Investigation on Rapid Solid Phase Crystallization of Amorphous Silicon Films Induced by Micro-Thermal-Plasma Jet

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Introduction: Solid phase crystallization (SPC) of amorphous silicon (a-Si) films has been attracted much attention because of its widely application in semiconductor industry [1-2]. However, it is limited publications about the characteristics of SPC films formed at a high temperature and microsecond region. In this research, we will investigate the properties of SPC films fabricated by annealing a-Si films using a micro-thermal-plasma jet (µ-TPJ).

Experiment: Experimental set-up is shown in Fig. 1. It consists of a µ-TPJ to irradiate the samples and a high-speed camera (HSC) was set on the motion stage which moved linearly with sample in front of µ-TPJ with scanning speed ranging from 500 to 800 mm/s. The He-Ne laser was introduced to objective lens of HSC and focused on the a-Si film. The transient reflectivity of Si films during µ-TPJ irradiation was collected by a photodiode connected with a fast oscilloscope. Crystalline volume fraction was extracted from transient reflectivity by the time-resolved reflectivity method. High-resolution transmission electron microscopy (HRTEM) was used to observe the grain size. A theoretical model was introduced to explain the kinetics of SPC in the microsecond regime.

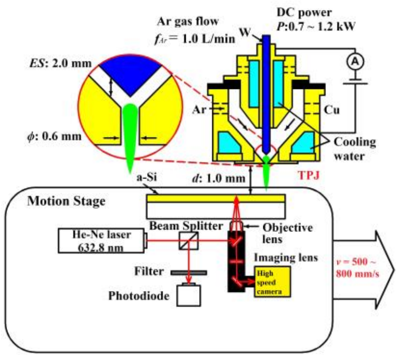

Fig.1. Experimental set up

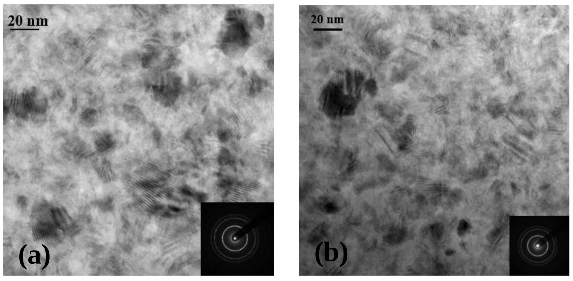

Fig.2. HRTEM images of SPC films annealed by µ-TPJ at v of (a) 500 mm/s, and (b) 800 mm/s, respectively

Results and discussion:

Figure 2 shows the HRTEM image of SPC films formed at v (a) of 500 mm/s, and (b) of 800 mm/s. When the v is 500 mm/s, rough estimation of grain size distribution is from 30 to 60 nm and when the v increases to 800 mm/s, most of the grains are smaller than 20 nm. It is clearly seen that the decrease of grain size is related to increasing of v. We suggest a simple physical model to estimate the crystal grain size based on the classical nucleation theory [3-4]. We assume that heating rate (R_h) will be constant during the phase transformation process. We divided the time for complete crystallization into small fractions with step Δt. At the initial time, a-Si film reaches to nucleation temperature, no crystal inside the volume. Then, temperature linearly increases with slope R_h. After Δt µs, there are N_1 nuclei appearing inside the volume and grow up with velocity v_{g1}, and volume of a-Si reduces. In the next time step, N_2 nuclei additionally appear and grow with velocity v_{g2}. In addition, N_1 nuclei in previous time step continue to grow with the same velocity v_{g2}. The volume of a-Si keeps on reducing. This process will be continued until the crystal grains fill out the considering volume and no appearance of a-Si. Figure 3 show the crystalline volume fraction from experimental data (solid line) and theoretical calculation (dotted line). It is easy to observe the best fit between them. Moreover, from the theoretical calculation, when v is 500 mm/s, the grain size varies from 3 nm to 36 nm, average grain size *(r)* is 20 nm. In case v is 800 mm/s, the grain size varies from 1 nm to 20 nm, r is 16 nm. The r decreases with the increasing of R_h. This estimated r is fairly agreed with HRTEM observation shown in Fig.2.

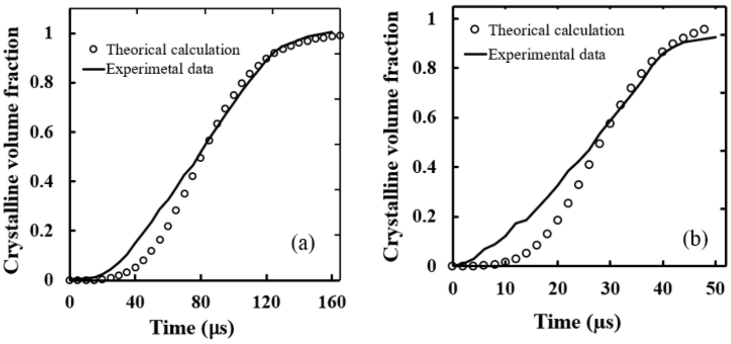

Fig.3. Crystalline volume fraction as function of time during phase transformation when a-Si film was annealed by µ-TPJ under v as 500 mm/s (a), and 800 mm/s (b), respectively. The dotted line is calculation data of R_c based on the physical model.

References

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