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The Effects of Annealing Parameters on the Evolution of Surface Morphology of A-Si Thin Films Irradiated by ArF Excimer Laser

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ABSTRACT

Polycrystalline silicon (poly-Si) thin films have been regarded as one of promising materials for manufacturing today's commercial multi-media products such as mobile phones, television, PDAs. The main advantage of using poly-Si films to fabricate high performance electronic devices is due to the ability of achieving higher field effect mobility. However, the surface morphology and defect density of the poly-Si film have profound effect on whether this is to be achieved. The surface morphology of a-Si films annealed at 1Hz, shot number of 100, 300 shots and laser fluence ranging from 200 to 500mJ/cm^2 were observed, depending on the laser fluence, to be evolved as ridges, hillocks, network micro-craters, pillars with some formation of redeposited debris due to the evaporation of a-Si films. The increase of shot number has shown capable of enhancing the laser fluence accumulation, leading to the consequence of forming enlarged surface structures such as pillars, craters. The alteration of repetition rate has effect in affecting the geometrical size of obtained surface structures on a-Si films due to the modification of melting duration and resolidifaction speed involved during the laser irradiation process.

Keywords: excimer laser irradiation, surface morphology, poly-Si, SLG, TFT-LCDs

ArF 準分子雷射退火參數對非晶矽薄膜退火後表面形貌變化影響之研究

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摘 要

具有大晶粒及高電子遷移率之多晶矽薄膜，被認為可取代非晶矽薄膜以提高顯示器等光電電子元件之可靠度、解晰度並進而達到系統整合性之目的。然而這些特性能否達到將受到多晶矽薄膜之表面形貌與缺陷密度之影響。本研究係調變準分子雷射之能量密度、脈衝重複頻率與擊發數進行非晶矽薄膜之結晶研究，以探討準分子雷射退火參數對退火非晶矽薄膜之表面形貌的影響。實驗結果發現當退火參數為脈衝頻率 1Hz、擊發數 100、300 下及能量密度 200 至 500mJ/cm^2 時，隨者能量密度的增加，表面形貌由脊狀、丘狀、熔融網路坑狀逐漸改變至柱狀物並發現有因融熔矽被蒸發後再沉積之碎片。增加脈衝重複頻率與擊發數被發現有調控退火時之融熔時間及固化速度之效應，而提高退火時能量密度之累積，產生使非晶矽薄膜退火後之表面形貌幾何尺寸增加之結果。

關鍵詞：準分子雷射，表面形貌，多晶矽，超側向成長，薄膜電晶體液晶顯示器

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I. INTRODUCTION

Cathode ray tube (CRT) displays had become a primary tool for image transfer and information collecting, since the CRT oscilloscope was invented in 1897. However, owing to the increasing demands on image resolution, low-power consumption, lightweight and portability, the flat panel displays (FPDs) have been developed to replace the CRT displays. Various FPDs such as liquid crystal displays (LCDs), plasma display panels (PDPs), field emission displays (FEDs) and electroluminescent displays are now attracting much interest in research works aimed on manufacturing today's commercial multi-media products such as mobile phones, television, PDAs, notebooks, PCs and camcorders. One of the promising type of LCDs is the active-matrix LCD, in which a built-in thin-film transistor (TFT) is applied to control the on/off of the liquid crystal. The TFTs are often produced from amorphous silicon (a-Si) or polycrystalline silicon (poly-Si) thin films deposited on glass substrate. Because of more defects formed in as-deposited a-Si films resulting in lower carrier (electrons and holes) mobility and limited switching speed, the experimental studies in developing a fast and cheap fabrication process for producing poly-Si thin films with higher carrier mobility are demanding to realize LCDs with good brightness, sharp contrast, high resolution, fast switching speed and wide viewing angle.

Techniques used to fabricate poly-Si films, applied for producing active-matrix liquid-crystal displays (LCDs) on low-temperature (< 600°C) glass substrates at low cost have been under increasingly significant researches and developments in recent years [1-4]. In general, the fabrication technique of poly-Si films can be categorized as as-deposited (low pressure chemical vapor deposition - LPCVD), solid phase crystallization (SPC), rapid thermal annealing (RTA) and excimer laser annealing (ELA). The as-deposited poly-Si films produced by LPCVD have the drawbacks of using deposition temperatures higher than 600°C with the microstructures containing small grain size, poor crystallinity and high density of impurities/defects. The SPC is useful in improving the poly-Si film's carrier mobility due to the increase of the grain size, however it is required to be operated under a longer annealing time up to 60-70 hours. ELA has been recognized to be more superior compared to other techniques, while considering the fabrication cost/efficiency with better LCDs' performance capable of being achieved during the manufacture of poly-Si TFT-LCDs by ELA of a-Si films [5-7]. The higher carrier mobility of poly-Si films are able to be realized by excimer laser recrystallization of a-Si films. This is caused by the ability of allowing local supply of large enough energy in annealed a-Si films without overheating the substrate during the short pulsed (10-30ns) melting/regrowth process due to a-Si films' strong optical absorption to UV laser light. Therefore, the poly-Si films with required surface morphology, good crystallinity and few in-grain defects [6, 7] can be achieved by ELA process using adequately controlled annealing parameters such as laser energy density, beam homogeneity, repetition rate and number of laser shots have to be controlled.

