relative with energy density. As a result of different energy condition was less relative with grain size, the laser energy just only influenced the high voltage value of laser, when laser energy was increased the high voltage value would be increased by laser machine. The Fig. 3-13~3-18 were shown the SEM micrographs of the ELA poly-silicon film after Secco etching for 60seconds. The excimer laser energy densities were adjusted from 330 to 430 mJ/cm². The grain structure was same each other in any laser energy condition, and optimum grain size was about 0.32um.

In the different laser anneal ambiance [21]; the average grain size distribution was observed the trend similar to pre treatment clean of O3 20ppm, as shown in the Fig. 3-19. It could be separated three regions that was included the high energy density region of

410~430mJ/cm², the middle energy density region of 360~410mJ/cm² and the low energy density region of 350~360mJ/cm². The medium energy density region is shifted forward 20 mJ/cm²; it meant the surface oxidative speed of α-silicon was faster than pre treatment clean of O3 20ppm. The maximum grain size distribution had larger grain size between high energy density region and middle energy density region, as shown in the Fig. 3-20. As a result of maximum grain size distribution had similar to pre treatment clean of UV exposure condition with maximum grain size distribution. It was obviously that oxidative surface of α-silicon was used gas of oxidant like O3 or O2 gases. The energy density was increased higher the grain size was decreased in high energy density region. The minimum grain size distribution was same as pre treatment clean of O3 20ppm and UV exposure, as shown in the Fig. 3-21. In the minimum and maximum grains size distribution with O2 concentration 500ppm had larger grain than others in energy density 390 mJ/cm² and 400 mJ/cm². The second large grain size was O2 concentration 2000ppm in minimum grains size distribution with energy density 390mJ/cm² and in the average grain size distribution with O2 concentration 2000ppm had larger grain than others in energy density 390 mJ/cm², so the optimization of different laser anneal ambiance was O2 concentration of 2000ppm in energy density 390 mJ/cm2 and optimum grain size was about 0.42um. In the Fig. 3-22~3-31 were shown the SEM micrographs of the ELA poly-Silicon film after Secco etching for 60seconds. The excimer laser energy densities were adjusted from 350 to 430 mJ/cm². In the Fig. 3-22 and 3-23, the grain structure of 100ppm O2 concentration was same as pre treatment clean of HF1%, the grains structure were unregulated and non uniform in high energy densities, so the energy densities more high the grain size more large and non uniform. In the Fig. 3-24 and 3-25, the O2 concentration was 500ppm the grain structure had 1D self-alignment grain structure like O3 pre treatment clean condition in the middle energy density. If the O2 concentration was increased the grain structure had more regularization in middle energy densities. In the Fig. 3-26~3-31, the grain structure also had 1D self-alignment grain structure in the middle energy density, it was obvious unregulated and non-uniform in high energy densities also.

The atomic force microscopy (AFM) was shown in Fig. 3-32. The O2 ambiance with concentration 2000ppm was shown the mean roughness and maximum roughness in the energy densities 300, 340, 360 mJ/cm^2, respective. The applied laser energy density was 300 mJ/cm^2 and the mean roughness was 7.67nm, maximum roughness was 67.56nm, the applied laser energy density was 340 mJ/cm^2 and the mean roughness was 11.02nm, maximum roughness was 90.69nm, the applied laser energy density was 360 mJ/cm^2 and the mean roughness was 7.76nm, maximum roughness was 70.20nm, the roughness was more rough than O3 pre treatment clean condition in optimization grain size condition. But the shape was different with O3 pre treatment clean condition, the shape of O3 pre treatment clean condition was similar to those invert V-shaped of the ELA poly-Silicon thin films and before chapter was mention the roughness shape was the location of grain boundary. The shape of O2 ambiance was like the cylinder.

3.3.2 Electrical Characteristics

The field effect mobility (μ_{FE}) versus laser frequency as shown in the Fig. 3-33 had similarly result in every frequency condition. The average μ_{FE} had maximum value 127cm^2/V*s with laser frequency 300Hz for n-type LTPS TFTs; the average μ_{FE} had maximum value 102cm^2/V*s with laser frequency 200Hz for p-type in the energy density 390 mJ/cm^2. The trend of the threshold voltage was same as field effect mobility, as shown in the Fig. 3-34. The average Vt had minimum value 2.8V for n-type LTPS TFTs; maximum value –2.6V for p-type with laser frequency 300Hz in the energy density 390 mJ/cm^2. The file transfer characteristics of ELA LTPS TFT using laser frequency 300Hz in energy density 390 mJ/cm^2. Some important electrical characteristics of LTPS TFTs were also listed, it was included the W/L = 6μm/12μm, Vd=0.1V, Vt –2.8V, Ufe 97 cm^2/V•sec, Ioff 2.93E-13A, SS 0.22 for p-type LTPS TFT and Vt 3.0V, Ufe 124 cm^2/V•sec, Ioff 1.23E-13A, SS 0.62 for n-type, as shown in Fig. 3-35 and 3-36.

