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Crystallization behavior of FALC processed a-Si at various electric field intensities

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The effect of various electric field intensities on a Cu-field aided lateral crystallization (FALC) process of amorphous silicon (a-Si) films has been studied. The electric field intensity investigated in this study ranged from 15 V/cm to 180 V/cm. The intensity of the Raman spectral peak from the polycrystalline silicon (c-Si) increased monotonically with the electric field intensity during thermal annealing at a temperature of 450°C. The degree of crystallization calculated from the intensity of the Raman peak increased as well and resulted in 82% at the highest electric field of 180 V/cm. The crystallization velocity obtained from the sample at 180 V/cm was about 50 times larger than that from the sample at 15 V/cm. Consequently, it was verified that both the degree of crystallization and crystallization velocity depend strongly on the electric field intensities in FALC process.

Key words: Cu catalyst, Field aided lateral crystallization (FALC), Electric field intensity, Degree of crystallization, Crystallization velocity.

Introduction

Low temperature polycrystalline silicon (LTPS) shows great promise for the fabrication of thin film transistors (TFTs) for 3D integrated circuits, device sensors, large area electronics, two-dimensional imaging systems, active matrix liquid crystal displays (AMLCD), etc [1-3]. Particularly in LCDs, the peripheral drive circuits and the pixel elements using poly-Si TFTs can be integrated on the same substrate, reducing the number of external drivers and connections. These reductions would lead to a large improvement in reliability and a decrease in potential cost. In addition, the poly-Si TFTs have superior field-effect mobility, when compared to a-Si TFTs [4]. In spite of the many advantages of poly-Si, some problems, such as lowering the crystallization temperature in order to realize a system on a glass substrate for commercial applications and decreasing the leakage current density in the off-state, have to be resolved. In much research into solutions to there problems, the focus has been on the effect of metal catalysts on the crystallization of a-Si films [5, 6]. In particular, Russell *et al.* have shown that the temperature for the crystallization of a-Si was drastically reduced to around 485°C when the Si films were in contact with a Cu catalyst [7].

In order to lower the crystallization temperature of amorphous silicon and to improve the mobility in the poly-Si TFTs, we have proposed a field aided lateral crystallization (FALC) process, in which an electric field is applied to the metal deposited a-Si thin films on selective areas during thermal annealing [8-10]. There are two major aspect of the FALC process. Firstly, the crystallization time can be shortened due to the electric field compared with processes based on plain thermal diffusion. Secondly, the applied field would force the crystal growth to be directional, which is an advantage in terms of the electrical properties of transistors. Recently, the crystallization of a-Si by a FALC process using a Cu catalyst has been reported [11]. The crystallization of a-Si was successfully carried out by thermal annealing at 500°C for 3 hours with an electric field of 30 V/cm.

In this study, we have examined the crystallization of a-Si by a Cu-FALC process at 450°C which is lower than the previously reported temperature of 485°C. The crystallization behavior under various electric field intensities during annealing were investigated in order to study the effect of an electric field in the FALC process on the degree of crystallization and the crystallization velocity. In addition, computer simulation has been performed to interpret the electric field distribution in the process.

Experimental Procedure

An amorphous silicon film of 80 nm thick was deposited by plasma enhanced chemical vapor deposition (PECVD) at 280°C using Si_2H_6 on a 500 nm thick silicon oxide coated glass (Corning 1737) substrate. On the glass substrate, 50 nm thick SiO_2 was deposited by RF magnetron sputter at room temperature as a patterned mask. SiO_2 outside the patterns was etched away using a buffered oxide etchant (BOE). All the patterns

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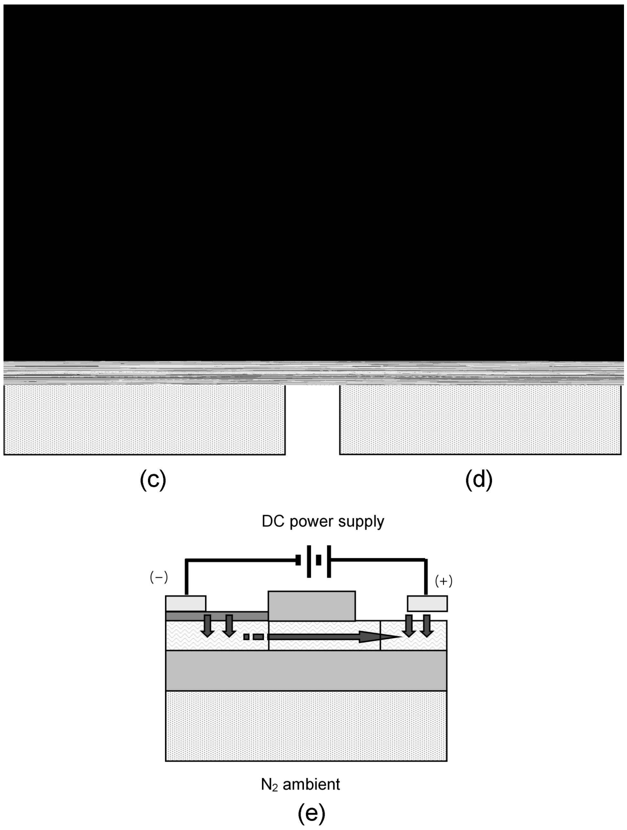