Based on the recent studies on the surface morphology and recrystallization behaviour a-Si films induced by ELA process, three possible annealing regimes - low energy density regime, super lateral growth (SLG) regime and high energy density regime, being dependent on the laser fluence and shot number, are assumed to be involved during the irradiation process. At lower energy density, a-Si film is partially melted. The micro-structure achieved during this regime consists of mainly two kinds of layers：an upper layer with larger grains whose thickness is dependent upon the primary melt developed in a-Si film and a lower layer with finer grains which is considered to be recrystallized by a so-called explosive crystallization process. As the laser fluence is increased up to a threshold amount. The a-Si films are almost complete-melted with few unmelted microcrystalline clusters found on the molten silicon/substrate interface. The grains of induced poly-Si films are enlarged and grown laterally around the unmelted Si clusters until they are impinged on each other. The grain size of up to 1μm is thought to be achievable. This particular phenomenon is often regarded as SLG. The SLG is considered to be dependent on the heterogeneous recrystallization of the molten a-Si film, starting from the nucleation seeds sitting around the molten silicon/substrate interface. At higher energy density, a-Si film is over-melted. A fine-grained structure is produced due to the occurrence of the substantial super-cooling throughout the whole molten a-Si film before re-solidification, homogeneous nucleation and grain growth can be carried out [8-10].

Because ArF ELA process is conducted in an extremely short pulse duration (~20ns) resulting in a shallow melting/regrowth process. The formation of the adequate grain size of poly-Si film with required surface morphology, affecting the manufacturing of TFT displays, are thought to be dependent on the vertical solidification speed of the molten silicon involved during laser annealing process. Early investigations on the laser recrystallization of a-Si films have attributed the characteristics of the induced surface morphology of annealed a-Si films to the differences of latent heat and thermal conduction occurred between the interface of poly-Si/a-Si and a-Si/glass substrate, to the hydrogen gas formed in plasma-enhanced chemical vapor deposition a-Si film, to the positive feedback of optical interference effects involved during multi-shots laser recrystallization process, to the capillary wave excited by the volume change at the silicon-melt transition resulting in the viscous damping and the agglomeration of the molten silicon and also to the adhesion force between molten silicon and unmelted microcrystalline Si greater than the agglomeration force of the molten silicon, leading to the formation of some surface structures such as bumps, ridges, craters and hillocks [11].

In early reports of surface evolution involved during laser irradiating a-Si thin films, two main models were proposed. One model suggested that during annealing process, the a-Si thin films were recrystallized by a threshold laser energy density resulting in poly-Si's grain growth. The grains were grown from heterogeneous nucleus nucleated from unmelted microcrystalline silicon and squeezed each other due to a capillary waves induced by the volume change at the silicon-melt transition interface. The formation of SLG grains with poorer surface roughness was achieved with the grain boundary formed at the areas with hillock-like protrusions while two grains were grown and impinged on each other [12, 13]. The other model assumed that the micro-hillocks were formed during laser annealing process due to the adhesion force occurred between the molten Si and unmelted silicon clusters larger than the agglomeration force of the molten Si. However, the micro-hillocks were not always formed on the grain boundary areas [11].

This paper focuses on the experimental investigation of the evolution of induced surface morphology of laser irradiated a-Si film, deposited on glass substrate using PECVD technique, using 193nm-ArF ELA technique. The effects of the laser fluence, number of laser shot and repetition rate on the surface microstructure formed on the ELA-annealed a-Si film surface are analyzed with the Secco-etching and SEM techniques.

