REVISTA MEXICANA DE FÍSICA S**53** (1) 1–4 ENERO 2007

Fabrication of low temperature poly-Si thin film transistor using field aided lateral crystallization process

Hyun-woong Chang[a], Hyun-chul Kim[a], Young-Bae Kim[b], Yu-hang Wang[c], and Duck-Kyun Choi[a], ∗
[a]*Department of Ceramic Engineering, Hanyang University,*
17 Haengdang-dong, Seongdong-ku, Seoul 133-791, Korea.
[b]*Physics Department,*
110 Cox Hall 2700 Stinson Dr. Box 8202 Raleigh, NC 27695, USA.
[c]*National Key Laboratory of Advanced Welding Production and Technology, Harbin Institute of Technology,*
Harbin 150001, China.

Recibido el 9 de junio de 2006; aceptado el 8 de septiembre de 2006

Polycrystalline silicon thin film transistors (poly-Si TFTs) for LCD application were fabricated on glass substrate using the field-aided lateral crystallization (FALC) process. The crystallization of amorphous silicon (a-Si) was significantly enhanced when the electric field of 100V/cm was applied to selectively Ni-deposited a-Si film during thermal annealing at 500° in N_2 ambient for 5 hrs. The channel of the transistors was directionally crystallized from the negatively biased electrode side. The field-effect mobility of the fabricated poly-Si TFTs was about 200.5 cm^2/V-s. Therefore, the possibility of high-performance and low-temperature (<500°) poly-Si TFTs was demonstrated by using the Ni-FALC process.

Keywords: Field aided lateral crystallization; Ni catalyst; polycrystalline silicon thin film transistors; low temperature crystallization.

Se fabricaron transistores de silicio policristalino de película delgada (TFTs poli-Si) para aplicación LCD en sustrato de vidrio mediante un proceso de cristalización lateral asistida por campo (FALC). La cristalización de silicio amorfo (a-Si) se reforzó significativamente cuando se aplicó un campo eléctrico de 100 V/cm a una película a-Si con deposición selectiva de Ni durante recocido térmico a 500° en ambiente de N2 por 5 horas. El canal de los transistores se cristalizó directamente del lado del electrodo con sesgo negativo. La movilidad del efecto de campo del TFT poli-Si fabricado era de 200.5 cm2/V-s. Por consiguiente, se comprobó la posibilidad de producir TFTs poli-Si de alto rendimiento y baja temperatura (<500°) por medio del proceso Ni-FALC.

Descriptores: Cristalización lateral asistido por campo; nanocatalizador de Ni; transistores de película delgada de silicio policristalino; cristalización a baja temperatura.

PACS: 73.61.Jc; 81.10.Jt

1. Introduction

Until now present, amorphous silicon (a-Si) has been mainly used as an active layer for thin film transistors (TFTs), of which fabrication is a key technology for active matrix liquid crystal displays (AMLCDs) [1-4]. Recently, polycrystalline silicon thin-film transistors (poly-Si TFTs) have been replacing amorphous silicon thin-film transistors (a-Si TFTs) for their advantages in high field-effect mobility and response time [1,5,6]. In spite of the outstanding performance of poly-Si TFTs, lowering the crystallization temperature is a great concern because the amorphous silicon that has to be crystallized is deposited on the glass substrate. In addition, decreasing the leakage current density in the off-state mode is another issue to be tackled for the practical application [7,8].

Among various crystallization techniques for poly-Si at low temperature, field aided lateral crystallization (FALC) is a unique process in the sense that the crystallization is induced by an influence of the electric field toward the specified direction. The electric field can enhance the migration of the silicide crystallization mediator formed by the reaction between metal catalyst and amorphous Si [8,9]. In this process, it is not only possible to crystallize the a-Si at lower temperatures but also to minimize the undesirable incorporation of the crystallization mediator in the region of the channel, which is the crucial area for determining the electrical properties in TFTs. Previously, this idea was implemented in the fabrication of poly-Si TFT on a Si (100) wafer using Ni-FALC, and successfully demonstrated the transistor characteristics.

In this present work, we have extended this idea to fabricate the poly-Si TFTs on a glass substrate (corning 1737) at 500° using Ni-FALC [10,11].

