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Aluminium-Induced Crystallization of Silicon Thin Film by Excimer Laser Annealing

(Penghabluran Teraruh Aluminium Terhadap Saput Tipis Silikon Melalui Sepuhlindap Laser Eksimer)

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ABSTRACT

Polycrystalline silicon (poly-Si) film was fabricated by indirect process of re-crystallization of amorphous silicon (a-Si) thin film. This enhancement process is important to determine the performance of silicon thin film (STF). In this attempt, a fundamental study was carried out to enhance the crystallization of aluminium doped silicon thin film. An a-Si thin film was prepared by low pressure physical vapour deposition (PVD) and doped with 10% aluminium. The aluminium-induced crystallization (AIC) process was carried out in two sequence steps. Firstly, the amorphous film was annealed by using conventional heat treatment at operating temperature of 350°C. Secondly, the poly-Si underwent excimer laser anneling (ELA). The microstructure of thin film was analyzed using atomic force microscope (AFM). The results showed that, the grain size of the a-Si film is increased with the energy density of the excimer laser. The optimum grain size obtained is 129 nm corresponding to energy density of 356 mJ cm^{-2}.

Keywords: Aluminium; crystallization; excimer laser annealing; amorphous silicon lateral growth

ABSTRAK

Saput polihablur silikon (poly-Si) disediakan melalui proses penghabluran semula saput tipis silikon amarfos (a-Si) secara tidak terus. Proses peningkatan ini adalah penting untuk menentukan prestasi saput tipis silikon (STF). Kajian asas telah dilakukan untuk meningkatkan penghabluran saput tipis silikon terdop aluminium. Saput tipis silikon amorfus disediakan menggunakan pemendapan wap fizikal bertekanan rendah (PVD) dan didop dengan 10% aluminium. Proses aruhan aluminium (AIC) dijalankan dalam dua langkah berturutan. Pertama, saput amorfus disepuhlindap menggunakan pemanasan konvensional pada suhu operasi iaitu 350°C. Kedua, poli-Si disediakan melalui sepuhlindap laser eksimer (ELA). Struktur mikro saput tipis dianalisis menggunakan mikroskop daya atom (AFM). Keputusan menunjukkan bahawa, saiz butiran saput a-Si meningkat dengan meningkatnya ketumpatan tenaga laser eksimer. Saiz butiran optimum yang diperoleh ialah 129 nm sepadan dengan ketumpatan tenaga pertumbuhan sisi super iaitu 356 mJ cm^{-2}.

Kata kunci: Aluminium; penghabluran; sepuhlindap laser eksimer; silikon amorfus; pertumbuhan sisi super

INTRODUCTION

Indirect re-crystallization of a-Si film is an inexpensive and effective technique in order to fabricate poly-Si thin film. It offers a great interest for large-area electronics devices, flat channel displays, thin film transistors (TFTs) and solar cells (Angelis et al. 2000; Carluccio et al. 1997; Klein et al. 2004; Peng et al. 2010; Widenborg & Aberle 2002). This is due to its high large field effect and high current driving capability of poly-Si (Marmostein et al. 1999; Park et al. 1999). Aluminium-induced crystallization (AIC) of a-Si has been reported as the best method to fabricate large-grained poly-Si thin film (Klein et al. 2004; Marmostein et al. 1999; Park et al. 1999; Sieber et al. 2003; Widenborg & Aberle 2002). The eutectic temperature (T_{eu}) that was proposed for AIC process is 577°C (Peng et al. 2010; Schneider et al. 2003; Tang et al. 2009). However, Pihan et al. (2004) successfully fabricated large-grained poly-Si (>20 μm) with operation temperature below the T_{eu}.

A longer processing time might cause several defects to the thin film surface. In order to shorten the processing time, excimer laser was used to anneal the a-Si together with conventional heat treatment process. This process is also known as two-step annealing (TSA) (Bidin & Ab-Razak 2011; Carluccio et al. 1997). Excimer laser annealing (ELA) technique is able to fabricate a good poly-Si because it can heat the film up to the melting point and at the same time no thermal damage occur into the glass substrate (Carluccio et al. 1997). TSA by combination of conventional and ELA would promise a good crystallinity of poly-Si with very few in-grain defects, due to the melt-regrowth process (Fortunato et al. 2000). It also offers low thermal budget to the film during annealing process due to short pulse duration of excimer laser (within nanosecond).

