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High Performance Polycrystalline Thin-Film Transistors Formed by Copper Metal Induced Unidirectional Crystallization

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Polycrystalline silicon thin-film transistors fabricated by metal induced lateral crystallization (MILC) have been demonstrated as promising devices for realizing electronics on large area, inexpensive glass substrates. However, it takes a relatively long time to crystallize amorphous silicon thin films. In this work, we proposed a new crystallization method using copper and nickel metals together and proved that this method could be used to fabricate thin-film transistors. It turned out that a four times faster crystallization rate could be obtained and that device performance was similar to conventional nickel MILC TFTs. This means that the proposed crystallization method is quite acceptable for practical use.

Keywords: metal-induced lateral crystallization (MILC), copper, nickel, thin-film transistors

1. INTRODUCTION

Polycrystalline silicon (poly-Si) thin-film transistors (TFTs) on glass are of special interest for use in liquid crystal display (LCD) and organic light-emitting diodes (OLEDs). In addition, the characteristics of flat panel display devices, such as brightness, resolution, and image transport speed, are very much dependent on the carrier mobility of TFTs, which in turn depends on the crystallinity of the silicon thin-film substrate. Current laser annealing processes, however, suffer from non-uniform crystallinity, due to the inevitable scan overlap involved, as well as surface roughness, due to the liquid solid phase transformation of silicon.[1] An alternative method for the poly-Si on glass is MILC of amorphous silicon (a-Si). It is well known that the solid phase crystallization temperature of a-Si can be significantly lowered by the addition of certain metals. Asthis is a solid state phase transformation, no liquid is involved during crystallization.[2] Further, MILC does not require extra equipment, such as an expensive laser. For these reasons, MILC is generally agreed to be more appropriate for industrial application than laser techniques. There are various low-temperature crystallization techniques using MILC phenomena.[3-5] However, it takes a relatively long time to crystallize a-Si thin films. The conventional Ni MILC rate is 5 μm/h at 550°C and decreases exponentially as the annealing temperature decreases.[6] Therefore, for practical use, a faster crystallization rate is necessary. We used adjacent Cu for this crystallization rate enhancement and proved the feasibility of this novel method by fabricating TFTs. The electrical performance of the fabricated MILC TFT has been compared with normal MILC TFT.

2. EXPERIMENTS

A-Si thin films, each of 60 nm thickness, were deposited on a glass substrate using a low pressure chemical vapor deposition or plasma enhanced chemical vapor deposition system. Silane (SiH_4) gas was used as a source gas and hydrogen was used as a carrier gas. The substrate temperature was kept at about 450°C. Metal catalysts for crystallization or Ni and Cu thin films of 10 nm thickness were deposited after the lithography for the lift-off technique. The Ni was deposited on only one side of the channel, namely the source region of TFTs, and the Cu on the other side by sputtering. A conventional tube furnace was used for MILC, which was carried out at the temperature of 550°C in hydrogen ambient. Other processes were carried out according to the common processes for TFT fabrication in a class 100 environment. Finally, the fabricated TFTs were analyzed at the probe station, HB 4140B.

3. RESULTS AND DISCUSSION

In Fig. 1, the optical microscopy image of Ni MILC enhanced by adjacent Cu was presented. In transmitted light, the a-Si films are orange red (sometimes pink) and the crystallized silicon films are lemon yellow; thus, the position of the crystallization front can be seen clearly. Ni MILC was dramatically enhanced by adjacent Cu compared to the con-

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ventional case. The rate of Ni MILC enhanced by adjacent Cu was 24 μm/h (region A) and normal Ni MILC was 4 μm/h (region B). This means that the crystallization rate of Ni MILC can be enhanced six times over the conventional rate

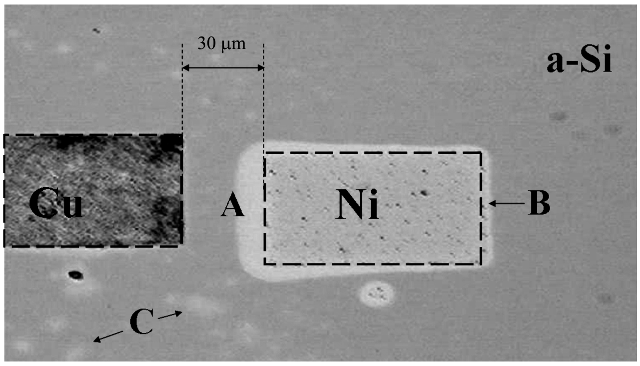


Fig. 1. Optical Microscope image of Ni MILC enhanced by adjacent Cu. A region shows enhanced Ni-MILC, B region shows normal Ni-MILC and C region represents crystal spots.