2. Experiment

300 nm of silicon dioxide was deposited on corning glass 1737 by atmospheric pressure chemical vapor deposition (APCVD) to passivate the glass substrate. 80 nm of amorphous silicon film (a-Si) was deposited on the silicon dioxide by plasma enhanced chemical vapor deposition (PECVD) at 280° using SiH_4 and H_2 as source gases. The specimen was then annealed to dehydrogenate at 450° for 2 hrs in N_2 ambient in a tube furnace. In order to effectively remove the unwanted impurities on a-Si films, an RCA cleaning was conducted. The organic cleaning using a mixed solution (NH_4OH:H_2O_2: deionized (DI) water = 1:1:5) was carried out in temperatures ranging from 70 to 75° for 10 min. Thereafter, the diluted buffered oxide etchant (BOE) (10:1) solution dip followed immediately to remove the native oxide on the exposed a-Si thin films.

After cleaning the specimen, active layer (source, drain, and channel region) photoresist (PR) patterns on a-Si were

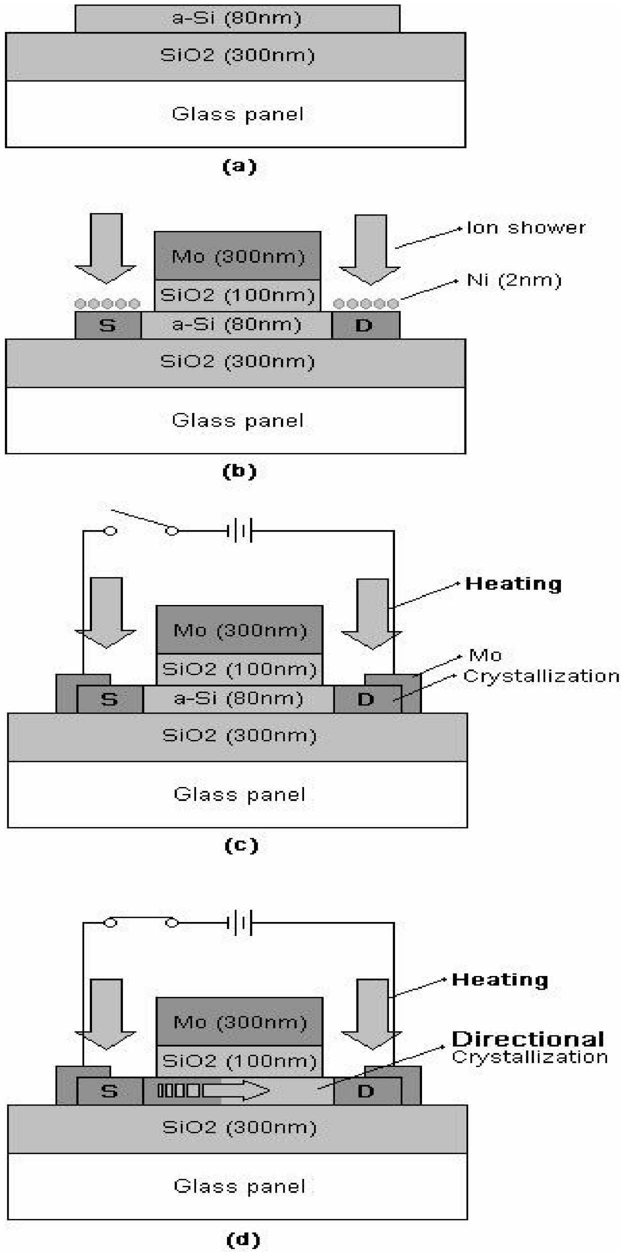

FIGURE 1. Process flow of poly-Si TFT by field-aided lateral crystallization process: (a) active area defined (b) selective deposition of Ni and PH_3 doping on source and drain region (c) Mo contact formation and source and drain crystallization (d) crystallization of a-Si in the channel region by FALC.

formed by the photolithography process. 100 nm-thick SiO_2 and 300 nm-thick Mo were sequentially deposited for gate oxide and gate metal, respectively. Then, the source and drain contact holes were etched after the photolithography process using the second mask. On the patterned substrate, 2 nm-thick Ni crystallization catalyst was deposited using a DC sputtering system, which was followed by phosphorus doping using an ion mass doping system at room temperature. For the practical application, the electric field was introduced a through Mo metal line which was directly connected to source and drain. The crystallization of a-Si in the channel region was carried out at the temperature of 500° with an electric field intensity of 100V/cm in N_2 ambient. The sequence of the fabrication process described above is presented in Fig. 1. The electrical characteristics of transistors the fabricated were measured by an HP 4140B system.