II. EXPERIMENTAL PROCEDURES

100 nm-thick a-Si∶H films were deposited on alumosilicate glass (NEG – OA10) with the thickness of 0.7mm using PECVD (Plasma Enhanced Chemical Vapor Deposition) technique, which is followed by dehydrogenization treatment at 450°C for 2hrs. The a-Si∶H films were then annealed at room temperature to be transformed into poly-Si films using (Figure 1.) ArF excimer laser light (λ=193 nm) with the maximum pulse energy of 450mJ, maximum repetition rate of 100 Hz and average power of 35W and the irradiated area fixed at (spot size = 1.4mm x 1.4mm) 1.96 mm^2. Each pulse in a duration of 20 ns provides a maximum laser fluence (energy density) of 3J/ cm^2 over a 2.8 cm^2 area. The laser annealing of a-Si∶H films was conducted incorporated with a beam homogenizer ensuring a uniform

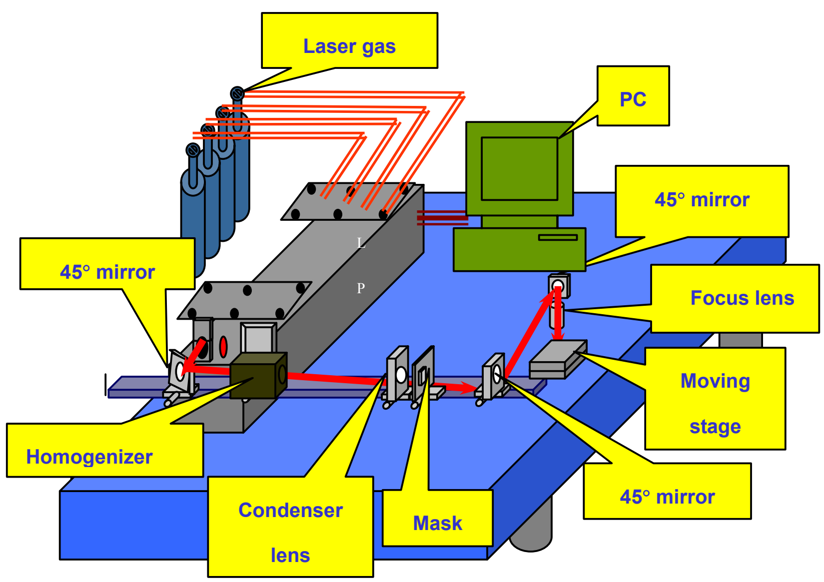


Fig. 1. A schematic diagram of excimer laser annealing equipment.

distribution of energy density over the laser irradiated areas. The processing parameters involved in this study are shown in Table 1. The surface morphology of the laser irradiated a-Si films were investigated by Secco-etching and SEM techniques in order to understand the mechanisms for the evolution of surface morphology of laser irradiated a-Si films which is assumed strongly affecting the carrier mobility of produced poly-Si films applied for developing high efficient TFT LCDs.

Table 1. Processing parameters involved for ELA of a-Si films.

Laser fluence (mJ/cm^2)	200、300、400、500
Shot number (shots)	50、100、300、500
Repetition rate (Hz)	1、5、10、25、50、100

III. RESULTS AND DISCUSSION

3.1 The analysis of threshold laser fluence involved during laser annealing of a-Si films

Theoretically, the evolution of induced surface morphology of laser annealed a-Si films, depending on the chosen laser fluence, can be illustrated in Figure 2. As the laser fluence is controlled below Em – the threshold fluence for the initial melting of a-Si films, it is shown that there is almost no change of surface morphology induced on annealed a-Si film surface. With a-Si film laser irradiated at a laser fluence controlled between Em, and Ev – the threshold fluence for the evaporation of, it would induce some surface microstructures. Using a lower fluence controlled between Em and Ev, bumps, ridges, hillocks or pillars are likely to be induced on the annealed film surface. While a higher fluence over Ev is used, craters, pillars and molten silicon islands are obtained on the surface. It is considered that the poly-Si grains are likely to be produced with the laser fluence set between Em and Ev resulting in the surface morphology of small ridges and hillock-like structures.

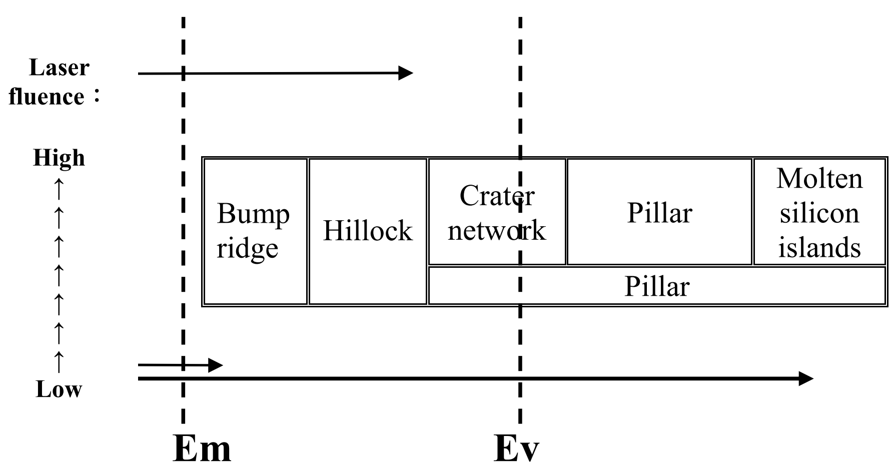


Figure 2. A schematic diagram showing the dependence of laser fluence on the induced surface morphology of laser irradiated a-Si films.

