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Impact on TFT Characteristics of Rapid Crystallization of Si using Nickel-Metal Induced Lateral Crystallization

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1. Introduction

Polycrystalline silicon thin film transistor (poly-Si TFT) is promising to add various electronic functions to system on panel devices. It is highly demanded to produce high-quality poly-Si films on glass substrates at a high through-put and low energy cost. Metal induced lateral crystallization (MILC) using nickel di-silicide catalyst is a strong candidate to meet the requirement because it is able to grow a poly-Si film having a large grain with high uniformity and, therefore, to fabricate high performance TFTs[1]. Furthermore, as we showed in the previous report[2], grain filtering can be applied to the lateral growth of Ni-MILC to further improve performance of TFTs.

On the other hand, investigation of MILC process has been mostly carried out at temperatures below 600°C. Therefore, the growth speed of MILC crystals is limited and MILC consumed a long time, for example, several hours to a few tens hours to fully crystallize an a-Si film. This is a drawback of MILC for application, which should be overcome. To realize rapid crystallization, it is straightforward to elevate temperature for crystallization. This work aims at collecting fundamental knowledge about crystallization kinetics of Ni-MILC at elevated temperature and impact of it on TFT performance.

When MILC proceeds, solid phase crystallization (SPC) resulting from spontaneous nucleation of a-Si takes place. SPC interrupts MILC. In this study, therefore, we first investigate the growth kinetics of MILC and incubation time of spontaneous nucleation, and estimate the maximum growth length at the each temperature. Then, we apply crystallization to MILC in a grain filtering structure. Quality of the films is characterized by fabricating TFTs. Results show that MILC at elevated temperature is able to significantly enhance crystallization speed while keeping performance of TFT high.

2.Experimental

Figure 1(a) shows schematic cross section of lateral structured and MILC growth. Si wafers covered with a SiO_2 layer grown by thermal oxidation was used as the substrate. A 100 nm-thick a-Si layer was deposited by ultra-high vacuum evaporation. A cap SiO_2 layer was deposited by spin-on-glass (SOG), and Ni-supply regions were formed by etching the SOG layer with a BHF solution. Then, to reduce Ni quantity diffusing into a-Si, a Ni-supply limiting layer was formed by boiling the sample with a mixture of $NH_4OH : H_2O_2 : H_2O = 1 : 1 : 2$ [3] at 80°C for 15 min. A thin Ni layer was deposited by vacuum evaporation on the entire surface of the sample. We investigate the crystallization velocity in Ni-MILC and the incubation time of SPC spontaneous nucleation at 550-660°C for several hours to a few ten hours in an N_2 ambient.

Figure 1(b) shows the top-view layout of an a-Si island used as TFT active layer. The wide regions at the ends are used as source and drain contacts and the narrowed region at the middle is used as the channel of a TFT. Ni-supply region was formed at one end of the pattern (left end in the schematic in Fig. 1). MILC progresses from the Ni deposited region toward the other end, while the grain filtering takes place at the narrowed region.

After crystallization, Ni and cap SiO_2 layer were removed by wet etching process. The gate oxide film was grown at 1050°C for 20 min in O_2 ambient. Phosphorus ions at a dose of 3×10^{15} cm^{-2} were implanted to form the n^+ source/drain region. The dopants were activated by rapid thermal annealing (RTA) at 900°C for 5 min, and contact holes were opened by photo lithography and wet etching process. Finally, the aluminum layer was deposited by vacuum evaporation and patterned for source, drain and gate electrode.

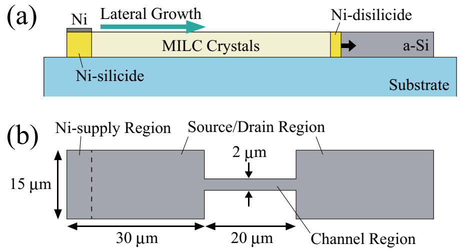

Fig. 1: (a) Schematic illustration of MILC process (cross section). Slices of nickel di-silicide move towards a-Si leaving epitaxial silicon behind. (b) Layout of the patterned a-Si film and the position of Ni to induce MILC.

3. Results and Discussion

3.1 Investigation of Rapid Crystallization

Figure 2 shows Arrhenius plot of the MILC crystallization velocity v_g and the incubation time τ in spontaneous nucleation. This figure indicates that the activation energy of the growth speed and incubation time are 2.3 eV and 3.6 eV, respectively. From this result, we find that the MILC crystallization velocity at 670°C and 770°C is about 10 and 100 times larger than previous technique at 600°C, respectively. From the results, we are also able to estimate the maximum growth length which is the length that MILC crystals can grow without interruption of SPC. The maximum growth length are 30 μm and 10 μm at 670°C and 770°C, respectively. These values are large enough to cover at least one active channel of TFT.

Next, we executed the crystallization using 80 μm-long TFT-active islands. Figures 3(a)-3(c) show Electron Back Scattering Pattern (EBSP) images of the crystallized 2 μm-wide active islands. The MILC was carried out to crystallize the islands from the left to right. The samples of Figs. 3(a)-3(c) were annealed at 600°C for 300 min, 670°C for 40 min, and 770°C for 4 min, respectively.

