FABRICATION of POLY-SILICON SPIKES ON GLASS SUBSTRATES BY EXCIMER LASER IRRADIATION of SUBMICRON THICK a-SI:H FILMS

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Introduction

In this paper, we report on the fabrication of homogenous, high density and sharp conical polycrystalline silicon (poly-Si) spikes by repeatedly irradiating the submicron thick hydrogenated amorphous silicon (a-Si:H) films on metal coated glass substrates using KrF excimer laser with a slope beam profile at a laser fluence near to material ablation threshold. The fabricated high aspect ratio ploy-Si spikes are beneficial to electron field emission with a low turn on electric field. Meanwhile, the microstructured poly-Si material also exhibits an excellent optical absorbance property with the potential to develop highly responsive photodiode detectors and efficient solar cells.

Experiment

The a-Si:H films used in this work were deposited by plasma-enhanced chemical vapor deposition (PECVD) on 150 nm Mo coated Corning Eagle 2000 glass substrates. During the deposition process, the substrates were heated to 220 ^{o}C, the discharge RF power was set at 10 W and the precursor gas SiH_4 was introduced into the chamber with a flow rate of 75 sccm. The growth of 400 nm a-Si:H films were carried out for 50 minutes by PECVD of SiH_4 which was maintained at 100 mTorr.

The 248 nm, 20 ns KrF excimer laser was used to irradiate the a-Si:H films. The output laser beam passes through a specially designed optical system to produce a so-called asymmetrical slope beam profile as illustrated in Fig.1. The dimension of the rectangular–shaped laser beam pattern on the film surface is roughly 4mm x 8mm. In the long axis Y of the laser beam pattern, the laser fluence is uniform and has a top-flat beam profile, and in the short axis X, the laser fluence has an asymmetrical slope-beam profile.

The multi-pulses laser irradiation of a-Si:H films was carried out in air and at room temperature with a laser pulse energy varying from 35 to 150 mJ. During the irradiation process, the sample was mounted on a motorized and computer-controlled translation stage and scanned along the short axis X or -X directions as illustrated in Fig.1d. When the sample was scanned in the X direction in relative to the laser beam, the a-Si:H film will subject to an irradiation with the laser fluence slowly and gradually increases until it arrives at its maximum, and then the fluence rapidly reduces to zero. In contrast, if the sample was scanned in -X direction, the irradiated area on the thin film surface will see an abrupt increase in laser fluence and the fluence quickly arrives at its maximum and then gradually and slowly reduces to the zero. To facilitate our descriptions, we define the irradiation process when the sample is scanned in -X direction as the process with high laser energy as the leading edge. In contrast, the process when the sample is scanned in X direction is defined as the laser irradiation process with low energy as the leading edge.

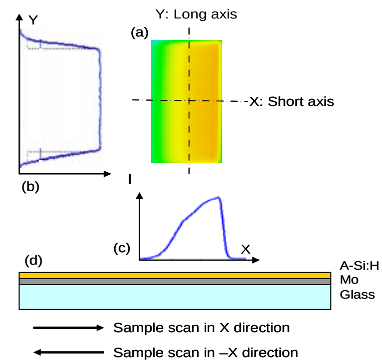

Fig.1 Schematic diagram of excimer laser microstructuring a-Si:H films using a slope beam profile, (a) top view laser beam pattern (4 mm x 8 mm) on sample surface, (b) top-flat beam profile along the long axis Y, (c) slope beam profile along the short axis X, (d) cross section view of the sample and the sample scan directions in ±X relative to the laser beam.

Results and discussion

The homogeneous, high density and well-defined sharp conical poly-Si spikes can be fabricated with laser pulse energy in the range from 40 to 120mJ, pulse numbers per unit area from 350 to 550, and the sample were irradiated with high laser energy as the leading edge. Fig.2 shows the representative scanning electron micrographs of the excimer laser microstructured a-Si:H films which were irradiated with high laser energy as the leading edge. The sharp and conical poly-Si spikes in Fig.2 are typically 150 to 250 nm in diameter on base and 1.5 to 2.2 μm tall, and the average separation of the resulting poly-Si cones is roughly from 1.5 to 2 μm. The samples presented in Fig.2 were irradiated with a laser pulse energy 75 mJ, laser operation frequency 50 Hz and sample scanning speed 0.5 mm/s. Under these processing conditions, each spot on the sample surface was irradiated by 400 laser pulses with varying laser energy fluence.

When the a-Si:H films were irradiated with the so-called asymmetrical slope beam profile, the sharp conical poly-Si features can be produced only when the sample was scanned in the negative X direction i.e., with high energy as the leading edge. When the sample was scanned in the positive X direction i.e, the low energy as the leading edge during the sample scan and irradiation, no sharp conical features could be microstructured even by a wide range of varying the laser fluence and the total laser pulse numbers. Fig.3 shows the typical surface morphologies of the a-Si:H films irradiated under these conditions. In this situation, the pillar-shaped microstructures fabricated on the a-Si:H film surface tend to be blunt and usually with a round cap on the tip. The sample shown in Fig.3 was also irradiated by 400 laser pulses with a same pulse energy of 75 mJ. At present, it is not quite clear why the sharp conical poly-Si features can only be fabricated by scanning the sample with high energy as the leading edge when using a slope-beam profile during laser irradiation.

