Influences of directional crystallization using field aided lateral crystallization on the electrical characteristics of poly-Si thin film transistors

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Abstract

Crystallization behavior of amorphous silicon (a-Si) using the field aided lateral crystallization (FALC) process was investigated. The lateral crystallization of a-Si was remarkably enhanced at the negative electrode side with the aid of an electric field, while it was retarded at the positive electrode side. FALC velocity using Ni was as high as 11 μm/h at 500 °C with an electric field of 4 V/cm. In addition, the nickel silicide phase, known to be a mediator for low temperature crystallization, can be driven from either the drain to source or source to drain in the active layer, depending on the bias conditions during crystallization. Thus, the defects originating from residual nickel silicide can be driven out from the channel region. Due to such an asymmetric location of the residual nickel silicide, the leakage current of the polycrystalline silicon thin film transistor (poly-Si TFT) using the FALC process showed a leakage current of approximately one order of magnitude lower when we reversed the probing polarity. Therefore, it was judged that the judicious selection of the bias condition during the FALC process can be useful in improving the electrical properties of poly-Si TFT. © 2002 Elsevier Science B.V. All rights reserved.

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1. Introduction

The growth of interest in polycrystalline silicon thin film transistors (poly-Si TFTs) over the past decade has been stimulated by the rapid commercial development of active matrix liquid crystal displays (AMLCDs) for their high definition and fast response time [1]. Since poly-Si TFTs should be fabricated on cost-effective glass substrates, which are not quite durable at high temperatures, amorphous silicon (a-Si) thin films must be crystallized below 500 °C. Among the various techniques available to form poly-Si, metal-induced crystallization (MIC) has been studied as a lower temperature process alternative to solid-phase crystallization (SPC) of a-Si thin films [2]. The MIC process, however, possesses a serious drawback: the incorporation of metal impurities, thus making it difficult to apply in the fabrication of poly-Si TFTs. Recently, a metal-induced lateral crystallization (MILC) process, where the crystallization initiated by the MIC process propagates to the metal-free region at 500 °C, has been presented [3,4]. In poly-Si TFT produced by the MILC process, however, a line defect is formed at the center of the channel region after the completion of crystallization because a-Si in the channel is crystallized by the thermal diffusion of the nickel silicide phase from both the drain and source region toward the center of the channel. In particular, because the defect consists of the highly conductive nickel silicide phase [5], the nickel silicide at the center of the channel provides a current path and causes deterioration of the electrical properties such as the leakage current in poly-Si TFTs [6].

In order to overcome such problems, a novel concept of a crystallization method that can minimize the defect in the channel area [7], field-aided lateral crystallization (FALC), has been proposed. As yet, the FALC process is known to take relatively a short time for crystallization
and shows directionality in crystallization behavior, depending on the polarity of the electric field [8,9]. Also, the fabricated FALC TFTs shows a low off-state leakage current and a high on/off current ratio, compared with the MILC TFTs [10].

In this study, we investigated the directional crystallization of a-Si thin film through tracing a silicide phase, and the asymmetric crystallization effects on the leakage current of FALC TFTs were examined by changing the probing method. That is, the position of the drain or source probe was exchanged to identify the effects of asymmetric distribution of silicide on the leakage current characteristics.

2. Experimental details

The following experiment was conducted to observe the lateral crystallization behaviors and the trace of silicide phase at the boundary between FALC poly-Si and the a-Si region. a-Si thin film (1000 Å thick) was deposited on a thermally oxidized Si substrate by plasma enhanced chemical vapor deposition (PECVD) at 300 °C using SiH₄ and H₂ as source gases. Various designed photoresist (PR) patterns on a-Si were formed by the photolithography process, which was followed by a 50-A-thick Ni layer deposition by the DC sputtering system. By dipping the specimen in acetone, the Ni layer on the T-shaped PR pattern was lifted off, leaving T-shaped Ni-free patterns. To apply an electric field, parallel electrodes using silver paste were formed on the opposite sides of the specimen and connected to a DC power supply. The crystallization was performed at 500 °C for 3 h with an electric field of 4 V/cm. The electric field was calculated by dividing the applied voltage by the distance between the electrodes.

