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Effects of pinhole diameters on beam characteristics for silicon thin film optical inspection

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ABSTRACT

Peak power density stability and beam-wander precision of probe laser are important factors affecting the inspection results in the precision thin film optical measurements. Pinhole is frequently used as a spatial filter in the optical inspection system. In this work, four different diameters of pinhole are investigated experimentally. It is found that pinhole diameter of 0.3 mm is considered to be a promising candidate for mounting in front of probe laser for silicon thin film optical inspection due to better peak power density stability and better beam-wander precision.

1. Introduction

The development of a system on glass requires high-performance silicon devices fabricated on large glass substrates [1]. Low temperature polycrystalline silicon (LTPS) thin film transistors (TFTs) are essential for large area electronic circuits due to their high field-effect mobility. It is known that excimer laser annealing (ELA) is a useful technique for manufacturing high-performance LTPS without thermally damaging the glass substrate [2]. Ultraviolet (UV) excimer laser energy is highly coupled to amorphous silicon (a-Si) thin films due to their high UV absorption coefficients. Upon irradiation, melting and solidifying of Si thin films occur during tens of nanoseconds, with the melt depth mainly determined by the excimer laser energy. The solid phase of a-Si thin films is semiconducting but the liquid silicon is metallic [3], so that the physical properties such as optical, thermal and electrical constants are significantly different for the liquid phase and solid phase at similar temperature and pressure. Such abrupt discontinuities in physical properties provide unique opportunities for in situ real-time optical measurements of the phase transformation of Si thin films. Thus, time-resolved optical reflectivity and transmissivity measurements have been proven to be effective for investigating the rapid melting and solidification scenarios in thin films owing to their potential for in situ, real-time, and non-intrusive monitoring [4]. Although pinhole is frequently used as a spatial filter in the optical inspection system [5–12], the effects of pinhole diameters on beam characteristics for silicon thin film optical inspection have not been reported previously. In this work, beam characteristics including peak power density stability and beam-wander precision were investigated.

2. Experiment

Fig. 1 shows a schematic diagram of the in situ time-resolved optical reflectivity and transmissivity (TRORT) inspection system for monitoring structural transformation dynamics of a-Si thin films during ELA. The sample had a stacked structure consisting of a 300-nm thick SiO_2 capping layer and a 90-nm thick a-Si layer formed on a 0.7-mm thick non-alkali glass substrate (Corning 1737). The capping layer was provided to promote uniform grain growth as the recrystallization begins. All the films were prepared by plasma-enhanced chemical vapor deposition (PECVD). These samples were then dehydrogenated by performing a thermal treatment at approximately 500 °C for 2 h to reduce the hydrogen content for preventing the ablation caused by sudden hydrogen eruption during annealing. The sample was then held in self-closing tweezers at the end of the cantilever beam fixed on the x–y precision translation stage. The x- and y-axis displacement of the two stages can be accurately manipulated (resolution = 0.625 μm) using a LabVIEW TM (National Instrument Inc.) based custom design interface. The movement of the focusing lens mounted on the z-axis stage was precisely controlled to adjust the desired laser fluences for annealing. The pulsed laser energy levels were monitored using pyroelectric Joule meter (Vector H410 SCIENTECH). The variation in pulse-to-pulse excimer laser energy was found to be less than 5%. All samples were irradiated with an excimer laser (λ = 351 nm,

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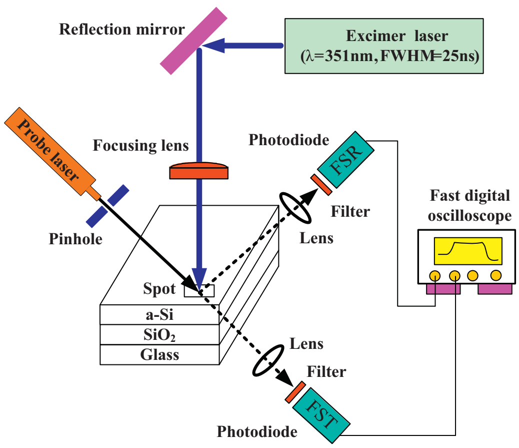

Fig. 1. Schematic diagram of the TRORT optical inspection system. FST and FSR represent frontside transmissivity and frontside reflectivity, respectively.

pulse duration = 25 ns, repetition rate = 1 Hz). The entire recrystallization process during ELA was in situ on-line monitored by the optical measurement system. He–Ne laser (λ = 632.8 nm, 0.8 mW, TEM_{00}) had a 45° of incidence from the normal of the sample's surface and the laser beam was focused on the center of the laser-irradiated spot. The reflected beam from the sample was focused on the fast photodiode (response time = 1 ns). The interference filter was mounted in front of the photodiode, allowing only red light from the probe laser to contribute to the detected signal. The photodiode was placed in an excellent position where the maximum signal was obtained. A quartz beam splitter was used to reflect 10% of the excimer laser beam to a photodiode for triggering the record of reflectivity and transmissivity spectra using a fast digital storage oscilloscope (bandwidth = 500 MHz, sampling rate = 2 GS/s, 4 channels, LeCroy WS454). All the experiments were carried out under ambient conditions.