A diagram illustrating the evolution of the surface morphology involved during laser annealing of a-Si films is shown in Figure 3. As shown in Figure 3a, some bumps are formed with the laser fluence to be set around Em resulting in initial melting of a-Si films. With the laser fluence to be increased and controlled between Em and Ev, it results in the required energy accumulated and transferred into a-Si films during laser annealing process with ridges and hillocks formed on the films surface. Three different annealing regimes can be identified as below, depending on the laser fluence involved during ELA process leading to various melting depths：

(i) Partial melting regime：This regime is assumed to occur while the melting depth obtained in annealed a-Si films is controlled smaller than the a-Si film thickness. The obtained surface structures of annealed a-Si films are shown to be ridges and hillocks (Figure 3b) produced probably due to the capillary wave excited by the volume change at the silicon-melt transition interface, resulting in the viscous damping and the agglomeration of the molten silicon. The microstructures induced during this annealing regime (analyzed after the Secco-etching) are small poly-Si grains nucleated vertically from the unmelted silicon nanoclusters acting as heterogeneous nucleation seeds situated in the interface of molten silicon/unmelted a-Si by explosive recrystallization process.

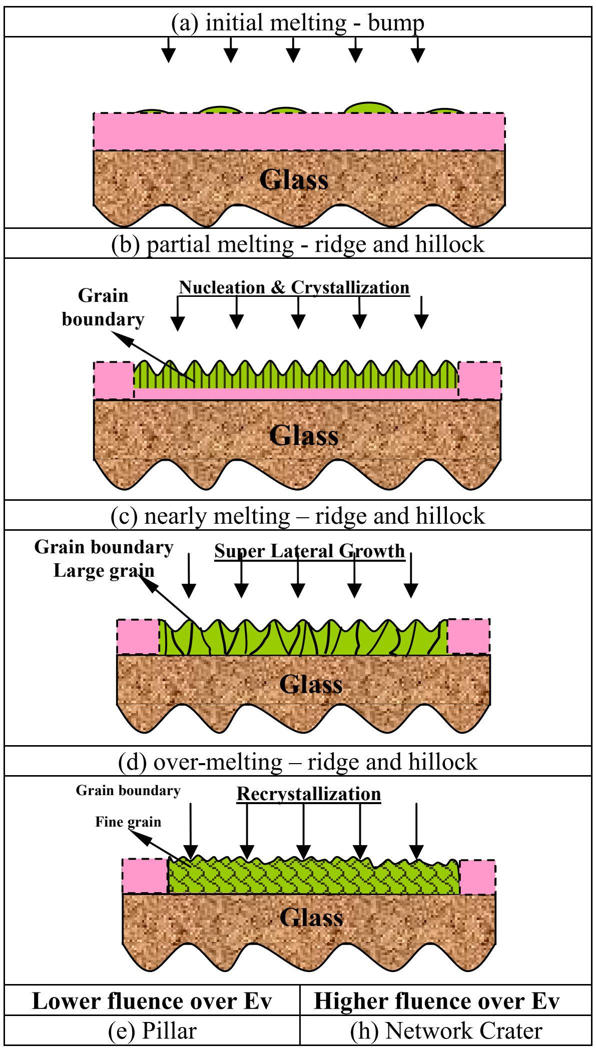
(ii) Nearly melting regime：As the laser fluence is increased up to a threshold amount enough for nearly melting a-Si films, the grains of induced poly-Si films are enlarged and grown vertically and laterally around the unmelted Si clusters until they are impinged on each other. The grain size of up to 1μm is considered to be achievable. This particular phenomenon is often regarded as SLG considered to be dependent on the heterogeneous recrystallization of the molten Si film, starting from the nucleus sitting around the Si/glass substrate interface. The surface morphology induced during this regime is shown to be polygonal ridge-like structure and protruded hillocks sitting on the grain boundary areas of poly-Si films (Figure 3c).

(iii) Over-melting regime：At higher energy density, a-Si is found to be over-melted. A fine-grained structure is achieved due to the substantial super-cooling occurred during the recrystallization from the homogeneous nucleus existed in the whole molten a-Si film, resulting in the formation of ridges and hillocks on the annealed a-Si films (Figure 3d).

As shown in Figures 3e to 3j, with the laser energy density to be increased over Ev – the required fluence for evaporation of a-Si films, the obtained surface morphology is shown to be network-craters, pillars or molten silicon islands with some micro-debris redeposited on the outer regions of laser ablation areas.