Fig. 1. Sequential process flow of the preparation of a FALC sample. (a) SiO_2 deposition and PR coating on the substrate (a-Si/SiO_2/glass), (b) Pattern formation, (c) deposition of Cu on a-Si film, (d) PR lift-off and electrode formation, and (e) schematic of the experimental set-up of the specimen for the FALC process.

used in this experiment have an identical configuration of 100 μm (W) × 600 μm (L). A thin layer of Cu (2 nm thick) was then deposited on the patterned substrate by DC sputtering at room temperature. After the Cu on the patterned oxide was removed by a lift-off process, only the Cu directly deposited on the a-Si film remained. The electric field was applied to the metal-deposited specimens on the selected areas by a DC power supply during the crystallization process after electrodes were formed using silver paste at the two opposite sides of the substrate. Schematic diagrams of the specimen preparation and the experimental set-up for the FALC process are shown in Fig. 1. The annealing was carried out in nitrogen ambient at 450°C with electric fields ranging from 15 V/cm to 180 V/cm. The ramp-up rate to the annealing temperature was set to 5 K minute^{-1} and the annealing time was 3 hours.

The crystallization behavior and the lateral crystallization velocity in every pattern after the thermal annealing were inspected by an optical microscope. The degree of crystallization in the poly-Si area was estimated from the area integration of the relevant peaks in micro-Raman spectra. A laser source of 515 nm wavelength was used and its diameter was in the range from 5 μm and 10 μm.

Results and Discussion

Figure 2 shows the optical microscope images of partially crystallized a-Si films annealed at 450°C for 3 hrs at various electric fields of 15 V/cm, 60 V/cm, 120 V/cm and 180 V/cm. During the annealing, the crystallization of a-Si in the rectangular pattern (100 × 600 μm) proceeded laterally from the negative electrode side to the positive electrode. This result is from the considerably accelerated crystallization on the negative electrode side (region A) compared to the positive electrode side (region B), which is a typical aspect of the FALC process.

Depending on the electric field intensity, however, the crystallized area in the identical patterns varies. Further, a careful look at the crystallized images reveals that dendrite structures developed outside the crystallized area in the patterns. Dendrites are seen much more obviously in the sample with the lowest electric field (15 V/cm) where only 12 μm in length of crystallization was achieved. Russell *et al*. have reported in their study on the reaction in a Si-Cu binary system that the Cu_3Si phase starts to form at 170°C and dendrites begin to form and grow in a Cu silicide matrix at around 485°C [7]. In our experiment, the growth of dendrites was observed at 450°C which is lower than the onset temperature reported, presumably due to the influence of an electric field during crystallization.

The crystallized region labelled as 'A' in Fig. 2(a)-(d) increases with the electric field intensity, and there is a clear demarcation between the crystallized regions, A, and the uncrystallized regions, B. It is interesting to note from the crystallization morphology that the leading edge of the crystallized region is not flat but rather curved. This bowed crystalline front is nicely

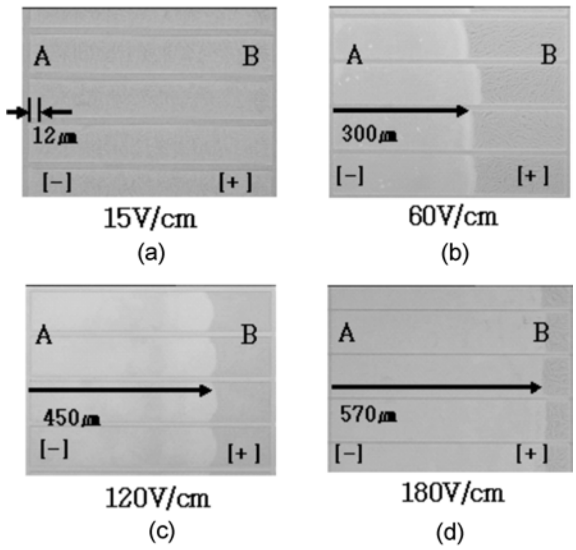

Fig. 2. Optical micrographs of samples after annealing at 450°C for 3 hrs with electric fields of (a) 15 V/cm, (b) 60 V/cm, (c) 120 V/cm and (d) 180 V/cm. A and B represent c-Si and a-Si areas, respectively.