In order to analyze the leakage current characteristics depending on the probing method, poly-Si TFTs were fabricated. Fig. 1a shows a schematic diagram of poly-Si TFTs fabricated by the FALC process. PR patterns were formed on a-Si film by the photolithography process, and the active islands were defined by reactive ion etching (RIE) using SF₆ plasma. A 1000-Å-thick SiO₂ gate dielectric film was deposited by RF magnetron sputtering at 200 °C, which was followed by molybdenum gate electrode (3500 Å) deposition by DC sputtering at room temperature. For the gate definition, the gate metal and the gate oxide films were selectively etched by RIE using SF₆ plasma and wet etching using diluted HF solution, respectively. The thin layer of nickel (∼20 Å) was deposited by DC sputtering, and then ion mass doping (IMD) using PH₃ gas was carried out at room temperature with an acceleration voltage of 18 kV. Parallel electrodes were formed using silver paste on the opposite sides of the specimen. Crystallization and dopant activation processes were accomplished simultaneously in N₂ ambient at 500 °C for 5 h with an application of an electric field of 6 V/cm. In order to form source and drain contacts, aluminum film (300 Å) was deposited by the DC sputtering system and patterned.

MILC TFTs were fabricated using the same experimental procedure except for the applied field during annealing, to relatively compare the electrical characteristics with FALC TFTs. The electrical characteristics of fabricated TFTs were analyzed using a HP4140B system. For the purpose of analyzing the effect of asymmetric distribution of the nickel silicide phase, we switched the polarity of probes between drain and source when the electrical characterization of fabricated TFTs was carried out. The "normal probing method" presented in Fig. 1b is defined as the condition where the source probe makes contact with the area to which the nickel silicide phase is driven, while the drain probe makes contact with the area from where the nickel silicide is driven. After reversing the polarity of the probes in the same

![Fig. 1. Schematic diagram of poly-Si TFTs fabricated by FALC process and probing methods to analyze the effect of nickel silicide phase on TFT's electrical characteristics. (a) Schematic diagram of experimental set-up, (b) normal probing method, and (c) reverse probing method.](image-url)
poly-Si TFTs, we evaluated the electrical properties again. This method of measuring in Fig. 1c is represented as a 'reverse probing method'. The electrical characteristics of MILC TFTs were also measured by both probing methods. In addition, we studied traces of the nickel silicide phase with a scanning electron microscopy (SEM) analysis to confirm the asymmetric characteristics of FALC.

3. Results and discussion

Fig. 2 shows the Nomarski optical micrograph of partially crystallized poly-Si film annealed at 500 °C for 3 h with an electric field of 4 V/cm. During the thermal annealing, the left-hand side of the specimen was negatively biased relative to the right-hand side. In Fig. 2, we can see the clear demarcation between the crystallized and uncrystallized areas in the film. The outside regions of the T-shaped pattern are the original a-Si film in direct contact with Ni. The low temperature crystallization initiates from this region and propagates toward the inside of the metal-free T-region by an electric field-assisted thermal diffusion of nickel silicide phase. The metal-induced and field-aided laterally crystallized region shows bright contrast while the region with dark contrast represents the uncrystallized a-Si area. Since the width of the lightly contrasted area (crystallized area) at the left-hand side of the T-shaped pattern is much wider than that of the right-hand side, the micrograph reveals that the crystallization is asymmetric and proceeds from the negatively biased side toward the positively biased side. The lateral crystallization velocity of the negatively biased side is more than 10 times faster than that of the positively biased side. In previous report, this phenomenon was explained in terms of dominant diffusing species (DDS) in the reaction between metal and Si and also, it is associated with the local electric field built up in the metal silicide in the presence of electric field [11].

In order to trace and confirm the crystallization mediator at the advancing edge of the poly-Si film, the partially crystallized specimen was etched by a nickel silicide etchant, and the surface morphologies of the interesting areas marked as A and B in Fig. 2 were examined by scanning electron microscopy (SEM), as shown in Fig. 3. Fig. 3a is an image obtained from area A in Fig. 2, which corresponds to the boundary between the MIC area (where the Ni or nickel silicide originally existed) and the FALC area. It reveals that the etch pits are rare on the surface of the FALC area, while many etch pits ranging from a few micrometers to 100 μm are seen on the Ni-deposited area. These etch pits are due to the existence of residual Ni or the nickel silicide.
Fig. 4. The transfer characteristics of poly-Si TFTs fabricated by the (a) MILC and (b) FALC process.

