A RELIABLE APPROACH TO A RAPID CALCULATION OF THE GRAIN SIZE OF POLYCRYSTALLINE THIN FILMS AFTER EXCIMER LASER CRYSTALLIZATION

ZANESLJIV NAČIN HITREGA IZRAČUNA VELIKOSTI ZRN V POLIKRISTALNI TANKI PLASTI PO UV-LASERSKI KRISTALIZACIJI

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Excimer laser crystallization (ELC) is the most commonly employed technology for fabricating low-temperature polycrystalline silicon (LTPS) thin films. The grain size of polycrystalline thin films after ELC is usually determined with a manual calculation, which includes certain disadvantages, i.e., human error and is time-consuming and exhausting. To mitigate these disadvantages, a high-efficiency approach to calculating the grain size of polycrystalline thin films automatically is proposed. It was found that the selected-boundary-definition approach is a promising candidate for calculating the grain size of polycrystalline thin films. The savings in the analysis time is up to 75 %. The average error rate of the measurement can be controlled within 8.33 %.

Keywords: low-temperature polycrystalline silicon, automatic grain-size analysis, excimer laser crystallization

1 INTRODUCTION

High-performance complementary metal-oxide-semiconductor (CMOS) circuits on glass are essential for the system-on-panel (SOP) technology, which has potential applications in various information devices including cell-phones, laptop computers and large-size flat panel television sets. Polycrystalline silicon (poly-Si) thin films have been widely used as CMOS gates, thin-film transistors (TFTs), solar cells and various other applications in semiconductor-device technology. Excimer laser crystallization (ELC) is an industrial technique used for preparing poly-Si thin films on commercially available, inexpensive glass substrates for the development of high-performance TFTs in active-matrix flat panel displays.1-6 A rapid deposition of the laser-energy density, on a nanosecond time scale, onto the surface region of the an amorphous-silicon (a-Si) thin film leads to its melting and recrystallisation into a poly-Si thin film, while keeping the glass substrate at a low temperature. The final quality of the device depends significantly on the phase-transformation mechanisms which need to be manipulated precisely for obtaining poly-Si thin films with a large grain size and a good uniformity. The phase-transformation mechanisms of a-Si thin films have been extensively investigated using an in-situ optical diagnostic technique during ELC in the previous studies.7-17 Numerous researches have been done for fabricating large-grained poly-Si thin films because the performance of TFTs is significantly affected by the size of the poly-Si thin films after ELC.18-23 Until now, however, the grain size of the poly-Si thin films after ELC has usually been determined with a manual calculation. This approach included certain disadvantages such as human error and was time-consuming and exhausting. Therefore, a high-efficiency approach is proposed in this work for calculating the grain size of polycrystalline thin films efficiently and accurately using the Image-Pro software.24,25

2 EXPERIMENT

Figure 1 shows a schematic illustration of the experimental set-up for ELC. The sample has a stacked structure consisting of a thick 300 nm SiO2 capping layer and a thick 90 nm a-Si layer formed on a thick 0.7 mm non-alkali glass substrate (Corning 1737). All the films were prepared with plasma-enhanced chemical vapor deposition (PECVD). These samples were then dehydroge-
nated with a thermal treatment at 500°C for 2 h to reduce the hydrogen content in order to prevent the ablation caused by a sudden hydrogen eruption during ELC. The samples were then held by self-closing tweezers at the end of a cantilever beam fixed to an x–y precision translation stage. The x- and y-axis displacements of the two stages can be accurately manipulated (resolution = 0.625 μm). The movement of the focusing lens mounted onto a z-axis stage was precisely controlled to adjust the desired excimer laser fluences for crystallization. The pulsed excimer laser-energy levels were monitored using a laser power meter (Vector H410 SCIENTECH). The variation in the pulse-to-pulse excimer laser energy was found to be less than 5%. The a-Si thin films were irradiated with an excimer laser beam (λ = 351 nm, repetition rate = 1 Hz, LAMBDA PHYSIK COMPex 102) with laser fluences ranging from 100 mJ/cm² to 500 mJ/cm². A stainless-steel slit (2 mm × 15 mm) located in the optical path of the excimer laser was employed to transform the incident Gaussian beam into a rectangular beam spot with a better than ±10% energy variation. All the experiments were performed at ambient temperature and pressure.

After ELC, the microstructural analyses of the annealed poly-Si thin films were carried out using field emission scanning electron microscopy (FE-SEM) with JEOL JSM-6500F. Before the FE-SEM observation, the crystallized silicon films were Secco-etched in order to highlight the grain boundaries (GBs) and intra-grain defects. The acceleration electron beam energy for FE-SEM was 15 kV (a resolution of 1.5 nm). Six approaches (count, auto-split, watershed split, limited watershed split, boundary definition and selected-boundary definition) were employed for calculating the grain size of the poly-Si thin films.