Fig. 2 shows the schematic illustration of experimental system for evaluating the effects of pinhole diameters on beam characteristics. Four kinds of pinholes (ψ = 0.3 mm, ψ = 0.4 mm, ψ = 0.5 mm, and ψ = 0.6) were used to investigate the effects on beam characteristics. Pinhole was mounted in front of the He–Ne probe laser. Beam characteristics such as peak power density stability and beam-wander precision were investigated using a beam profiler (Beam star FX 50, spectral response = 260–1100 nm, OPHIR). To reduce the experimental error, the distance between beam profiler and probe laser was fixed at 40 cm, the incident beam of probe laser was adjusted perpendicular to the beam profiler, and the measurement environment was keep at the same illumination. Beam characteristics including peak power density stability and beam-wander precision were investigated and analyzed for evaluating suitable pinhole for mounting in front of probe laser in the precision thin film optical measurements.

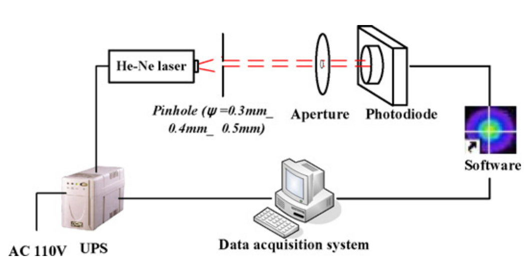

Fig. 2. Schematic illustration of experimental system for evaluating the effects of pinhole diameters on beam characteristics.

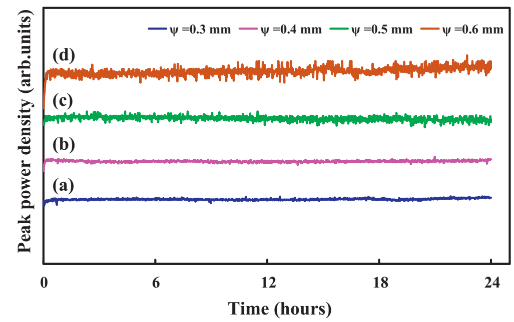

Fig. 3. Peak power density as a function of time for (a) pinhole diameter 0.3 mm, (b) pinhole diameter 0.4 mm, (c) pinhole diameter 0.5 mm, and (d) pinhole diameter 0.6 mm during 24 h of laser operation.

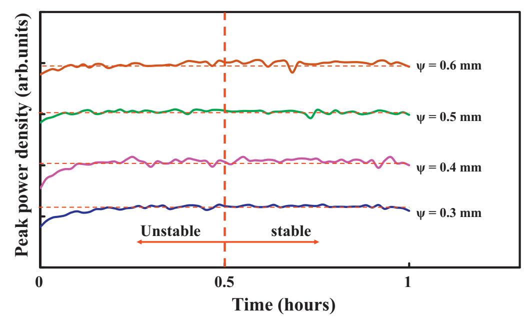

Fig. 4. Variation of the peak power density for four different diameters of pinhole at the first 1 h of laser operation.

3. Results and discussion

Fig. 3 shows the peak power density as a function of time for four different diameters of pinhole during 24 h of laser operation. As can be seen, the peak power density as a function of time for pinhole diameter of 0.3 mm is lower than that of pinhole diameters of 0.4 mm, 0.5 mm, and 0.6 mm, while the peak power density of He–Ne laser is unstable at the first 30 min. The peak power density becomes stable gradually after 30 min warm-up, as shown in Fig. 4. It means that adequate warm-up times are necessary in precision thin film optical measurements using He–Ne laser, which requires stable temperature for stable operation [13].

The standard deviation of peak power density can be calculated according to Eqs. (1) and (2) [14]. Fig. 5 shows the standard deviation of peak power density as a function of time for four different diameters of pinhole during 24 h of laser operation. As can be seen, the standard deviation of peak power density for pinhole diameter of 0.3 mm is smaller than that of pinhole diameter of 0.4 mm, 0.5 mm, and 0.6 mm and the standard deviation of peak power den-

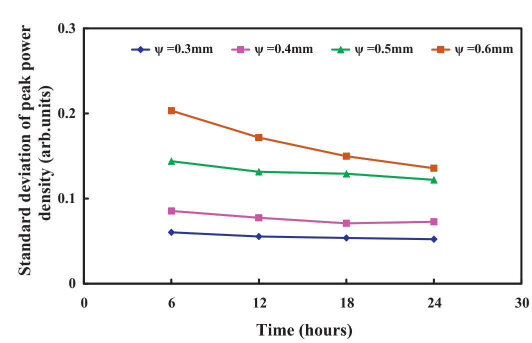

Fig. 5. Standard deviation of peak power density as a function of time for four different diameters of pinhole during 1–24 h of laser operation.