The field effect mobility (μ_{FE}) versus laser energy as shown in the Fig. 3-37 had similarly result in every energy condition. The average μ_{FE} had maximum value 124cm^2/V*s with laser energy 950mJ for n-type LTPS TFTs; the average μ_{FE} had maximum value 97cm^2/V*s with laser energy 900mJ for p-type in the energy density 360 mJ/cm^2. The trend of the threshold voltage was same as field effect mobility, as shown in the Fig. 3-38. The average Vt had minimum value 2.9V with laser energy 850mJ for n-type LTPS TFTs; maximum value –2.0V with laser energy 950mJ for p-type in the energy density 380 mJ/cm^2. The file transfer characteristics of ELA LTPS TFT using laser energy 950 mJ in energy density 380 mJ/cm^2. Some important electrical characteristics of LTPS TFTs were also listed, it was included the W/L = 6μm/12μm, Vd=0.1V, Vt –2.1V, Ufe 101 cm^2/V•sec, Ioff 1.85E-13A, SS 0.21 for p-type LTPS TFT and Vt 2.8V, Ufe 123 cm^2/V•sec, Ioff 2.02E-13A, SS 0.38 for n-type, as shown in Fig. 3-39 and 3-40.

In the Fig. 3-41, the field effect mobility (μ_{FE}) versus different laser irradiation ambiance, the different O2 concentration was shown the concentration more high the μ_{FE} was increased. The O2 concentration was 2000ppm that μ_{FE} was 145 cm^2/V*s for n-type LTPS TFT at mean value and p-type was 97 cm^2/V*s in energy density 390 mJ/cm^2. The threshold voltage of different O2 concentration was depicted the variation in different O2 concentration, in 2000ppm the threshold voltage of Vtn-Vtp was smaller than others concentration, as shown in Fig. 3-42. In the Fig. 3-43, the transfer characteristics of p type ELA poly-Silicon TFTs with ambiance of 2000ppm O2 concentration in laser energy density 410mJ/cm^2 had data listed W/L = 6μm/12μm, Vd= 0.1V, Vt –1.7V, Ufe 100 cm^2/V•sec, Ioff 1.18E-13A, SS 0.15. The transfer characteristics of n type were drawn in Fig. 3-44, Vt 2.0V, Ufe 148 cm^2/V•sec, Ioff 2.94E-13A, SS 0.47.

3.4 Summary

As a result of different frequency condition was less relation with grain size, only the energy density was relation with grain size. If the laser frequency was 300Hz the scan speed was higher, because of the scan speed equal to frequency (Hz) multiplied by pitch (mm), owing to the running throughput was considered the frequency was set 300Hz always.

As a result of different energy condition was less relative with grain size, the laser energy just only influenced the high voltage value of laser, when laser energy was increased the high voltage value will be increased by laser machine.

In different ambiance of ELA crystallization had different efficiency, before mention the process of ELA crystallization had ambiance of N2 gas, now the concentration of low O2 concentration with 2000ppm was utilized in ELA crystallization ambiance. From the results of material analysis, the LTPS thin films fabricated by ELA crystallization in ambiance of low O2 concentration had surface roughness like before mention process, the maximums surface roughness was about 90nm and average surface roughness was about 11nm, but the shape had some difference, the LTPS thin films surface roughness of low O2 concentration status had the shape like the cylinder in which the position was grain boundary and potential barrier was larger than grain area. The cylinder top surface were close to the gate bottom, when gate applied the forward bias, it would enhance the high electric file near the gate then induced the average thresholds voltage degradation. LTPS TFT's fabricated by ELA crystallization in ambiance of low O2 concentration had lower thresholds voltage than N2 ambient condition, the thresholds voltage of +2V and –2V could be achieved for n-channel and p-channel ELA LTPS TFTs, respectively.