The electron field emission measurement results indicate that the miscrostructured a-Si:H films with sharp and conical poly-Si spike features exhibit a better electron field emission property with a low turn-on electric field threshold and a large saturated emission current. The diode structured display device tests demonstrate that this kind of poly-Si material is feasible to be used as the cold cathode material in the electron field emission display devices.

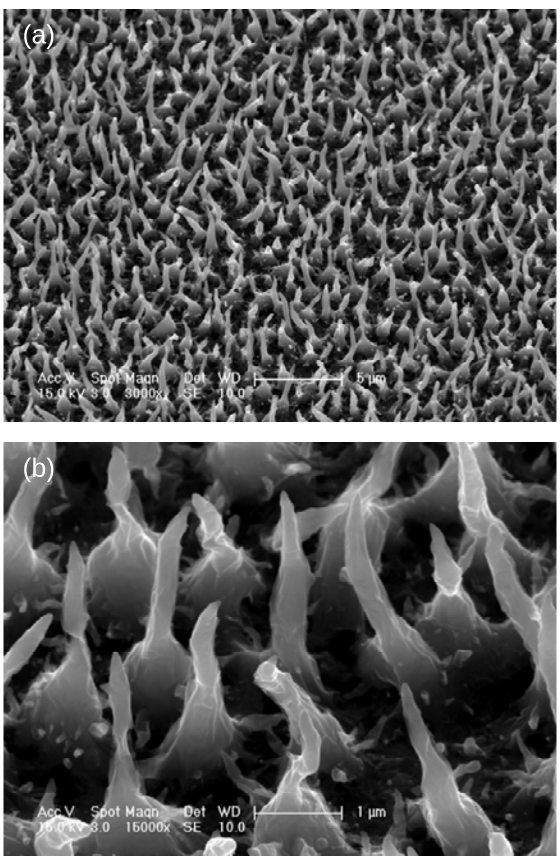

Fig. 2 Scanning electron micrographs of the excimer laser microstructured a-Si:H films using a slope beam profile with high laser energy fluence as the leading edge during sample scanning. (a) Overall view at an angle of 40^o to the surface normal, (b) close up view of the sharp poly-Si silicon spikes.

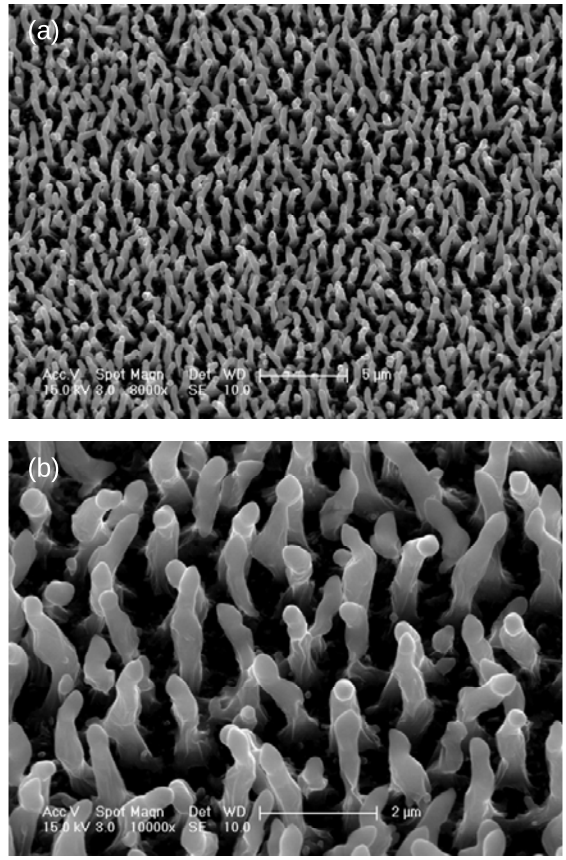

Fig. 3 Scanning electron micrographs of the excimer laser microstructured a-Si:H films using a slope beam profile with low laser energy fluence as the leading edge during sample scanning. (a) Overall view at an angle of 40^o to the surface normal, (b) close up view of the blunt poly-Si pillars.

Microstructuring the silicon spikes on the surface of silicon wafers by femtosecond laser pulses have been reported previously [1-2]. However, to the author's knowledge, the research work introduced in this paper is the first report on the fabrication of homogeneous, high density and high aspect ratio sharp poly-Si spikes on the metal coated glass substrates by excimer laser irradiation of thick a-Si:H films in air. The optical absorbance measurement results have indicated that the processed a-Si:H films possess a similar optical property to that exhibited by the 'black silicon' obtained by femtosecond laser irradiation of silicon wafers [2]. These exciting results convince that the established technique of excimer laser microstructuing a-Si:H films can initiate new approaches to produce the technologically important black silicon material in large area, on variety of low meting point substrates and even on flexible polymer substrates such as polyamides. The further in-depth investigations on these relevant research subjects are just under way.

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[2] Crouch, C. H., Carey, J. E., Shen, M., Mazur, E.and Genin, F. Y. Infrared absorption by sulfur-doped silicon formed by femtosecond laser irradiation. *Appl. Phys. A,* 79 (2004) 1635-1641