As a-Si films are laser irradiated at a lower energy density being accumulated over Ev, there is less molten silicon to be ejected out of the laser irradiated areas. The surface morphology induced during this regime are pillars formed by the agglomeration of molten silicon onto hillocks, which are gradually becoming higher and thicker and uniformly distributed over the laser irradiated areas (Figures 3e to 3g).

As a-Si films are laser irradiated at a higher energy density being accumulated over Ev, there is lots of molten silicon to be ejected and redeposited on the outer regions of laser irradiated areas. The surface morphology produced during this regime are network craters, pillars which are formed by agglomeration of molten silicon onto the hillocks sitting on the boundary of network craters and molten silicon islands (Figures 3h to 3j).



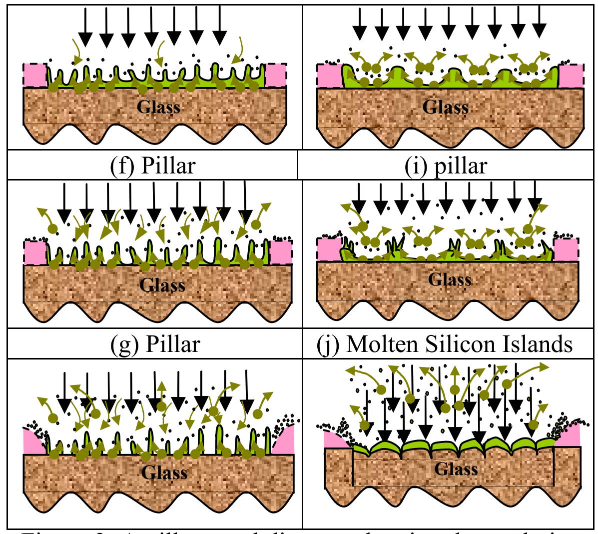
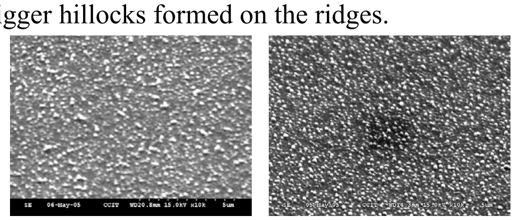


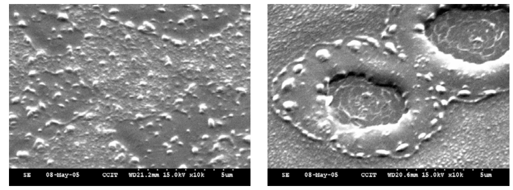
Figure 3. An illustrated diagram showing the evolution of the surface morphology of laser irradiated a-Si films (■ : represents a-Si, ■ : represents poly-Si).

3.2 Effect of laser fluence

Figure 4 shows the effect of laser fluence on the evolution of achieved surface morphology of a-Si films laser irradiated using 100 shots, repetition rate of 1 Hz and laser fluence ranged from 200 to 500mJ/cm^2. As a-Si films were laser annealed under multi-shot condition at 1Hz-100shots, the a-Si films were observed to be nearly melted at the laser fluence of 200mJ/cm^2 due to the laser photon energy being accumulated during the 100 laser shot irradiation process. It resulted in the surface morphology of smaller ridge-enclosed structures with well-scattered hillocks, which were considered to be grown from the homogeneous nucleation seeds in molten silicon and the heterogeneous nucleation seeds in silicon/glass substrate interface by the agglomeration of the molten silicon (Figure 4a). As the energy density is increased up to 300 mJ/cm^2, the heat accumulated by the 100-shot excimer laser irradiation is high enough to fully melt the whole a-Si film, leading to the formation of uniformly distributed small hillocks grown from the homogeneous nucleation seeds of unmelted nano-crystalline silicon clusters, by absorbing the molten silicon (as shown in Figure 4b). From Figure 4c, it is indicated that the annealed a-Si film was over-melted resulting in the mixed structures of larger hillocks and smaller hillocks well-scattered around the enlarged ridge-enclosed structures, which are recrystallized from the homogeneous nucleation seeds situated in molten silicon by the mixture of explosive crystallization and lateral crystallization processes as the laser annealing process is conducted at 400mJ/cm^2 with the shot number set at 100 shots. During this cyclic melting/re-solidification process at 400mJ/cm^2, the hillocks and ridges behaved like the silicon attraction centers due to the capillary force of the molten silicon, therefore, the size of hillocks and ridge-enclosed structures were enlarged. As the energy density was increased over 500mJ/cm^2, the a-Si films were observed to be over-melted with some-part of regions to be ejected induced by laser evaporation as shown in Figure 4d. The achieved surface morphology of a-Si films annealed at 500mJ/cm^2 under 100 laser shots were shown to be mixture of non-uniformly distributed small hillocks, network craters produced by the ejection of molten silicon due to the laser evaporation of a-Si films and ring-shaped ridge-enclosed structures with some bigger hillocks formed on the ridges.