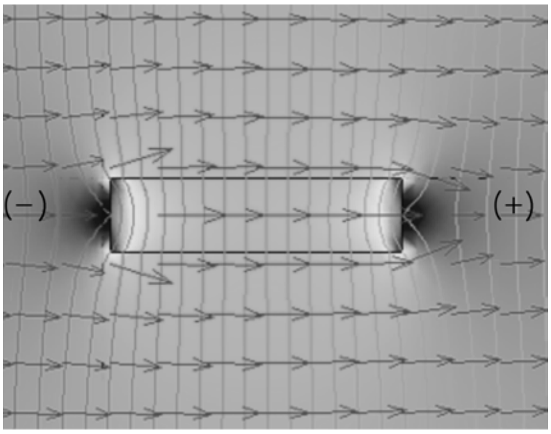

Fig. 3. Computer simulated electric field distribution around the pattern with 100 μm × 600 μm (The direction and magnitude of the arrows indicate the predicted crystallization directions and the crystallization velocities, respectively).

seen in Fig. 2(c). This curved interface might be associated with the spatial variation of the electric field intensity since the crystallization behavior is affected by an electric field as previously explained. In order to work out the electric field distribution in the patterned substrate, a computer simulation was performed using the fine element method. The simulation result is presented in Fig. 3. As shown in Fig. 3, the electric field intensity is not uniformly distributed along the line between the electrodes. The contour of the equivalent potential in the pattern predicts that the field intensity is the strongest at the center of the negatively-biased electrode and it decreases as the position moves towards the corner of the electrode. This simulation result is in good agreement with the experimental observations.

Figure 4 shows the crystallization velocity at various electric field intensities. The crystallization velocity was calculated from the crystallization distance measured from the pictures in Fig. 2 divided by the annealing time. As the electric field intensity increased to 15 V/cm, 60 V/cm, 120 V/cm, and 180 V/cm, the crystallization velocity increased to 4 μm/h, 100 μm/h, 150 μm/h, and 190 μm/h, respectively. The crystallization velocity increases monotonically with the field intensity in the experimental range. And the value obtained at 180 V/cm is approximately 50 times larger than that at 15 V/cm. However, the increment in crystallization velocity decreases as the field intensity increases.

Figure 5 shows a comparison of Raman spectra obtained from the crystallized regions ‘A’ in Fig. 2, processed by the Cu-FALC process with various electric field intensities at 450°C. It is reported that single crystalline silicon (c-Si) shows a sharp peak at 521 cm^{-1}, whereas amorphous silicon has a broad peak centered at 480 cm^{-1} [12, 13]. All the samples in this study exhibited a characteristic peak at 521 cm^{-1}, indicating that the films are crystallized. However, from the fact that the peak at 521 cm^{-1} is not symmetric and has a shoulder on the left hand side of the peak, the peak is considered to be not solely from the crystalline phase but also partly from the amorphous phase. Therefore, the crystallized areas are in fact a mixture of crystalline and amorphous phases. The degree of crystallization

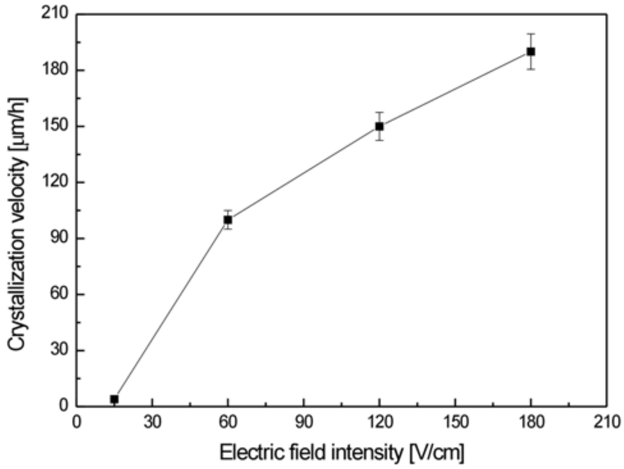

Fig. 4. Cu-FALC crystallization velocity of patterns as a function of electric field intensity at 450°C.