3 RESULTS AND DISCUSSION

Figure 2 shows a typical SEM micrograph of the poly-Si thin films after ELC. The grain size can be determined from the longest length inside the grain boundary. To determine the best approach to replace the tradition manual-calculation method, a test SEM micrograph was selected to be investigated. Figure 3 shows the grain-size calculation result using the manual-calculation approach. The total number of the grain size of poly-Si was 24. The largest grain size, the smallest grain size and the average grain size were (333.3, 26.6 and 152.2) μm, respectively. Figure 4 shows the grain-size calculation result using six different approaches. Figure 5 shows the variation in the counts of the grain size for seven different calculation approaches. The average error rate for the approaches of count, auto-split, watershed split, limited watershed split, boundary definition and selected-boundary definition was (21.32, 19.33, 20.76, 20.76, 16.29 and 8.33)% respectively. As one can see, the selected-boundary-definition approach provides the lowest average error rate in the grain-size calculation compared with the tradition manual-calculation approach in this case. The average error rates for the approaches of count, auto-split, watershed split and limited watershed split were higher than those of the approaches of boundary definition and selected-boundary definition because the Image-Pro software cannot precisely evaluate the...
Figure 4: Grain-size calculation result using six different approaches of: a) count, b) auto-split, c) watershed split, d) limited watershed split, e) boundary definition and f) selected-boundary definition.

Slika 4: Rezultat izračuna velikosti zrn s šestimi različnimi načini: a) štetje, b) avtomatska razdelitev, c) razdelitev po razvodnicah, d) omejena razdelitev po razvodnicah, e) definicija mej in f) selektivna definicija mej.

Figure 5: Variation in the counts of the grain size for seven different calculation approaches.

Slika 5: Razlike v izračunu velikosti zrn pri sedmih različnih načinih izračuna.

Figure 6: SEM micrograph of poly-Si thin film of case study 1.

Slika 6: SEM-posnetek poli-Si tanke plasti pri študiju primera 1.
grain boundary of a SEM micrograph. To reduce the average error rate of the measurement, the two approaches of boundary definition and selected-boundary definition were further applied. The average error rate of the measurement was still not acceptable, though the boundary-definition approach can reduce the average error rate of the measurement. Finally, the selected-boundary-definition approach was applied. The selected-boundary-definition approach provides the best accuracy of the grain-size calculation because the grain boundary of the SEM micrograph was traced first and then calculated using the Image-Pro software.

To evaluate the accuracy of the selected-boundary-definition approach, two case studies were applied to investigate the average error rate. Figure 6 shows a SEM micrograph of the poly-Si thin film of case study 1. Figure 7 shows the variation in the counts of the grain size for two different calculation approaches in case study 1. The average error rate of the measurement was only 1.28 %. In this case, the total time for calculating the grain size with the manual calculation was approximately 16 h. However, the total calculating time was drastically reduced to approximately 4 h using the selected-boundary-definition approach. The saving in the analysis time was up to 75 %. Figure 8 shows a SEM micrograph of the poly-Si thin film of case study 2. The average error rate of the measurement was only 4.03 %. In this case, the total time for calculating the grain size with the manual calculation was approximately 12 h. However, the total calculating time was drastically reduced to approximately 3 h using the selected-boundary-definition approach. The saving in the analysis time was up to 75 %. It is worth noting that the average error rate of the measurement was obviously smaller than for the test sample because the grain boundary was clear for the two SEM micrographs. Thus, a SEM micrograph with a clear grain boundary is critical for calculating the grain size with the Image-Pro software when the Secco etching is employed.

As discussed above, the Image-Pro software is a powerful tool for analyzing the grain size of the poly-Si thin films after ELC. The saving in the analysis time is up to 75 % and the average error rate of the measurement can be controlled within 8.33 % when using the computer-calculation approach compared with the manual-calculation approach.

4 CONCLUSIONS

A simple and highly efficient approach for calculating the grain size of the poly-Si thin films after ELC was successfully demonstrated. A SEM micrograph with a clear grain boundary is critical for calculating the grain size with the Image-Pro software. The selected-boundary-definition approach was proved to be a promising candidate for calculating the grain size of the poly-Si thin films efficiently and accurately. The saving in the analysis time was up to 75 % and the average error rate of the measurement can be controlled within 8.33 % when compared with the manual-calculation approach.
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5 REFERENCES