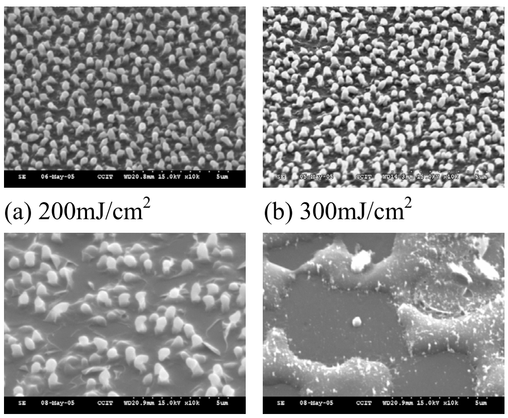
(a) 200mJ/cm^2 (b) 300mJ/cm^2



(c) 400mJ/cm^2 (d) 500mJ/cm^2

Figure 4. The evolution of achieved surface morphology of poly-Si films after laser irradiation using 100 shots, repetition rate of 1 Hz and laser fluence ranged from 200 to 500mJ/cm^2.

Figure 5 shows the effect of laser fluence on the evolution of induced surface morphology of poly-Si films produced by laser irradiation at the processing parameters of 300 shots, 1Hz and laser fluence ranged from 200 to 500mJ/cm^2. As a-Si films were annealed at the laser fluence of 200 and 300mJ/cm^2, they were shown to be completely melted. The induced surface morphology are uniformly distributed pillars (Figures 5a and 5b) which are grown by the agglomeration of molten silicon onto the hillocks produced by recrystallization from the homogeneous nucleation seeds created in molten silicon during the cyclic melt/resolidification induced by laser irradiation process. As a-Si films were annealed using the laser fluence of 400mJ/cm^2, they were shown to be over-melted, resulting in the formation of larger silicon pillars (Figure 5c). The pillars obtained during this annealing period were enlarged due to more molten silicon, created by the higher laser fluence, being absorbed by the smaller pillars. The larger pillars were considered to be induced by the recrystallization process, from unmelted microcrystalline silicon acting as heterogeneous nucleus, using the combination of lateral and vertically explosive crystallization process. As a-Si films were laser irradiated using the laser fluence of 500mJ/cm^2, they were shown to be evaporated, leading to the formation of the surface structures of network craters with some pillars and redeposited debris formed around the boundary of the craters (Figure 5d).



(a) 200mJ/cm^2 (b) 300mJ/cm^2

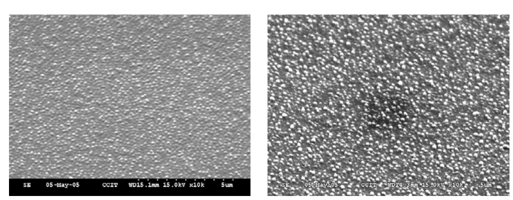
(c) 400mJ/cm^2 (d) 500mJ/cm^2

Figure 5. The evolution of surface morphology of poly-Si films produced at the processing parameters of 300 shots, 1Hz and laser fluence ranged from 200 to 500mJ/cm^2.

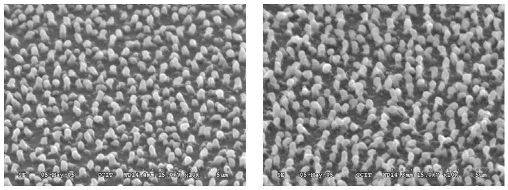
Based on the above discussion, it can be summarized that the surface morphology of laser annealed a-Si films are evolved sequentially as ridges, hillocks and network craters, while the processing parameter controlled as 100shots, 1Hz and laser fluence ranged from 200 to 500mJ/cm^2. The evolution of the induced surface morphology of poly-Si films are shown as ridges, hillocks, pillars and network craters, while the processing parameter set as 300shots, 1Hz and laser fluence ranged from 200 to 500mJ/cm^2, with some formation of redeposited debris due to the evaporation of a-Si films. The induced surface morphology is found dependent on the laser fluence involved during laser annealing of a-Si films. The increase of laser fluence causes the amount of molten silicon to be increased, resulting in the agglomeration of more molten silicon leading to the increasing of the geometrical size (diameter and height) of the surface structures such as ridges, hillocks and pillars.

3.3 Effect of shot number

Figures 6a to 6d show the obtained surface morphology of laser annealed a-Si films using the processing parameters of at 300mJ/cm^2, 1Hz and shot number ranged from 50 to 500 shots. It is shown that the induced surface morphology is strongly influenced by the shot number. The evolution of surface morphology is found to be changed sequentially as ridges formed at 50 shots, hillocks formed at 100 shots, pillars formed at 300 and 500 shots by the agglomeration of molten silicon onto the hillocks. The increase of the shot number has the effect on producing more accumulation of laser energy, therefore, more molten silicon will be absorbed by ridges and hillocks, leading to the formation of surface pillars. This phenomenon is quite similar to some literature which suggested that the increase of shot number favors the formation of surface pillars [3, 6].



