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Thickness effects on microstructural evolution of low-pressure-chemical-vapor-deposited amorphous silicon films during excimer-laser-induced crystallization

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Abstract

The effect of film thickness on the microstructural evolution of low pressure chemical vapor deposited amorphous silicon (a-Si) during excimer-laser-induced crystallization is reported. For film thickness less than 50 nm, homogenous nucleation and recalescence are the conditioning factors for the re-solidified phase. For the 30-nm-thick a-Si films, a wide laser energy fluence (>100 mJ/cm^2) is formed which results in constant grain size distributions. We estimate the homogenous nucleation density for a 30 nm a-Si film to be 2.7 – 4.7 events/cm^3 in the molten Si. Transmission electron microscopy is used to investigate the polysilicon grain microstructure of irradiated films. Specially, thicknesses between 24 and 36 nm are found to be the critical thickness range determining if the molten Si becomes amorphous or crystalline. To understand the crystallization mechanisms, heat flow calculations based on the laser-induced melting predictions are proposed.

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Keywords: Silicon; Laser irradiation; Transmission electron microscopy

1. Introduction

The use of polysilicon (poly-Si) thin-film transistors (TFTs) fabricated at low process temperatures offers many advantages particularly for size-increased liquid–crystal displays. High carrier mobilities and the availability of complementary metal-oxide-semiconductor field-effect transistors are two distinct advantages of poly-Si TFT technology when compared with amorphous (a-Si) [1]. Low-temperature poly-Si TFT process technology based on pulsed excimer laser crystallization of a-Si has been studied [2,3]. For the laser crystallization processes of a-Si, the process windows of laser energy for grain size and uniformity are two basic factors that determine both TFT device and panel performance. Normally, larger grains provide higher carrier mobility resulting in higher speed TFT devices by reduction of scattering by grain boundaries in the channel. On the other hand, uniformity of the grain sizes is the primary factor influencing image quality. Non-uniform grain sizes result in non-uniform TFT device characteristics, such as threshold voltage, drain current, etc., which result in fluctuation in pixel properties, such as brightness, fading, and then devices can not turn on or off as the driving signal or the current driving capability of devices is not consistent through the whole panel. Thus, the ability to obtain reproducible, uniform grain sizes is crucial for the laser process to succeed.

The development of grain microstructure and phase transformation in laser-crystallized Si thin films is controlled by the laser energy fluence and can be classified into three regions [4,5]. They are partial melting of the film (below full melt threshold), just melting the entire film (full melt threshold), and complete melt-through (above full melt threshold). Grains in these regions, which are gradual

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increasing in size with energy, are found to be small, ultra large, and small grains, constant in size with energy, respectively. This re-crystallization process exhibits a grain size distribution that has a peak in the distribution near the completely molten regime. Generally, there are two solidification modes for laser-induced molten silicon layers formed on quartz substrates [6,7]. One is homogenous solidification, in which rapid solidification is followed by the formation of an amorphous state. This mode requires irradiation with energies high enough to melt the silicon film long enough to result in a temperature gradient in the liquid silicon less than $\sim 1\times10^5$ K/cm. The rapid solidification is being governed by the temperature gradient in the Si film. The other solidification mode is interface-controlled. Here a liquid/solid interface is formed in the silicon film for temperature gradients higher than 1×10^5 K/cm resulting in crystallization of the silicon film, which is irradiated with energy lower than the amorphous threshold [6]. This mode exhibits that the crystalline phase was found in the irradiated a-Si films. Thus a low and constant temperature gradient across the film thickness results in amorphization occurring through homogenous solidification. Finally, recalescence, the latent released during solidification is proportioned to film thickness and is the driving force for recrystallization of the solidified film. Therefore, the re-crystallized phase of a-Si films after laser irradiation is dependent on the parameters of laser fluence, laser pulse duration, film thickness, and temperature gradient in crystallization process. In this paper, we examine the effect of film thickness on laser recrystallization of thin Si films on quartz. Details of the mechanism for laser recrystallization in the complete melt-through regime will be discussed.

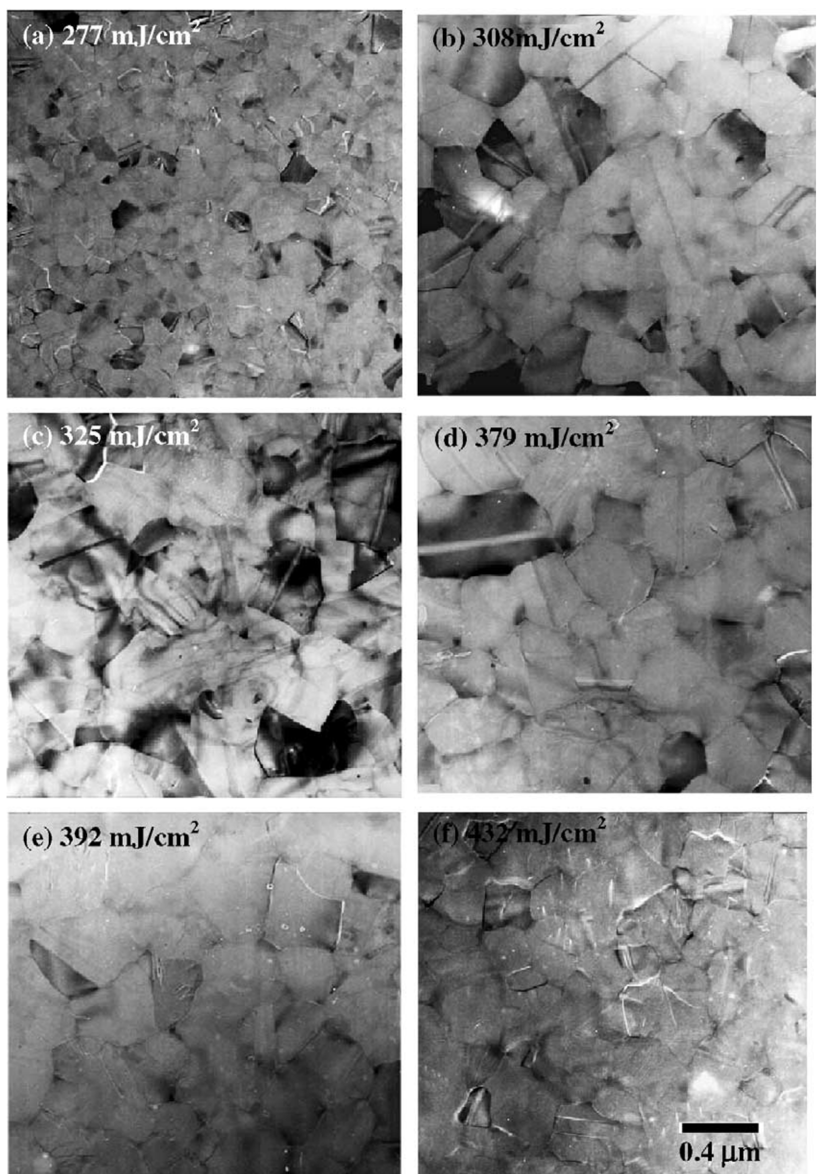

Fig. 1. Plan-view TEM micrographs of recrystallized 30-nm-thick a-Si film deposited on quartz. The laser energy fluences range from 277 to 432 mJ/cm^2.