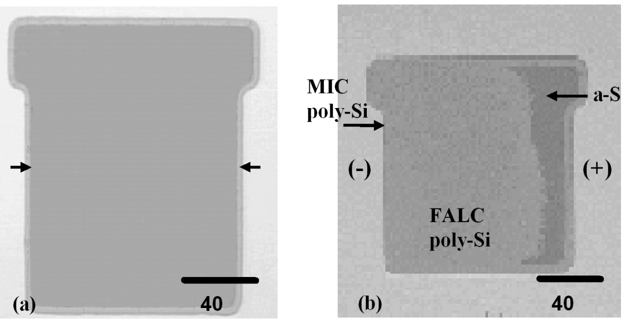

FIGURE 2. SEM micrographs of partially crystallized films processed at 500° in N_2 ambient without electric field (a), and with electric field intensity of 180V/cm (b).

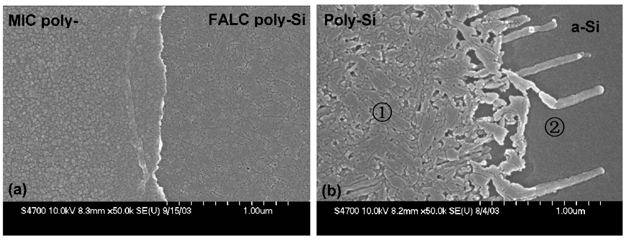

FIGURE 3. SEM images of crystallized microstructure using Ni-FALC boundary between MIC poly-Si and FALC poly-Si and (b) crystallization front of FALC processed poly-Si.

3. Results and discussion

Figure 2 shows optical microscope images of the partially crystallized a-Si films using a Ni catalyst without an electric field and with an electric field intensity of 180V/cm at 500°. In Fig. 2a, Ni was partially deposited on the outside of T-shaped pattern only. Therefore, the a-Si outside of T-shaped pattern was crystallized first due to the Ni catalyst. The crystallization under the metal catalyst is called metal induced crystallization(MIC). The crystallized region is then propagated laterally into the inside of the T-shaped pattern along the pattern boundary with the same speed. This crystallization is known to metal induced lateral crystallization (MILC), and this conformal crystallization is attributed to the diffusion of Ni-silicide [6]. On the contrary to MILC, the crystallization in this experiment proceeded noticeably from the negative electrode side toward the positive electrode side with an aid of the applied electric field intensity of 180 V/cm. As shown in Fig. 2b, this directional crystallization enables one to drive undesirable metal silicide out of the pattern. As a result of field aided lateral crystallization (FALC), we can minimize the metal residue in the pattern. In addition, it is not uneasy to get much faster crystallization speed than that of MILC at the same annealing temperature.

TABLE I. Device parameters of poly-Si TFT fabricated by Ni-FALC process.

	N-channel, V_d = 0.1V, 500°C, 5 hrs
Width/Length (μm)	17/12
Threshold voltage (V)	9.4
Field effect mobility (cm^2/Vs)	200.5
Maximum on/off current ratio	8.9×10^4
Leakage current (A) at V_g = –5V	4.7×10^{-11}

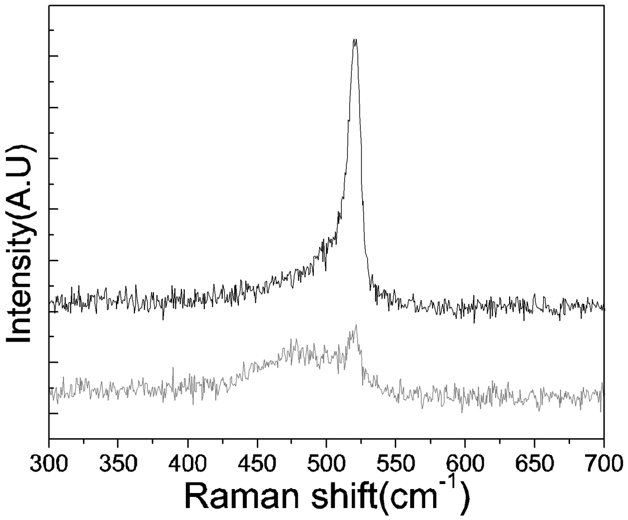

FIGURE 4. Comparison of Raman spectra from (a) crystallized poly-Si and (b) uncrystallized a-Si using Ni-FALC.

