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Effects of an alternating field in field-aided lateral crystallization process for low temperature poly-silicon

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Abstract

The effect of the alternating field (AC voltage) instead of the static field (DC voltage) was investigated in the field-aided lateral crystallization process, which is one of the low temperature crystallization processes for the amorphous silicon films. Using a photolithography process, a 5-mm-wide bar-shaped photoresist (PR) pattern was formed on the *a*-Si. On the PR-patterned *a*-Si, a 2–3-nm-thick Cu catalyst layer was deposited by a DC sputtering, and then, the Cu layer on the PR pattern was lifted off. The silver electrodes were pasted at the opposite sides of the Cu-free bar pattern. Then, the patterned specimen was annealed at 500 °C in N_2 ambient for 5 h with the application of various AC fields (ranging from 1 to 5 V/cm) along with a DC field of 30 V/cm. As compared with the case of a DC field of 35 V/cm only, the specimen from a mixed field of 30 V/cm DC and 5 V/cm AC resulted in 1.5 times faster crystallization rate, regardless of experimental frequency values ranging from 10 Hz to 50 MHz. Presumably, the enhancement of the crystallization rate under the combined field is associated with an increase in the flux of the crucial diffusion species, Cu atoms, which govern the overall crystallization rate due to the effect by the AC field.

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1. Introduction

Polycrystalline silicon thin-film transistors (poly-Si TFTs) have recently attracted considerable attention for their high field-effect mobility and response velocity [1,2]. However, poly-Si TFTs, which are the essential part of liquid crystal displays, are processed over 600 °C so that the use of the high temperature durable expensive quartz substrate is inevitable for the high performance TFT fabrication. If it is possible to fabricate poly-Si TFTs below the softening point of low price commercial glass, we can integrate all the functions such as voice, display, information processing, memory, input and output in a very inexpensive way on the glass substrate. Thereby, it can be widely applied to laptops, personal digital assistants, mobile phones, and desktop computers. The important considerations for manufacturing low temperature poly-Si include not only the development of a low temperature process but also the guarantee of high quality poly-Si [3,4]. Therefore, to obtain poly-Si below 500 °C, hot-wire chemical vapor deposition (CVD) or very high frequency glow discharge CVD was studied [5–7]. But, the contamination in deposited poly-Si or the poor quality of the film is hampering the extensive study. Consequently, more studies are focused on the way to crystallize the amorphous Si (*a*-Si) film below 500 °C after depositing *a*-Si film at a temperature below 300 °C.

Among a variety of crystallization techniques available to obtain poly-Si at low temperatures, the field-aided lateral crystallization (FALC) process is known to be induced by an influence of the electric field toward a specified direction after the silicide phase formation by a reaction between a metal catalyst and *a*-Si [8,9]. It is reported that the crystallization rate by the FALC process is much faster than that by the metal-induced lateral crystallization (MILC) process [10,11]. It is also reported that the undesirable metal pollution in the channel region can be greatly reduced by the FALC process [12].

Up to now, all the reports related to the FALC process are dealing with a static field (DC voltage) to induce the crystallization. It would also be interesting to investigate the crystallization aspect by an alternating field (AC voltage). The

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aim of this study is to examine effects of AC field on the crystallization of *a*-Si in the FALC process. Compared with the case of the FALC process with a DC field only and the MILC process, the crystallization rate was increased in the FALC process with a mixed field of AC and DC. The potential role of the AC field on the crystallization was suggested.

2. Experimental details

Silicon oxide of 500 nm thick was grown on Corning glass 1737 for the surface passivation. Then 80 nm of amorphous silicon (*a*-Si) was deposited on the passivated surface by plasma-enhanced chemical vapor deposition at 280 °C using Si_2H_6 and H_2 as source gases. The wafer was cut into 3×3 cm^2 square specimens for the application of the electric field. To effectively remove the impurities on *a*-Si film, RCA cleaning was conducted [13]. The organic impurities were removed using a 1:2:7 NH_4OH/H_2O_2/deionized water solution in a temperature range between 50 °C and 60 °C for 10 min. Then, the specimen was immediately dipped into a diluted HF (10:1) solution to remove the native oxide in the *a*-Si thin film. After cleaning the specimen, 5 mm bar-shaped photoresist (PR) patterns were formed on the *a*-Si using a photolithography process. A thin Cu catalyst layer, about 2–3 nm, was deposited using a DC sputtering system at room temperature. Then, the Cu layer on the PR pattern was lifted off and the 5 mm bar-shaped Cu-free patterns were left.