Laser annealing is a kinetic process where heating process is used to change the microstructure through diffusion. When short, high-intensity laser pulses are used to heat a-Si thin films just below the melting point, crystallized silicon starts to grow as it cools (Yogoro et al. 2003). The principle advantage of excimer laser is the strong absorption of ultraviolet (UV) light in silicon (Palani et al. 2008). In the excimer laser crystallisation, there are some critical energy density levels exist (so-called super lateral growth or SLG regime) which maximizes the grain size (Ab-Razak & Bidin 2010; Bidin & Ab-Razak 2010; Matsumura & Oh 1999). If crystallization process takes place above this SLG regime, the grain size become smaller (Carluccio et al. 1997; Gaucci et al. 2007). Similar phenomenon has been reported by using other catalyst such as copper (Ab-Razak & Bidin 2010; Bidin & Ab-Razak 2010) and aluminium (Bidin & Ab-Razak 2011; Qi et al. 2005).

In the present paper, physical vapour deposition (PVD) by evaporation technique was used to fabricate a-Si thin film on the low temperature glass substrate. Aluminium was used as a catalyst to reduce the effects of heat on the other portions of the element to a minimum. PVD was used because of its high film deposition rates and less tendency for unintentional substrates heating. Besides it also promise less substrate surface damage from impinging atoms as the film is being formed, unlike sputtering that induces more damage because it involves high-energy particles. The purity of the film is excellent because of the high vacuum condition used by evaporation. Therefore, poly-Si thin films are expected to be fabricated by conventional annealing and ELA processes. The crystalline surfaces of poly-Si were characterized using atomic force microscope (AFM).

EXPERIMENT DETAILS

Silicon thin films were fabricated on a 7010 microscope glass substrate by PVD technique using thermal evaporator. The thickness of the films was fixed at 100 nm. Aluminium catalyst was used as dopant material since it is compatible with conventional manufacturing process of integrated circuits. Firstly, aluminium doped STF was annealed using conventional heat treatment by using tube furnace model 21100 with annealed temperature of 350°C for 4 h. Encapsulated annealing technique was used to avoid vaporization of thin film material. The film was placed into a carbon block.

Secondly, the heat treated films was exposed by ArF excimer laser model EX5/200. The ArF excimer laser generates ultraviolets laser light at 193 nm with 10 ns pulse duration and operated at room temperature (28ºC) with gas pressure of 3385.0 torr. The laser capacitor voltage was kept constant at 12 kV. The laser was triggered externally via function generator. The laser energy was verified from 57 to 409 mJ cm^{-2}. The laser power was measured by a broadband power meter 13PEM001. The crystallization and the surface structural characteristics of the fabricated poly–silicon thin films were then examined by using AFM.

RESULTS AND DISCUSSION

The microstructure of the poly-Si surfaces are arranged in the increasing order of the laser fluence which measured in mJcm^{-2}. All micrograms in Figure 1 are observed under the same measured area that is 1000 nm × 1000 nm. Uniform grain sizes are observed in the microstructure image of silicon thin film.

Initially, the grain size was measured before laser annealing started. As previously mentioned in the experimental procedure, the poly-Si underwent heat treatment almost 4 h before exposed with UV laser. The aim was to dry out all the possibility of water contained in the poly-Si film. The size of the grain after conventional annealing was found to be 6.00 nm (Figure 1(a)). The grain size is an indicator for the measurement of crystallization.

The size was noticed to gradually increased after received one to five pulses. In this particular case the crystallization were enlarged to be almost 15 nm, 23 nm, 39 nm, 42 nm and 63 nm respectively (Figures 1(b) to 1(f)). However, after received six number of pulses, the crystallization was notified to be accelerated much faster. The grain size rapidly increased to 129 nm (Figure 1(g)) which almost double from previous 5 pulses exposure. The corresponding energy density delivered to the target poly-Si films was 356 mJ cm^{-2}. However, the grain size drastically decreased after the seventh pulses exposure which corresponds to energy density of 409 mJ cm^{-2} (Figure 1(h)).

This meant, the super lateral growth SLG for this aluminium doped silicon is 356 mJ cm^{2}. After receiving greater than SLG energy the annealing process has demonstrated the rapid reduction in grain size. A fluence greater than SLG causes the Si:Al film to experience completely melts and substantial quenching occurs before solidification via homogenous nucleation and growth can take place. Hence, rapid drop of grain structure occurred. This phenomena is in good agreement with previous researcher (Ab-Razak & Bidin 2010; Bidin & Ab-Razak 2010; Carluccio et al. 1997; Fortunato et al. 2000; Gaucci et al. 2007; Matsumura & Oh 1999).