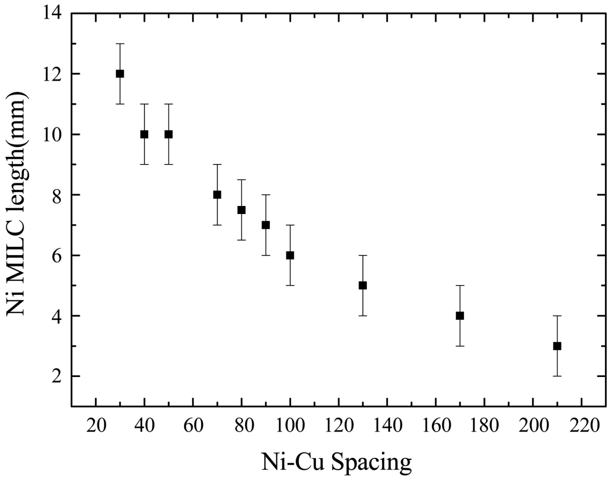


Fig. 2. Ni MILC length as a function of Ni-Cu spacing.

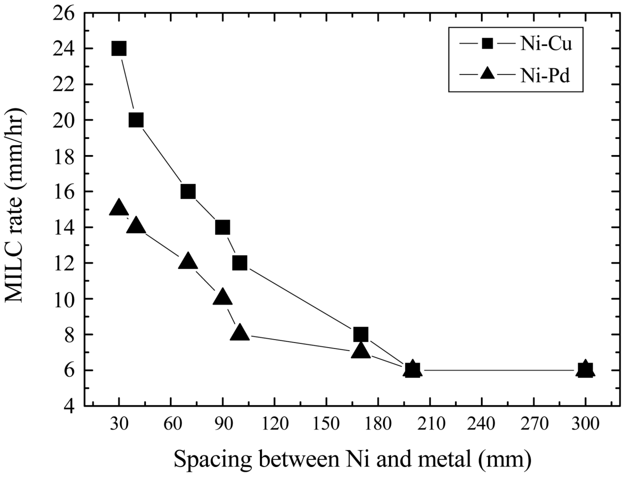
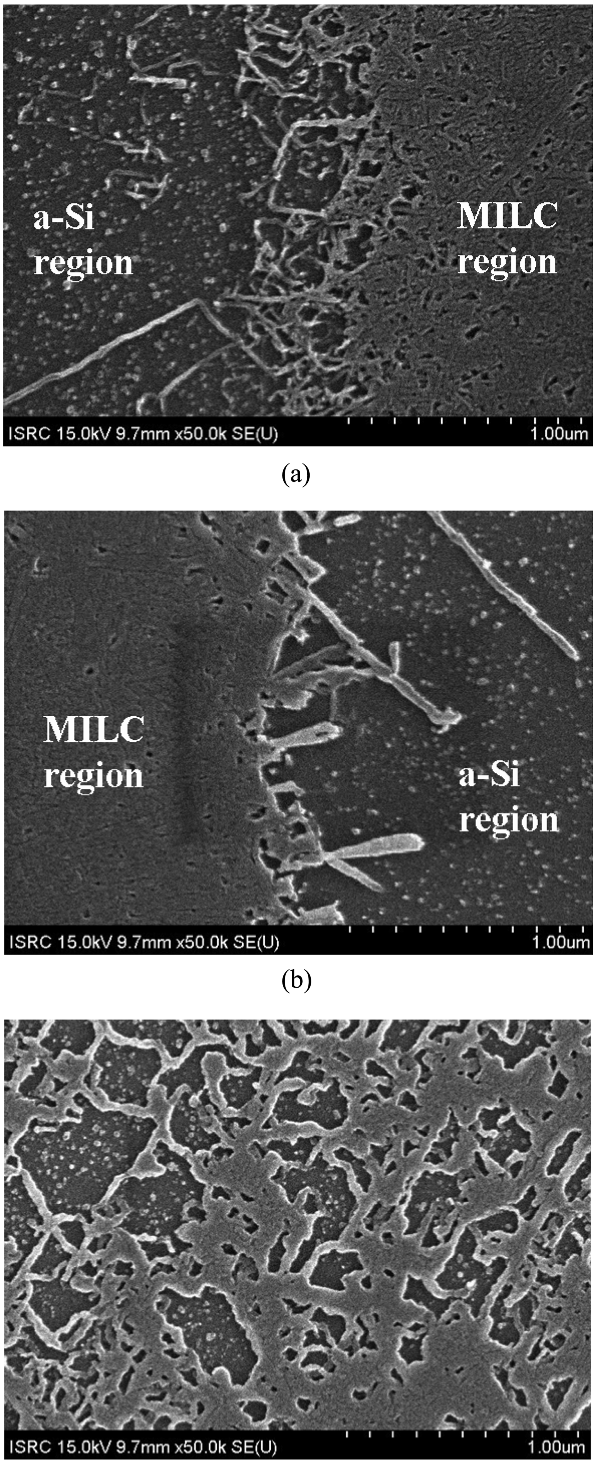