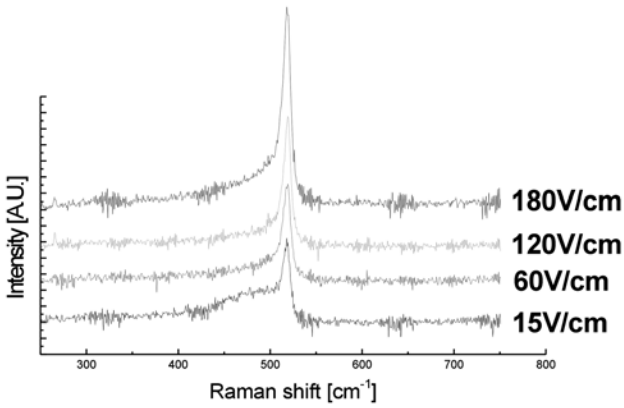

Fig. 5. Micro-Raman spectra from the crystallized areas in samples processed by Cu-FALC at various electric fields.

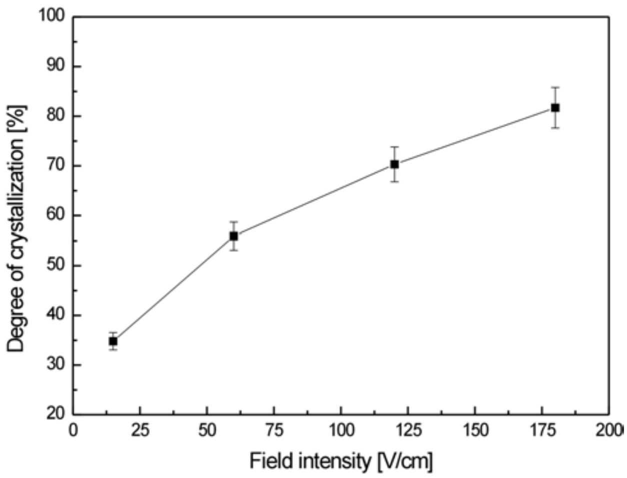

Fig. 6. Degree of crystallization for the FALC processed samples at various electric field intensities.

for each sample was calculated graphically from the area of the c-Si peak at 521 cm^{-1} and the area of the a-Si peak centered at 480 cm^{-1} using a computer program and the result is given in Fig. 6. The degree of crystallization can be expressed by the following equation [14]:

$$\sigma = \frac{I_c}{I_c + \gamma I_a} \quad (1)$$

where I_c and I_a are the areas of the c-Si and a-Si peaks, respectively and γ is the ratio of the back scattering cross sections, being set to 0.8 here [13]. When the electric field intensities were 15 V/cm, 60 V/cm, 90 V/cm, 180 V/cm, the degrees of crystallization reached 34%, 56%, 71%, 82%, respectively. The increment in the degree of crystallization is also reduced with an increase in the electric field intensity, which is the same as the result seen in the crystallization velocity. The degree of crystallization at 180 V/cm was about twice that at 15 V/cm.

Conclusions

Crystallization of amorphous silicon films was performed using a FALC process at 450°C under various field intensities in order to study the effect of the electric field on the crystallization behavior such as crystallization morphology, crystallization velocity, and the degree of crystallization. We observed dendrite formation inside the pattern in the very early stages of the crystallization process, which converted to a crystallized region later from the negatively biased electrode toward the positively biased electrode as the annealing progressed. Such a directional crystal growth caused by electrical polarity would result in an enhancement in mobility in poly-TFTs, since this direction corresponds to that of the carrier motion.

The crystallization temperature of 450°C in this experiment is lower than the previously reported temperature of 485°C, presumably due to the influence of the electric field. The curved shape of the crystallization front was interpreted in terms of the field distribution in the pattern and the field distribution calculated by computer simulation agreed with the experimental results very well.

The crystallization velocity turned out to increase with the electric field intensity. Such a result suggests that the most relevant species for governing the overall crystallization are likely to be charged. Otherwise, the electric field effect would not be seen. The relative intensity of the Raman spectra also increased with electric field intensity. When the electric field intensity was 180 V/cm, the crystallization velocity and the degree of crystallization were 190 μm/h and 82%, respectively. These numbers are about 50 times and 2 times larger, respectively, than the values at 15 V/cm.

Consequently, the crystallization of the a-Si by the Cu-FALC process was proven to be affected considerably by the electric field.

Acknowledgements

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