The most important stage of laser annealing processes is to modify the microstructure and the growth of crystallization before achieved the critical energy or the super lateral growth regime, in this particular experiment is 356 mJ cm^{-2}. Beyond this limit, the excimer laser annealing was not effective. Hence excimer laser annealing is clearly a high speed technique and desire low energy density. Consequently it involved only low temperature for annealing such sensitive and delicate material like silicon thin film and prevent damage to the substrate.

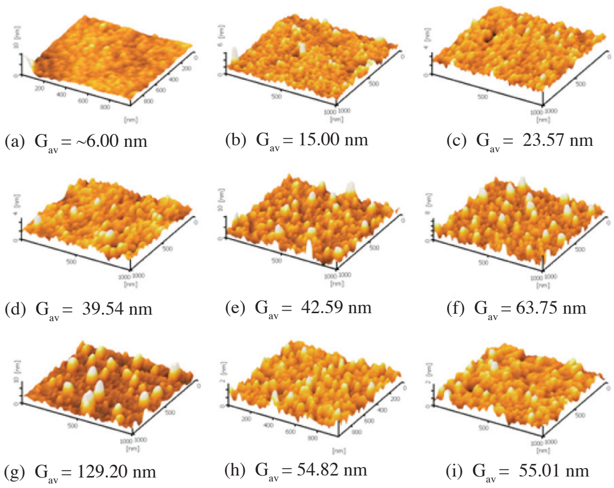

FIGURE 1. AFM images with magnification area of 1000 nm × 1000 nm of (a) silicon thin film after underwent conventional annealing and poly-Si surface after ELA with laser energy density of (b) 57.23 mJ cm^{-2}, (c) 116.40 mJ cm^{-2}, (d) 168.89 mJ cm^{-2}, (e) 241.13 mJ cm^{-2}, (f) 290.06 mJ cm^{-2}, (g) 356.11 mJ cm^{-2} and (h) 409.28 mJ cm^{-2}

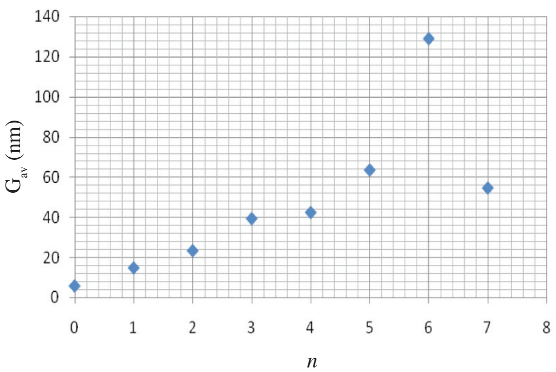

FIGURE 2. A graph of average grain size, G_{av} of silicon thin films versus the number of pulses of excimer laser, *n*

CONCLUSION

Aluminium-induced crystallization of poly-Si thin film was annealed by using TSA which combined the heat treatment and excimer laser annealing process. The result showed that, the maximum grain size can be increased to 129 nm at the critical energy density of 356 mJ cm^{-2}, which is also the SLG of the aluminium doped poly-Si film. Greater than SLG fluence result in dramatic reduction of the grain size due to fast quenching rate of ELA which unable for the normal homogenous nucleation and growth to take place in the fully melted silicon thin film. Hence the advantages of enhancing Si:Al film using ELA can be controlled by the microstructure of the fabricating material through the number of pulses. The low energy density of the ELA can protect damage on the substrate but high temperature within an ultra short time induce dramatic change in crystallization of Si:Al thin film.

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REFERENCES

Ab-Razak, S.N. & Bidin, N. 2010. Effect of multipulses exposure on excimer laser annealed polycrystalline silicon thin films. *Proc. International Conference on Enabling Science and Nanotechnology EsciNano*, KLCC, 1-3 Dec 2010.

Angelis, C.T., Dimitriadis, C.A., Farmakis, F.V., Brini, J., Kamarinos, G., Miyasaka, M. & Steomenos, I. 2000. Transconductance of large grain excimer laser-annealed polycrystalline silicon thin film transistors. *Solid-State Electronics* 44: 1081-1087.