phase. More clear evidence of the role of the crystallization mediator is shown in Fig. 3b. Fig. 3b shows a high-resolution surface image of the area B in Fig. 2, which contains the boundary between the FALC Si and the a-Si area to be crystallized. This boundary is, in fact, the leading edge of the crystallized area. In this image, the etch pits are located only at the boundary. These pits result from the selective etching of the Ni-based compound, which is known as nickel silicide \( \text{Ni}_x \text{Si} \). Therefore, it indicates that the crystallization of the a-Si film is led by the migration of the nickel silicide phase. From the observation that the trace of nickel silicide is located only at the leading edge of the crystallized phase and the migration of crystallization mediator is affected by an electric field (as explained earlier in Fig. 2), we could successfully perform a directional crystallization toward metal-free a-Si.

It was reported that the anomalous leakage current of poly-Si depends on a gate and drain bias [13]. In the case of MILC TFTs (FALC TFTs are also believed to exhibit the same behaviors), the nickel silicide phase is known to play a role as trap and recombination centers to generate the leakage current. Therefore, the anomalous leakage current of MILC TFTs is associated with the traps near the drain junction where the relatively high electric field is applied even at the off state. Accordingly, Kim et al. have fabricated MILC TFTs by means of asymmetric Ni deposition using the offset process so as to reduce the defects at the channel region [5]. However, the Ni-offset process requires not only an additional mask process but also unnecessary space.

In the FALC process, we expect to obtain the same effect as the offset process by simply applying a negative bias to the drain side and a positive bias to the source side on the specimen during crystallization. By doing this, the nickel silicide phase, which acts as leakage current generation sites, can be swept out from the drain region to the source region with much faster crystallization velocity. Thus, the FALC process does not require an additional mask process which may significantly drop the product yield.

In order to verify this concept experimentally, the effect of the one-way driven nickel silicide phase on the leakage current of the poly-Si TFTs was evaluated. The drain current \( I_d \) vs. gate voltage \( V_g \) characteristics of MILC and FALC TFTs are shown in Fig. 4. In both measurements, we reversed probing tips so as to switch the bias polarity between drain and source during the electrical measurement, as described in Fig. 1b,c. As shown in Fig. 4a, the off-state leakage current of the normal probing condition in MILC TFTs is almost identical to that of the reverse probing condition. This result is expected because the crystallization in the MILC process proceeds toward all of the directions with the same speed. Thus, the distribution of the residual nickel silicide phase is most probably at the center of the transistor channel region. Such a symmetrical distribution results in the same magnitude of leakage current regardless of the probing polarity between source and drain.

However, Fig. 4b shows that the off-state leakage current of the normal probing condition in FALC TFTs is approximately one order of magnitude lower than that of the reverse probing condition at \( V_g = -10 \) V. In contrast to the MILC TFTs, the off-state leakage current in FALC TFTs can be higher in the reverse probing
mode because the residual Ni silicide phase is mostly located near the drain where the electric field is higher than near the source. As a result, considering the amount of defects responsible for the leakage current, it is thought that the off-state leakage current in the reverse probing mode is larger than in the normal probing mode in the case of FALC TFTs.

Besides the off-state leakage current characteristics, FALC TFTs demonstrate superior electrical characteristics such as field-effect mobility and on/off current ratio, compared with MILC TFTs. The measured data are listed in Table 1.

### 4. Conclusions

The crystallization of a-Si initiates from the Ni-deposited area and propagates toward the metal-free region during thermal annealing. Especially, by applying an electric field during thermal annealing, lateral crystallization can be significantly enhanced from the negatively biased side toward the positively biased side. The crystallization velocity at the negatively biased side increased to 11 μm/h. The migration direction of the nickel silicide phases depended on the polarity of the applied electric field, which resulted in directionality of crystallization. Thus, because of the effect of the one-way driven nickel silicide, FALC TFTs exhibited a difference in the leakage current in the off state depending on the probing polarity. In contrast to the MILC process in which the defects remain halfway between source and drain, the FALC process can sweep the defects away from the channel area. Therefore, the electrical properties of FALC TFTs exhibited a lower leakage current and higher field-effect mobility in comparison with MILC TFTs.

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### References