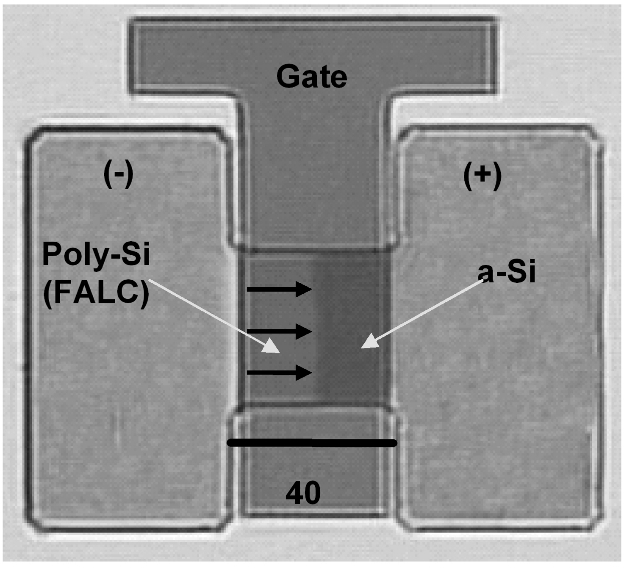

FIGURE 5. Optical microscope image of the partially crystallized transistor pattern prepared by Ni-FALC process at 500°.

Microstructures of the crystallized films are shown in Fig. 3. The left-hand side microstructure shows clear demarcation between the region crystallized by the Ni-FALC and MIC.

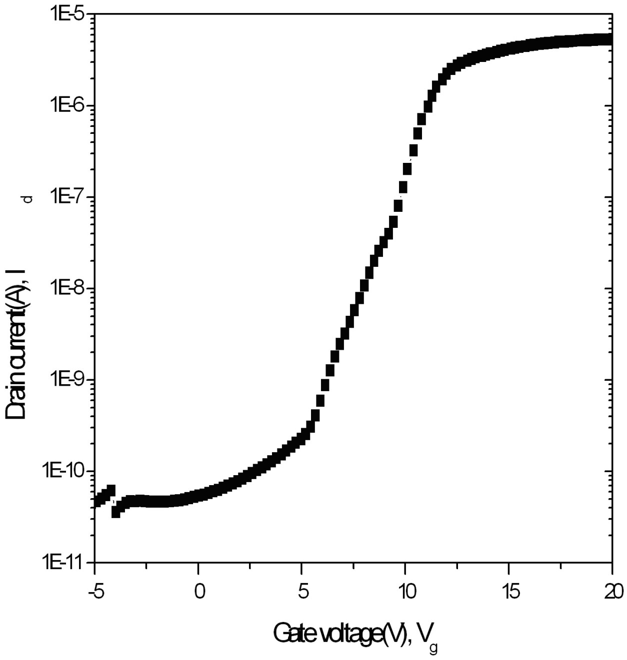

FIGURE 6. I-V characteristics of poly-Si TFT fabricated using Ni-FALC at a drain voltage of 0.1 V.

Generally, it is known that the poly-Si films processed by conventional MIC or MILC processes result in small grains with a slightly elongated shape. The magnified micro morphology of the crystallites at the boundary (Fig. 3b) between poly-Si and a-Si shows the needle-like crystallites. Presumably, mobility of the TFTs is closely related to the enhanced field-effect in the long needle-like crystallites.

In order to investigate the degree of crystallization of poly-Si by Ni-FALC process, a Raman beam was focused on the crystallized region in Fig. 3b as shown in Fig. 4a. Single crystalline silicon has a sharp peak around 521 cm^{-1} in Raman spectra. The intensity of Raman spectra measured from the crystallized region by Ni-FALC shows the obvious evidence of crystallization. On the other hand, the uncrystallized a-Si region in Fig. 3b shows a rather broad peak around 481 cm^{-1}, which is a typical characteristic of a-Si in Raman spectra. From the above results, Ni- induced lateral crystallization under the electric field was identified.