Fig. 3. A comparison of effect of adjacent Pd and Cu on Ni MILC rate.

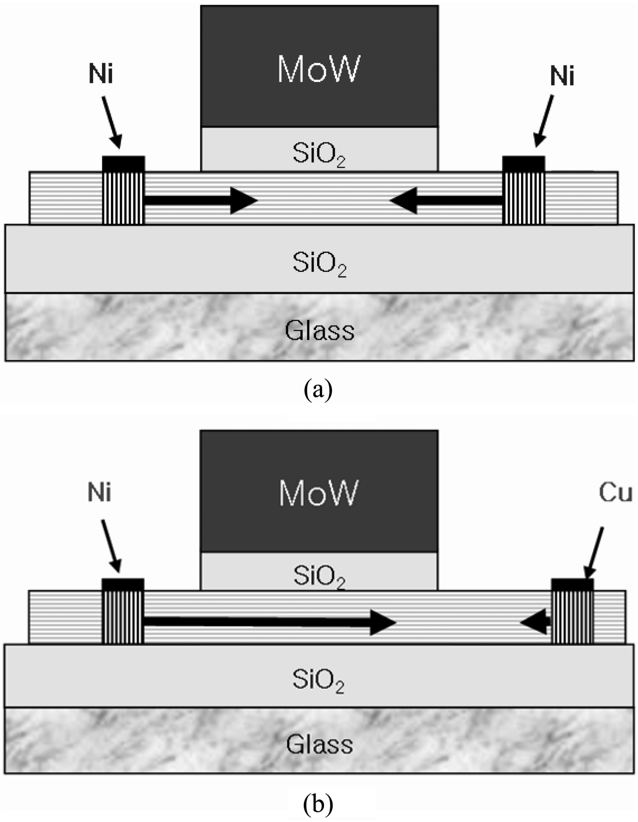


(a)

(b)

(c)

Fig. 4. Scanning electron microscopic images of crystallized region of (a) Ni-MILC front toward adjacent Cu, (b) normal Ni-MILC front, and (c) crystalline spot.



(a)

(b)

Fig. 5. Schematic diagram of fabricated TFTs (a) conventional Ni symmetric TFT (b) asymmetric TFT using Cu and Ni.

by adjacent Cu. This enhancement effect increased as Ni-Cu spacing decreased. We plotted the relationship between Ni-Cu spacing and Ni-MILC rate in Fig. 2. In our previous report, the Ni-MILC rate was enhanced by adjacent Pd.[7] However, in this case, the enhancement was much better than adjacent Pd. We plotted both results in same graph (Fig. 3). It is evident that adjacent Cu is more powerful than adjacent Pd. On the other hand, with adjacent Cu, some spots were observed near the Cu deposited area as shown in Fig. 1. When observed with scanning electron microscopy (SEM), they were found to be made of crystalline needles (Fig. 4). They were probably formed by Cu, since the diffusivity of Cu is extremely high and may cause Cu contamination in Ni MILC area.

In order to avoid this contamination in the channel area of a real device, we made asymmetric TFTs. Figure 5 (b) shows the asymmetrical deposition method of catalytic metal. A 10 nm thick Ni layer was deposited on one of the source or drain regions, and a 10 nm thick Cu layer was deposited on rest of the region. This was then annealed in a furnace at 550°C for 30min in H_2 ambient. Thus, asymmetrical unidirectional MILC can be achieved. For comparison, conventional Ni-MILC symmetric TFTs were also fabricated (Fig. 5 (a)). For conventional Ni-MILC, the TFTs were annealed for 2h in H_2 ambient.