It is found from the results shown in Fig. 3(a) that one of crystals generated in the MILC seed region at the left end is filtered. In other words, the grain filtering effect occurred. The grain filtering effect also occurred in the sample annealed at

670°C shown in Fig. 3(b). However, MILC growth stopped on the way to get through channel region due to spontaneous nucleation and SPC. In the sample annealed at 770°C as shown in Fig. 3(c), MILC growth stopped before reaching to channel region. From Fig. 2, it is found that the incubation time at 670°C and 770°C is about 10 min and a few ten seconds, respectively. The above results reasonably agree with these incubation time.

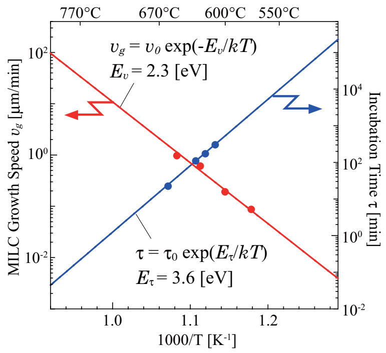

Fig. 2: Arrhenius plot of lateral crystallization velocity v_g in Ni-MILC and incubation time τ for crystallization to start in SPC.

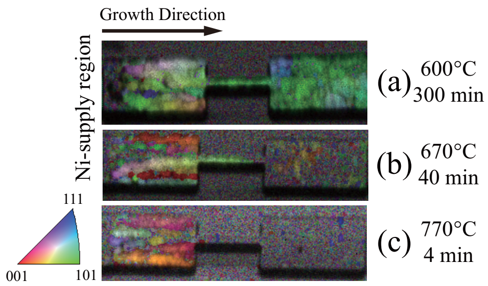

Fig. 3: EBSP patterns showing crystallized thin films at the temperature of 600°C, 670°C, 770°C, respectively.

3.2 Fabrication of TFT on rapid crystallized MILC films

We fabricated MILC-TFTs using rapid crystallized films at 670°C for 40 min and 770°C for 4 min. TFTs were also fabricated using a film crystallized at 600°C for 300 min. The gate length/gate width (L/W) is 2 μm/2 μm.

Figure 4(a) compares the switching characteristics of the respective MILC-TFT measured at the source-to-drain voltage (V_{DS}) of 0.1 V. Figures 4(b)-4(d) also show the normal probability plots of electrical characteristics of the three type TFTs. The number of TFTs tested was 30 for each type, which were randomly selected. From the result shown in Fig. 4(a), 670°C MILC-TFT has the same on-current compared with 600°C MILC-TFT. On the other hand, TFT on the 770°C MILC film indicates lower on-current than 600°C and 670°C MILC-TFT. In addition, from Fig. 4(b), it is found that the average value of carrier mobility decreases with elevating crystallization temperature. These results indicate that the increment of spontaneous nucleation by elevating temperature caused degradation of TFT driving current.

On the other hand, from the results shown in Fig. 4(a), it is clearly seen that TFT on the 770°C MILC film has lower off-current than 600°C and 670°C MILC-TFT. From Figs. 4(a) and 4(d), it is also found that TFTs on the 770°C MILC film has low sub-threshold swing compared with the two others. Figures 4(c) and 4(d) indicate that TFTs on the 770°C MILC film show smaller variation in threshold voltage and sub-threshold swing than the two others. These results suggest that amount of Ni contaminants in the channel region reduces as the crystallization temperature increases, which is probably due to SPC of the channel region prior to MILC growth.

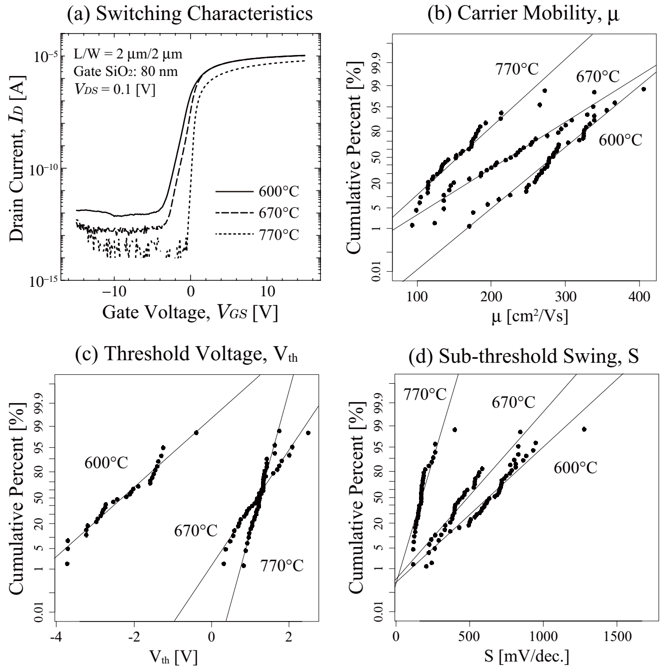

Fig. 4: Switching characteristics and normal probability plots of electrical characteristics of the fabricated TFTs. (a): Switching characteritics. (b): Carrier mobility. (c): Threshold voltage. (d): Sub-threshold swing.

4. Conclusions

We have investigated Ni-MILC at higher temperatures than previous study to investigate feasibility of rapid MILC and impact of rapid crystallization on TFT performance. From the experimental results obtained by using a grain filtered structure, we conclude that the crystallization temperature can be increased to enhance the lateral growth speed, while TFT performance is kept high, as far as the lateral growth is kept from random crystallization of SPC. A practical measure of the crystallization temperature is 670°C because of the softening temperature of the non-alkali glass substrate which is commonly used for flat panel displays. At this growth temperature, the crystallization time is reduced to 40 min from 300 min at 600°C.

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