An optical image of partially crystallized a-Si in the channel of the transistor using Ni at 500° with an electric field intensity of 100 V/cm is shown in Fig. 5. In order to check the directionality in crystallization, the specimen was not fully crystallized but partially crystallized. The neck or bridge region of the H-shape pattern is a channel region covered by the gate oxide and gate metal. Hence, the channel area is free from Ni catalyst. During annealing, a-Si in the source and drain area is crystallized first since the MIC process can occur, and the channel is laterally crystallized from the negative electrode side to the positive electrode as shown by arrows in the picture. This result confirms that the FALC process is possible even though the area to be crystallized is covered by an oxide. Only the source and drain regions are originally the areas directly in contact with Ni. The low temperature crystallization initiates from this region and propagates into the inside metal-free channel region by an electric field-assisted thermal diffusion of the nickel silicide crystallization mediator.

Figure 6 shows the drain current (I_d)-gate voltage (Vg) characteristics of Ni-FALC TFT at V_d (drain voltage)=0.1V. FALC TFT using Ni shows relatively superior properties compared with the previously suggested characteristics of TFTs fabricated using Ni solution, as summarized in Table I. It can be judged from the data that one possibility of such differences in transistor characteristics is associated with the gettering effect in the channel region in the transistor. It is reported in the case of MILC processed TFTs that the leakage current at high drain voltage and the high negative gate voltage might result in the field-enhanced tunneling of electrons in the valence band to the conduction band via grain boundary traps. The field-effect mobility of FALC processed TFTs could be relatively enhanced due to the minimization of metal residues in the channel region and the properly oriented microstructure in the channel region. Especially, it is quite noticeable that the field effect mobility is very high and about 200.5 cm^2/Vs.

4. Conclusion

Poly-Si TFTs adopting the Ni-FALC process were fabricated on a glass substrate by applying an electric field of 100 V/cm at 500°. Using the FALC process, the field-effect mobility increased to 200.5 cm^2/Vs. Such high mobility is attributed to the needle-shaped grain, which helps the movement of the carriers in the channel area. The leakage current and the threshold voltage were about $4.7\times$10-11A at Vg = -5 and 9.4V, respectively. Consequently, we demonstrated the possibility of low temperature ($<500^\circ$) and enhanced characteristics of poly-Si TFTs by the using the Ni-FALC process.

Acknowledgment

This work was financially supported by the Korea Institute of Science and Technology Evaluation and Planning (KISTEP) through the National Research Laboratory (NRL) program. This work was also supported by a Korea Research Foundation Grant (KRF-2004-005-D00167).

$*$ Corresponding author: duck@hanyang.ac.kr

1. C.H. Tseng, T.K. Chang, F.T. Chu, J.M. Shieh, and B.T. Dai, *IEEE* **23** (2002) 333.
2. K. Sera *et al.*, *IEEE Trans. Electron Dev.* **36** 12 (1989) 2868.
3. T.J. Konno $et al.$, *Mat. Sci. Eng. A* **1790** (1994) 426.
4. G. Radnoczi, *J. Appl. Phys.* **69** (1991) 6394.
5. G.A. Bhat $et al.$, *IEEE Electron Dev. Lett.* **20** (1999) 97.
6. C. Hayzelden $et al.$, *J. Appl. Phys.* **73** (1993) 8279.
7. H. Sehil, N.M. Rahmani, and F. Raoult, *Mater. Chem. Phys.* **42** (1995) 101.
8. T.H. Ihn, T.K. Kim, B.I. Lee, and S.K. Joo, *Microelectron. Realiab.* **39** (1999) 53.
9. Y. Kawazu, H.H. Kudo, S. Onari, and T. Arai, *Jpn. J. Appl. Phys.* **29** (1990) 2698.
10. K.S. Song, J.B. Lee, S.I. Jun, D.K. Choi, and S.K. Park, *J. Mat. Sci. Lett.* **18** (1999) 1209.
11. S.I. Jun, Y.H. Yang, J.B. Lee, and D.K. Choi, *Appl. Phys. Lett.* **75** (1999) 2235.