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Effects of the single and double (overlap) scanned excimer laser annealing on solid phase crystallized silicon films

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ABSTRACT

Thin amorphous silicon (a-Si) films were crystallized into polycrystalline silicon (poly-Si) by combining solid phase crystallization (SPC) and subsequent excimer laser annealing (ELA). Then thin film transistors (TFTs) were fabricated by using the poly-Si formed in the single and double excimer laser scanned area. The device performance of the TFTs fabricated with the excimer laser energy density of 230 mJ/cm^2 is almost equal for the single and double scanned area. This observation indicates that the overlapping laser irradiation with the laser energy density below 230 mJ/cm^2 does not change the characteristics of TFTs. Based on this result, we discuss the correlation between performance of active matrix organic light emitting display (AMOLED) panels and excimer laser energy density during ELA for SPC treated and non-treated poly-Si films.

1. Introduction

Use of low temperature processed poly-Si TFTs has been drawing an increasing interest for applications in large-area display electronics. The performance of TFTs is influenced by several factors, including gate insulator (GI), interface state between poly-Si and GI, activation, and hydrogenation. One of the critical steps in the fabrication of poly-Si TFTs is transforming amorphous silicon (a-Si) active area into poly-Si. Typically, poly-Si films are obtained either via directed deposition of poly-Si films using the chemical vapor deposition (CVD) or via crystallization of a-Si by thermal or laser annealing. Among these various methods to crystallize a-Si, ELA has attracted much research interest as an alternative low-temperature processing method to crystallize a-Si films.

The TFT uniformity issue about the overlapped area of excimer laser scans on a-Si layers has been investigated by Chang et al. [1]. They found that the higher excimer laser energy density dominates ELA-TFT characteristics, and the device performance in the overlap laser scanned area can be good as that in the non-overlapped area. Some attempts to improve the TFT performance by ELA process for SPC treated poly-Si films have been also proposed. Kodama et al. [2] have reported that the mobility is improved compared to the conventional TFTs. They also found that the mobility are same for both *p*- and *n*-channel TFTs, fabricated with the excimer laser energy densities ranging from 230 to 307 mJ/cm^2 and from 230 to 420 mJ/cm^2 for the 80 nm and 120 nm thick SPC treated poly-Si films, respectively. Recently, Jin et al. have reported the material properties of ELA processed poly-Si films and also enhanced electrical performance of TFTs formed in the single and double (overlap) scanned area along the long axis direction at various energy densities [3]. They found that the device performances were approximately equal to each region for the low excimer laser energy density (200 mJ/cm^2) processed TFTs. This fact indicates that the overlapped laser irradiation during ELA does not change the characteristics of TFTs while non-uniform line images were observed with a higher excimer laser energy density. Although the alteration of material properties of poly-Si films due to the high laser energy density during ELA was suggested as an origin of observed non-uniformity, it is not clear thus far how TFT parameters are evaluated with the excimer laser density and affect on AMOLED.

In this work, SPC process to improve TFTs performance is initially used to produce poly-Si films with very large but defect-rich grains, and subsequently ELA is processed to reduce in-grain defects, keeping the large grain size [4]. We analyze the correlations between the performance of AMOLED panels and irradiated excimer laser energy densities on SPC treated poly-Si films during ELA process in the single and double (overlap) scanned area.

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2. Results and discussion

2.1. TFT fabrication

To fabricate coplanar TFTs, we used Corning 1737 glass that was 370 × 400 mm^2. The main TFT fabrication has been reported in previous [3]. Silicon nitride (SiN_x) and silicon dioxide (SiO_2) films were deposited on the glass substrate as a buffer layer to block impurities from glass substrate. Next, the a-Si layer was deposited by plasma enhanced CVD (PECVD). Dehydrogenation was performed at 400 °C for 490 s. The a-Si film was crystallized in an In-line furnace, [5] with the surviving grains acting as SPC seeds. The resultant SPC treated poly-Si films were then irradiated by XeCl excimer laser beam with a wavelength of 308 nm at different laser energy densities ranging from 200 to 300 mJ/cm^2 at room temperature. To investigate the dependency on laser scanning time and laser energy density, scanning was carried out as shown in Fig. 1. The line shaped laser beam was scanned to partially overlapped. As a result, two different regions of poly-Si films were generated. After an interlayer deposition, the dopant was thermally activated using a conventional furnace. Then the contact holes were patterned and the source/drain metals were deposited, followed by subsequent patterning to form electrodes, thus completing the actual fabrication processes to make TFTs. For evaluation of TFT characteristics such as threshold voltage (V_{th}), field effect mobility, and sub-threshold swing (S factor), we fabricated self-aligned, conventional p-channel top-gate TFTs. Our AMOLED panel is composed of PMOS for reduction of mask steps as well as low-cost production.