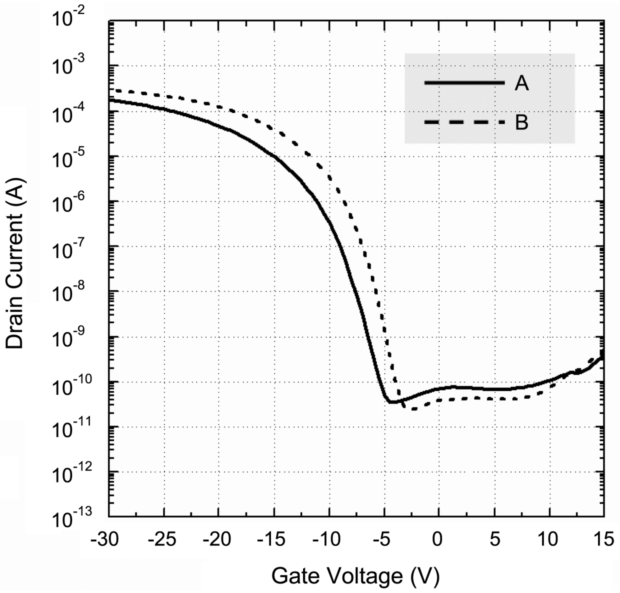


Fig. 6. Comparison of typical I-V curves between asymmetric MILC TFT (solid line, A) and symmetric MILC TFTv(dashed line, B) at V_d = -5.1 Volts.

Table 1. Comparison of the statistical device parameters of symmetric and asymmetric MILC TFTs at V_d = -5V

	Symmetric TFTs	Asymmetric TFTs
μ_{FE} (cm^2/Vs)	60	41
V_{th} (V)	-8.5	-11
S (V/decade)	0.87	1.03
I off (pA)	23.9	34.9
I_{on}/I_{off} ratio (×10^6)	12	5.1

The typical transfer curves of TFTs were represented in Fig. 6 and specific data of TFTs parameters were shown Table 1. Dashed lines represent the transfer curves of poly-Si TFTs made by symmetric Ni-MILC and solid lines represent those made by asymmetric MILC using Cu and Ni. The carrier mobility was calculated using the following formula with the V_g and I_d values obtained form HP 4140B.

$$\mu = \frac{I_d}{C_{ox}\left[(V_g - V_t)V_d - \frac{V_d^2}{2}\right]}$$

Here, the threshold voltage, Vt is the gate voltage when the I_d becomes larger than 1×10^{-6} A.

Even though the electrical properties were slightly poor compared to those of conventional Ni-MILC TFTs, they were quite acceptable considering that annealing time was one fourth of that in the conventional process.

In our discussions, we considered p-type TFTs only. However, carrier trapping and potential barriers formed in polycrystalline silicon are similar in p-type and n-type TFTs. Some minor differences in electrical behavior of n-type and p-type TFTs will be considered in future studies.

4. SUMMARY

Asymmetric Ni-MILC TFTs can be fabricated when Cu and Ni are deposited on source and drain region and Ni MILC rate significantly enhanced. Long annealing time of previous symmetrical Ni-MILC can be reduced using adjacent Cu enhanced Ni-MILC; annealing time was almost one fourth that of conventional symmetric MILC. The asymmetrical MILC TFT shows a leakage current of about 30 pA and electron mobility of $40 cm^2/(V \cdot s)$; these values are similar to those of conventional TFT. Therefore, it is expected that high performance electrical circuits using this device fabrication technique for AM-LCD and AM-OLEDs can be manufactured on a low-cost glass substrate.

REFERENSES

1. P. Migliorato, S. W. B Tam, O. K. B. Liu, T. M. Brown, M. J. Quinn, T. Shimonda, and H. Ohshima, *SID Tech. Digest*, p. 171, Boston, MA (1997).
2. S. W. Lee and S. K. Joo, *IEEE Electron Device Lett*. **17**, 160 (1996).
3. S.-M. Kang, J.-Y. Ahn, Y.-B. Kim, and D.-K. Choi, *J. Korean Phys. Soc*. **44**, 177 (2004).
4. K.-H. Kang, S.-J. Lee, B.-C. Song, M.-S. Band, S.-E. Nam, and H.-J. Kim, *J. Korean Phys. Soc*. **44**, 1552 (2004).
5. M.-S. Kim, J.-S. Lee, Y.-S. Kim, and S.-K. Joo, *J. Korean Phys. Soc*. **47**, 404 (2005).
6. S.-K. Joo, *Electron. Mater. Lett*. **1**, 7 (2005).
7. Y.-S. Kim, M.-S. Kim, and S.-K. Joo, *J. Electrochem. Soc.* **153**, 19 (2006).