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ScienceDirect

Solid-State Electronics 52 (2008) 359–364

SOLID-STATE ELECTRONICS

www.elsevier.com/locate/sse

Progress in fabrication processing of thin film transistors

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Available online 26 November 2007

The review of this paper was arranged by Guglielmo Fortunato

Abstract

This paper first discusses laser crystallization of silicon (Si) films with a carbon optical absorption layer, which makes it possible to use an infrared laser light. Then we discuss heat treatment with high-pressure H_2O vapor for defect reduction of laser crystallized Si films and their interface for fabrication of high performance Si thin film transistors (TFTs). Finally, we present a method of transfer process of electrical circuits from original glass substrates to foreign plastic films, developed with GeO_2 removing layer.

Keywords: CW laser; Carbon heat source; Defect reduction; Transfer technology; High-rate etching

1. Introduction

Low-temperature fabrication of poly-Si TFTs is now applied to flat display panels [1]. Many important research works have been done on low-temperature fabrication processing of poly-Si TFTs over the past two decades [2–6]. Many researches have been focusing on large grain growth by laser annealing to develop cost-effective poly-Si TFTs with high-performances.

As another research trend, there have been approaches on fabricating poly-Si TFTs on flexible substrates. Especially, transfer technology is expected as one of the promising approaches toward the formation of flexible devices.

This paper describes the authors' recent approaches related to the above topics, laser crystallization and transfer technology for poly-Si TFTs fabrication. Besides, we introduce defect reduction using high-pressure H_2O vapor heat treatment for fabrication of a high-performance TFT.

2. Laser crystallization

Pulsed laser annealing was initially developed for surface modification of bulk semiconductor substrates for 1980s [7–9]. Its application to crystallization of thin films formed on foreign substrates has been simultaneously developed in the same time [2,10]. Many works on pulsed laser crystallization have resulted in application of TFT production to flat panel displays [3,11,12]. High mobility and low threshold voltage is achievable using laser crystallization. Larger grain size reduces a grain boundary number and results in improving TFT performance. Researches on pulsed laser crystallization are currently focused on lateral grain growth. There have been a lot of methods for the lateral grain growth, including substrate heating (~400 °C) [13], double pulse irradiation [14,15], Phase-Modulated Excimer Laser Annealing [16,17], and sample-structural consideration [18,19]. Crystallization of Si films by CW laser is also a promising approach for cost reduction. A very stable, high-power-diode-pumped solid state CW laser ($Nd:YVO_4$) [20] has been recently developed. It has improved technologies for control of crystalline nucleation and crystallization in the lateral direction.

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0038-1101/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.sse.2007.10.005

Moreover, the authors have also developed a crystallization method of Si films using carbon films as a heating source layer. The method allows us to crystallize Si films with high efficiency for laser in the infrared range as well as the ultraviolet range [21]. We believe that this topic has a possibility of establishment of the cost-effective crystallization processing.

2.1. Si crystallization using a diamond-like-carbon heat source layer by XeCl excimer laser irradiation

We now report about the crystallization with the optical absorption layer. While the high absorption coefficient of Si films, $\sim 10^6\ \mathrm{cm}^{-1}$ at 308 nm, is advantageous to their localized heating with pulsed XeCl laser, the reflection loss of the Si films, ~60% at 308 nm, is a serious problem. Laser crystallization of Si films would be carried out with a less energy irradiation if an excellent heating source layer with a high optical absorbance and high heat resistance is used on the Si films. We discuss rapid thermal crystallization of silicon films with a heating layer of diamond-like-carbon (DLC) films. The previous research revealed that DLC films had low refractive indices from 1.3 to 1.9 and high extinction coefficients from 0.8 to 0.9 for wavelengths from 250 to 1100 nm [22]. These properties resulted in optical absorbance higher than 0.7 for 200 nm-thick DLC films at wavelengths shorter than 1000 nm.