Bidin, N. & Ab-Razak, S.N. 2010. Crystallization of polycrystalline silicon thin film by excimer laser annealing ELA. *Proc. of Faculty of Science Postgraduate Conference, Ibnu Sina Institute, UTM*, Johor Bahru. 5-7 Oct 2010, pp. 213-219.

Bidin, N. & Ab-Razak, S.N. 2011. Crystallization of poly-silicon film by different annealing techniques. *Electronics, Communications and Photonics Conference (SIECPC). IEEE Explore*. pp. 1-4.

Carluccio, R., Cina, S., Fortunato, G., Friligkos, S. & Stoemenos, J. 1997. Structure of poly-silicon films obtained by laser annealing. *Thin Solid Films* 296: 57-60.

Fortunato, G., Mariucci, L., Carluccio, R., Pecora, A. & Foglietti, V. 2000. Excimer laser crystallization techniques for poly-si thin film transistors. *Applied Surface Science* 154-155: 95-104.

Gaucci, P., Mariucci, L., Valetta, A., Pecora, A., Fortuno, G. & Templier, F. 2007. Electrical stability in self-aligned p-channel polysilicon thin film transistors. *Thin Solid Films* 515: 7571-7575.

Klein, J., Schneider, J., Muske, M., Gall, S. & Fuhs, W. 2004. Aluminium-induced crystallisation of amorphous silicon: Influence of the aluminium layer on the process. *Thin Solid Film* 451-452: 481-484.

Marmostein, A.M., Voutsas, A.T. & Solanki, R. 1999. Effect of multiple scans and granular defects on excimer laser annealed polysilicon TFTs. *Solid-State Electronics* 43: 305-313.

Matsumura, M. & Oh, C.H. 1999. Advanced excimer-laser annealing process for quasi single-crystal silicon thin-film devices. *Thin Solid Films* 337: 123-128.

Palani, I.A., Vasa, N.J. & Singaperumal, M. 2008. Crystallization and ablation in annealing of amorphous-si thin film on glass and crystalline-si substrates irradiated by third harmonics of $Nd^{3+:}$YAG laser. *Materials Science In Semiconductor Processing* 11: 107-116.

Park, C.M., Lee, M.C. & Jeon, J.H. 1999. A novel excimer laser crystallization method of poly-si thin film by grid line electron beam irradiation. *Materials Research Society* 557: 171.

Peng, C.C., Chung, C.K. & Lin, J.F. 2010. Formation of microcrystalline silicon films using rapid crystal aluminium induced crystallization under low-temperature rapid thermal annealing. *Thin Solid Film* 518: 6966-6971.

Pihan, E., Slaoui, A., Roca i Cabarrocas, P. & Focsa, A. 2004. Polycrystalline silicon films by aluminium-induced crystallisation: Growth process vs. silicon deposition method. *Thin Solid Films* 451-452: 328-333.

Qi, G.J., Zhang, S., Tang, T.T., Li, J.F., Sun, X.W. & Zeng, X.T. 2005. Experimental study of aluminium induce crystallization of amorphous silicon thin films. *Surface and Coatings Technology* 198: 300-303.

Schneider, J., Klein, J., Muske, M., Schopke, A., Gall, S. & Fuhs, W. 2003. Aluminium-induced crystallisation of amorphous silicon: Influence of oxidation conditions. *3rd World Conference on Photovollaic Energy Conversion*.

Sieber, I., Schneider, R., Doerfel, I., Schubert-Bischoff, P., Gall, S. & Fuhs, W. 2003. Preparation of thin polycrystalline silicon films on glass by aluminium induced crystallisation - an electron microscopy study. *Thin Solid Films* 427: 298-302.

Tang, Z., Shen, H., Huang, H., Lu, L., Yin, Y., Cai, H. & Shen, J. 2009. Preparation of high quality polycrystalline silicon thin films by aluminium-induced crystallization. *Thin Solid Films* 517: 5611-5617.

Widenborg, P.I. & Aberle, A.G. 2002. Surface morphology of Poly-Si films made by aluminium-induced crystallisation on glass substrates. *Journal of Crystal Growth* 242: 270-282.

Yogoro, Y., Masuda, A. & Matsumura, H. 2003. Crystallization by excimer laser annealing for a-Si:H films with low hydrogen content prepared by cat-CVD. *The Solid Films* 430: 296-299.

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