After the electrodes were formed using silver paste at two opposite sides of the bar pattern, an electric field was applied to the patterned specimen in a tube furnace during thermal annealing by a DC power supply and a DC/AC function generator, as illustrated in Fig. 1(a) and (b). The span between electrodes was 1 cm. In that configuration, the voltage applied (V) and the electric field (V/cm) can be interchangeably used hereafter. The specimen was heated at a rate of 5 °C/min in a tube furnace of N_2 ambient and held at a crystallization temperature of 500 °C for 5 h. A mixed AC (up to 5 V/cm) and DC field (30 V/cm) was applied. The frequency range of the AC-field was between 10 Hz and 50 MHz. After the thermal annealing, crystallization behavior and rates were identified by optical microscopy, and the crystallization degree in FALC poly-Si could be estimated by micro-Raman spectroscopy [14]. The laser of 515 nm wavelength was used and its diameter was in the range from 5 μm to 100 μm.

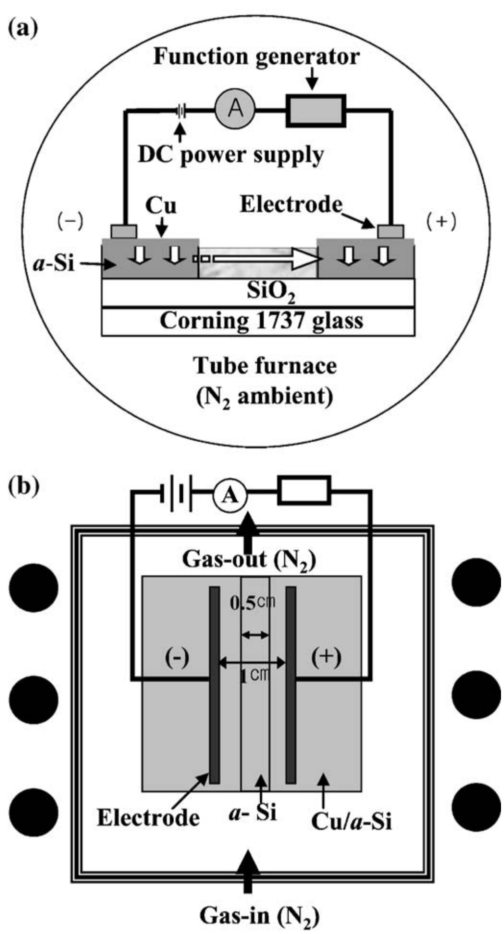

Fig. 1. Schematic diagram of experimental system for FALC process: (a) cross-sectional view and (b) top view.

3. Results and discussion

Fig. 2 shows the optical images of the patterns of partially crystallized *a*-Si at 500 °C after depositing the Cu catalyst outside the patterns. Fig. 2(a) shows that the crystallization length reached 4 μm on both sides after the MILC process for 5 h. When a DC field of 35 V/cm was applied, as shown in Fig. 2(b), the crystallization length reached 22 μm on the negative electrode side, whereas the crystallization scarcely occurred on the positive electrode side. At the same crystallization time and temperature, with a mixed electric field of an AC field of 5 V/cm (here, 100 Hz) and a DC field of 30 V/cm, the crystallization also appearing only on the negative electrode side exhibited a length of 38 μm. This result indicates that the addition of the AC field to the DC field in the FALC process not only induces the directional crystallization toward the metal catalyst-free region as in the case of the FALC process with the DC field only, but also enhances the crystallization rate.

To explore the influence of the AC field in depth, we tried various frequencies of the AC field for the crystallization. Fig. 3 shows the results of the crystallization at various crystallization conditions. As seen in Fig. 3, the crystallization rate of the mixed electric field was approximately 1.5 times faster than that of the DC field only (4.5 μm/h) and the frequency dependence was not significant in the present experimental frequency range between 10 Hz and 50 MHz. Considering the maximum value of the AC field (5 V/cm), the range of the mixed field is from 25 V/cm to 35 V/cm, which does not exceed the value of the DC field only case (35 V/cm). Still, the crystallization rate of the *a*-Si in the case of the mixed field is higher.

At present, the most reasonable and acceptable explanation for the FALC phenomenon is based on the combination of three kinds of driving forces: electromigration, potential gradient, and chemical activity difference. Among them, the driving force from the chemical activity difference is known to