(a) 50 shots (b) 100 shots

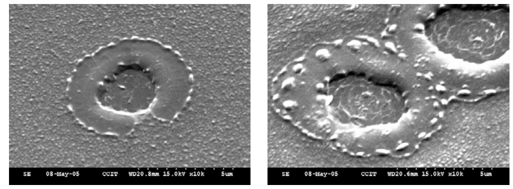


(c) 300 shots (d) 500 shots

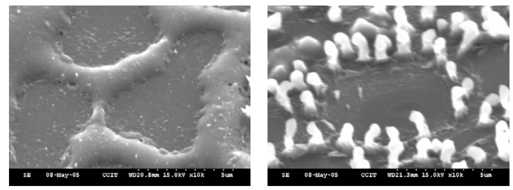
Figure 6. The evolution of surface morphology of laser annealed a-Si films using the processing parameters of at 300mJ/cm^2, 1Hz and shot number ranged from 50 to 500 shots.

Figure 7 shows the effect of shot number on the evolution of surface morphology of laser annealed a-Si films using the processing parameters of at 500mJ/cm^2, 1Hz and shot number ranged from 50 to 500 shots. As shot number is controlled at 50 and 100 shots, the induced surface structures were found primary as molten network craters with uniformly distributed ridges and hillocks sitting around the craters (Figures 7a, 7b). As the shot number is increased to 300 shots, the obtained surface structures were found to be molten silicon craters with some pillars and redeposited debris sitting around the boundary of craters (Figure 7c). While the a-Si films were laser annealed with the shot number increased to 500 shots, the larger regionally distributed pillars (Figure 7d) were formed due to the evaporation of a-Si films and more molten silicon produced, which were attracted by smaller pillars.

From the discussion described above, it can be concluded that the induced surface morphology is principally dominated by laser fluence selected. However, the increase of shot number has the effect in assisting the accumulation of laser fluence, leading to the formation of enlarged surface structures (such as pillars, craters).



(a) 50 shots (b) 100 shots

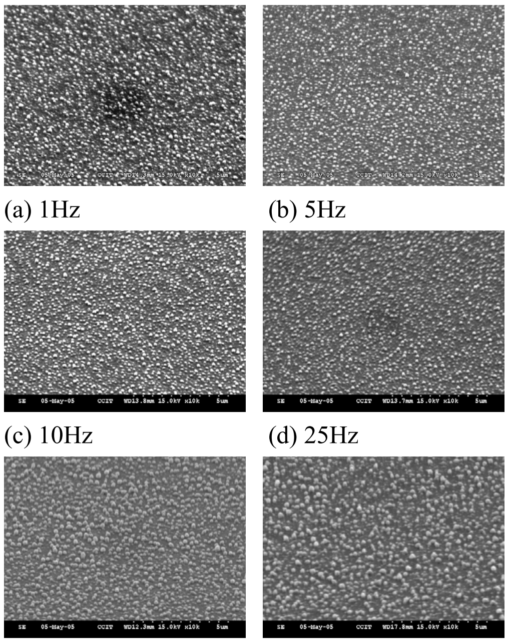


(c) 300 shots (d) 500 shots

Figure 7. The evolution of surface morphology of laser annealed a-Si films using the processing parameters of at 500mJ/cm^2, 1Hz and shot number ranged from 50 to 500 shots.