2.2. Poly-Si film characteristics and TFT performance

Raman spectroscopy measures the inelastic scattering of light from materials which results from changes in the polarizability of atoms. Thus, any effect which may change the lattice spacing and polarizability of nonmetallic solids (e.g., stress, temperature, crystal structure) will result in changes in the Raman signature. Fig. 2 shows the Raman spectra of the films before and after SPC of a-Si films. The Raman spectrum of a-Si (before SPC) shows a typical characteristics of a-Si; the broad peak indicates the wide optical phonon (lattice vibration) states of a-Si while the peak position of 480 cm^{-1} exhibits the zone center of the optical mode. However, the spectrum from SPC treated poly-Si films shows a sharp peak at 520 cm^{-1} with the full width at half maximum intensity of 6.8 cm^{-1} which corresponds to the crystallized phase. These observations confirm our expectation of crystallized a-Si films after the SPC treatment.

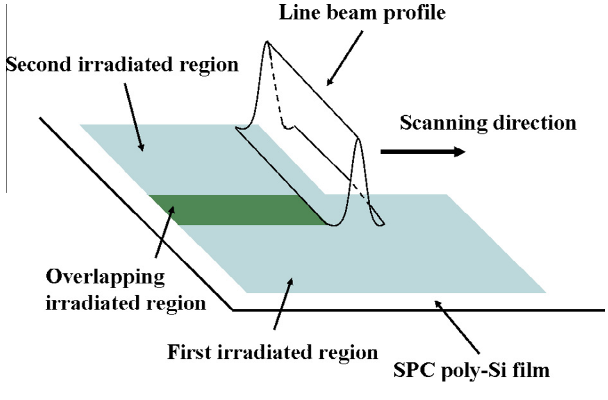

Fig. 1. Schematic diagram of overlapping excimer laser irradiation during ELA. The characteristics of TFTs arranged across the scanned regions were measured. The length and width of the channel of TFTs are 7 μm and 7 μm, respectively.

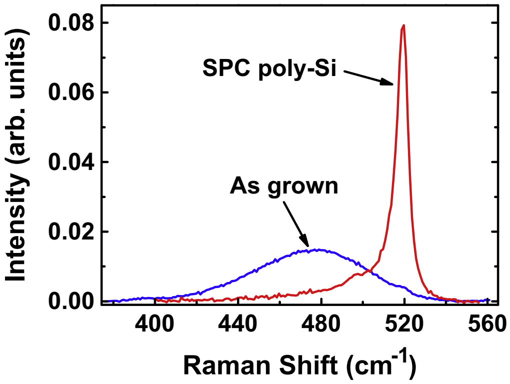

Fig. 2. Raman spectra of films before and after SPC treatment, where the crystallization temperature was around 700 °C.

To clarify the effects of combined SPC + ELA process and also irradiated laser energy density on SPC treated poly-Si films, the current–voltage (I–V) characteristics of the fabricated TFTs in single and double scanned regions at various laser fluences were measured by using a HP4145B semiconductor parameter analyzer for both TFTs fabricated via SPC + ELA and only SPC without ELA. Fig. 3 shows device parameters which are extracted from the drain current–gate voltage ($I_d - V_g$) characteristics of the SPC + ELA processed TFTs crystallized in each region at various excimer laser density (210, 230, 250, 270, and 290 mJ/cm^2). The channel width and length are 7 μm and 7 μm, respectively. In this study, the threshold voltage (V_{th}) is defined as a gate voltage which induces a drain current of 10 nA at a drain voltage of $V_d = -5.1$ V. The field effect mobility (μ_{fe}) is estimated by assuming the validity of the following equation for poly-Si TFTs;

$$\mu_{fe} = \frac{Lg_m}{WC_{ox}V_d}, \tag{1}$$

where g_m is the transconductance, C_{ox} is the capacitance per unit of area for the gate insulator, W is the channel width, and L is the channel length. The SPC-TFT without ELA showed the average values of p-channel field effect mobility of 16.9 cm^2/Vs, the threshold voltage of −4.6 V, and the sub-threshold swing of 0.9 V/dec, which are insufficient values for AMOLED panel application. In fact, Miyasaka and Stoemenos [6] proposed combining the low temperature SPC with subsequent ELA 25–50 nm for thick a-Si films to crystallize into poly-Si for their AMOLED panel application. Discussing the relation between the material properties and the electrical performance of poly-Si film, they reported that subsequent irradiation of excimer laser light to the SPC specimens with energy density ranging from 220 to 280 mJ/cm^2 improves film quality. Consistently to their observation, the PMOS TFT formed on a-Si films annealed by the energy density of 200 mJ/cm^2 showed field effect mobility of 0.15 cm^2/Vs, threshold voltage of −11 V, and sub-threshold swing of 1.6 V/dec in the single and double scanned region. It indicates that TFTs which were annealed but low laser density of 200 mJ/cm^2 have also poor characteristics [3]. The circuit design specification in our AMOLED panels is limited to the mobility of 30 cm^2/Vs and the threshold voltage of −4 V. This fact implies that the performance of poly-Si TFTs fabricated at the energy density of 200 mJ/cm^2 without SPC crystallization is not enough for driving AMOLED. However, as shown in Fig. 3, the threshold voltage, field effect mobility, and sub-threshold swing of poly-Si TFTs are significantly enhanced by ELA with higher energy density than 200 mJ/cm^2 and exhibit strong dependency on the annealing excimer laser energy density. As expected, the data favored lower mobility and higher S factor as the excimer laser energy density decreased [7]. At the laser