Fig. 1 shows Raman scattering spectra of silicon films for 100 nm-DLC/5 nm-SiO_2/25 nm-Si/quartz (a) and 25 nm-Si/quartz (b) when the samples were irradiated with the XeCl excimer laser [22]. Note the DLC films were formed by a plasma-sputtering method using a carbon target. The Raman scattering measurement was carried out after removing the DLC films by oxygen plasma etching after laser irradiation. High and sharp phonon bands of Si were observed for the laser-crystallized Si films at laser energy densities from 160 to 200 mJ/cm^2 in the case of the 100 nm-DLC/5 nm-SiO_2/25 nm-Si/quartz structure. On the other hand, there was no crystalline phonon band for laser irradiation at 160 mJ/cm^2 for 25 nm-Si/quartz due to laser energies just below the crystallization threshold for the Si/quartz structure.

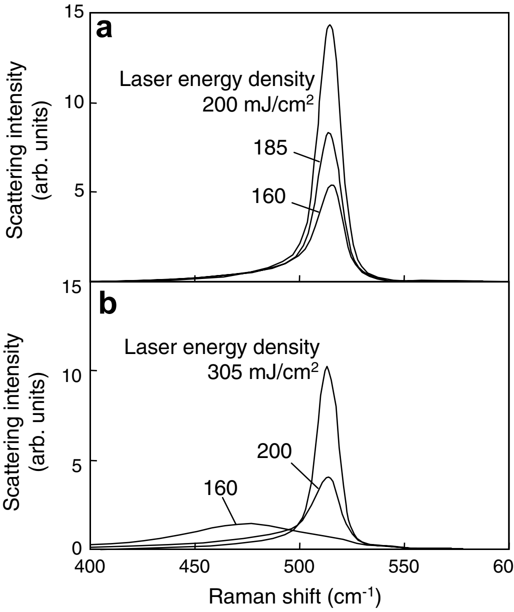

Fig. 1. Raman scattering spectra of silicon films 100 nm-DLC/5 nm-SiO_2/25 nm-Si/quartz (a) and 25 nm-Si/quartz (b) when the samples were irradiated with XeCl excimer laser with different energy densities.

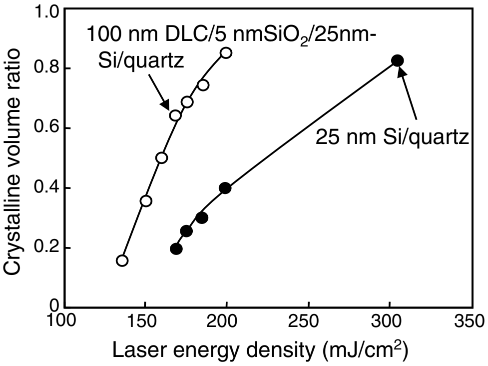

Fig. 2. Crystalline volume ratio of poly-Si obtained by analyzing of optical reflectivity spectra in the ultraviolet region, as a function of laser energy density.

The intensity of the crystalline phonon band was very low with 200 mJ/cm^2 laser irradiation for the Si/quartz structure. An energy density of 305 mJ/cm^2 was necessary in order to form crystalline Si with a phonon intensity comparable to that of 100 nm-DLC/5 nm-SiO_2/25 nm-Si/quartz formed at 200 mJ/cm^2.

Fig. 2 shows the crystalline volume ratio, obtained by analyzing optical reflectivity spectra in the ultraviolet region, as a function of laser energy density. The detailed analytical method to determine the crystallization volume ratio is described in Ref. [22]. Crystallization was observed with laser energy above 135 mJ/cm^2 for the 100 nm-DLC/5 nm-SiO_2/25 nm-Si/quartz, although the crystallization threshold was 170 mJ/cm^2 for the 25 nm-Si/quartz. The crystalline volume ratio of the silicon films was 0.85 at 200 mJ/cm^2 for the 100 nm-DLC/5 nm-SiO_2/25 nm-Si/quartz, while it was only 0.4 in the case of the 25 nm-Si/quartz. These results obviously show that the 25 nm-thick Si films were well crystallized even at a laser energy density of as low as 200 mJ/cm^2 when the DLC heating layer was used.

2.2. Si crystallization using a carbon particle heat source layer by continuous-wave infrared laser irradiation

We recently proposed to use a cheap infrared continuous-wave (CW) laser diode with a cheap optical absorption layer to crystallize Si films at a low cost. For the purpose, we use a carbon particle layer formed by the spin coating method instead of using DLC films formed by sputtering method. Carbon particles dispersed in water with a concen-