3.4 Effect of repetition rate

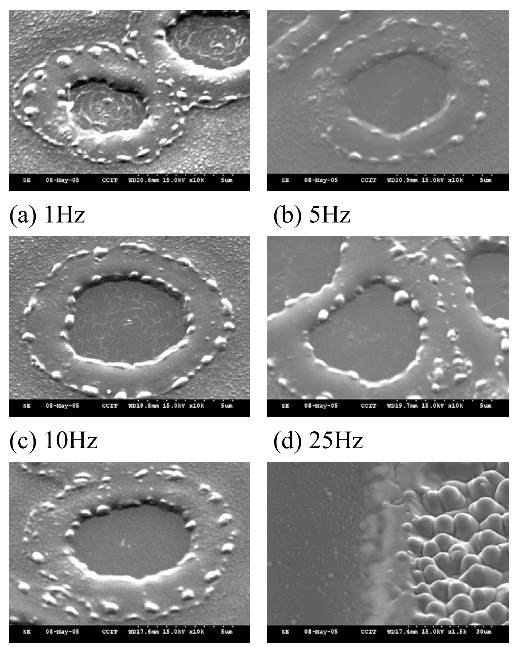
Figure 8 shows the influence of the repetition rate on the evolution of surface morphology of a-Si films laser irradiated using the processing parameters of 100 shots, repetition rate ranged from 1 to 100Hz and 300mJ/cm^2. Under these laser irradiation conditions, it is shown that ridges and hillocks are the primarily obtained surface structures. A higher repetition rate has the ability to modify the geometry of the ridges and hillocks. Under lower repetition rate ranged from 1 to 25Hz, the increasing of repetition rate has no clear influence on the achieved structures, formed on poly-Si films, which are all the mixture of ridges and hillocks (Figures 8a to 8d). As the repetition rate is increased to the range of 50 to 100Hz, it has shown that using the higher repetition rate is favorable in increasing the irradiation energy, which means more molten silicon obtained due to the accumulation of more laser fluence. It resulted in increasing the melting duration and reducing the solidification speed involved during the melt/regrowth laser annealing process, leading to the formation of enlarged ridges and hillocks (Figures 8e, 8f).



(a) 1Hz (b) 5Hz
(c) 10Hz (d) 25Hz
(e) 50Hz (f) 100Hz

Figure 8. The evolution of surface morphology of a-Si films laser irradiated using the processing parameters of 100 shots, repetition rate ranged from 1 to 100Hz and 300mJ/cm^2.

Figure 9 shows the influence of the repetition rate on the evolution of surface morphology of a-Si films laser irradiated using the processing parameters of 100 shots, repetition rate ranged from 1 to 100Hz and 500mJ/cm^2. The induced surface structures are mainly network craters due to the a-Si films being evaporated using a higher laser fluence of 500 mJ/cm^2 which is over the threshold fluence (Ev) for evaporation of a-Si films. With the repetition rate controlled ranged from 1 to 50Hz, the ring-shaped network craters with ridges uniformly distributed around the craters, hillocks sitting on the boundary of craters and debris are shown to be formed on the laser irradiated areas (Figures 9a to 9e). The height of the debris redeposition are shown to be increased due to the continuous accumulation of evaporated silicon, involved during this cyclic melt/evaporation/redeposition laser irradiation process, which are cooled and redeposited on the boundary of the craters. As the repetition rate was increased to 100Hz, it resulted in large amount of evaporated Si which is redeposited as debris on the outer regions of laser irradiated areas. It is shown that laser irradiation of a-Si films has resulted in the melting of glass substrate occurred on the boundary of craters, which means the whole a-Si film on the irradiated areas has been evaporated leading to the formation of an molten silicon island-like structures.



(a) 1Hz (b) 5Hz
(c) 10Hz (d) 25Hz
(e) 50Hz (f) 100Hz

Figure 9. The evolution of surface morphology of a-Si films laser irradiated using the processing parameters of 100 shots, repetition rate ranged from 1 to 100Hz and 500mJ/cm^2.

To compare Figure 8 and Figure 9, it is shown that the type of induced surface morphology is dominated by the laser fluence chosen for the laser annealing of a-Si films. Since the laser fluence determine the amount of energy provided for the irradiation of a-Si films which affects the melting depth, melting duration and resolidification speed leading to various recrystallization mechanisms involved during the annealing process. However, the increasing of repetition rate is proved to have the effect on improving the accumulation of energy density resulting in modifying the geometrical size of the induced surface structures obtained on laser irradiated a-Si films.

IV. CONCLUSIONS

Based on the results on the experimental investigation of the evolution of surface morphology of a-Si thin films irradiated by ArF excimer laser, described above, it can be concluded as below：

(1) With a-Si film laser irradiated at a lower laser fluence controlled between Em, and Ev, it would induce some microstructures such as bumps, ridges, hillocks or pillars on the annealed film surface. While a higher fluence over Ev is involved, craters, pillars and molten silicon islands are likely to be produced. The poly-Si grains are considered be produced at the laser fluence ranging between Em and Ev, resulting in the surface morphology of small ridges and hillock-like structures.

(2) The obtained surface morphology is found strongly influenced by the laser fluence involved during laser irradiation of a-Si films. The increase of laser fluence results in increasing the volume of molten silicon, leading to the agglomeration of more molten silicon and the increase of the geometrical size (diameter and height) of the surface structures such as ridges, hillocks and pillars.

(3) Although the induced surface morphology is principally dominated by operated laser fluence, which affects the melting depth leading to various recrystallization mechanisms involved during the annealing process. However, the alternation of shot number and repetition rate have shown to be able to improve the accumulation of laser fluence, resulting in the modification of melting duration and resolidification speed for the recrystallization of a-Si films, leading to the formation of enlarged surface structures (such as pillars, craters).

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