The material properties and thin-film transistors characteristics of nickel/copper-induced polysilicon are investigated. It was discovered that by combining Cu and Ni, the lateral growth rate of polysilicon is about an order of magnitude higher than that induced by Ni alone, and much better than the Cu-induced case. The grain size of Ni/Cu-induced polysilicon is 1.5 times larger than that of Ni alone, and also 30 times larger than that of the Cu induced case. The mechanism is attributed to the Cu-enhanced Ni silicide migration. The Ni/Cu-induced low-temperature polysilicon thin-film transistor shows a field-effect mobility of 10–25 cm²/V s, a threshold voltage of 8–22 V, and an on/off current ratio about 10⁶–10⁷.

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at 200 °C, increasing the temperature to 550 °C at a rate of 4–5 °C/min, and keeping the sample at 550 °C for various times, then lowering the temperature to 200 °C at a cooling rate of 10 °C/min.

The fabrication processes of the nickel on copper (Ni/Cu)-induced polysilicon TFTs are as follows: first, 4-nm-thick copper, followed by 4-nm-thick nickel, was deposited by an e-gun evaporator on a pre-annealed 1737F glass substrate over a photoresist mask using a lift-off process. Next 50-nm-thick undoped a-Si:H film and 20-nm $n^+$-type a-Si:H film were deposited on the prepared substrate by PECVD at 250 °C. After PECVD, the $n^+$-type a-Si:H layer was patterned and etched by reactive-ion etching (RIE) to define the conducting-channel region of the TFT. The samples were then put into a high-temperature furnace at 550 °C for 8 h to fully crystallize the channel region. The temperature ramp rate was set to 2 °C/min. The sample was then mesa etched by RIE to define the device region and channel width. Next, using low-pressure chemical-vapor deposition, 150-nm low-temperature oxide was deposited at 550 °C as the gate insulator. The contact holes were defined by lithography and etched by RIE. Ammonia plasma was then used to passivate the poly-grain boundaries and Si/SiO$_2$ interface for 3.5 h. Finally, 200-nm-thick Al-Si(1%) was evaporated and patterned to form the source, drain, and gate electrode contacts of the TFT. The schematic view of the substrate patterned by Ni/Cu and device structure of the TFT are depicted in Figs. 1(a) and 1(b), respectively. Figure 1(c) displays the top-view photograph under optical microscopy of a finished TFT.

III. RESULTS AND DISCUSSION

Figures 2(a) and 2(b) show the pictures taken by optical microscope of the typical nickel- and copper-enhanced lateral crystallization of poly-Si after annealing at 550 °C for 6 h. Apparently, the growth rate of Ni-induced poly-Si is generally uniform and isotropic. As shown in Fig. 2(a), the shape of induced poly-Si follows the shape of Ni bars in all
directions. In the central region of Fig. 2(b) where many long Cu bars are closely spaced, Cu leads to a much faster growth rate. The growth rate is apparently nonuniform and the contour of the nucleation front is close to a circle, as can be seen from the lower-right corner of Fig. 2(b). Figures 3(a)–3(c) show the Ni/Cu (Ni on Cu), Cu/Ni (Cu on Ni), and Ni-Cu (weight ratio 40:60) alloy-enhanced lateral crystallization of poly-Si after annealing at 550 °C for 6 h, respectively. In the case of the Ni/Cu (Ni on Cu) structure, obviously almost all of the amorphous silicon was transformed into poly-Si. The growth rate is hard to estimate, but it is higher than 25 μm/h (as listed in Table I), which is an order of magnitude higher than that of the Ni-induced case. In the case of Cu/Ni (Cu on Ni), the growth rate is much slower than the Ni/Cu case (i.e., 6~8 μm/h), and the shape of poly-Si region is a more similar to the mixture of copper and nickel-induced case. This may be due to the lack of a contact region between Ni and Si, so that copper dominates the crystallization process. However, Ni does play a role, as can be seen at the edge of the bar.

In the alloy case, the growth rate is as fast as in the Ni/Cu case (i.e., ~25 μm/h), as listed in Table I. However, after the lift-off process, the alloy adheres poorly to the glass substrate. The lateral growth width a of Ni/Cu-induced lateral crystallization of poly-Si after annealing at 550 °C as a function of annealing time is shown in Fig. 4. The shape of poly-Si is more like the Ni-induced case, but with a much larger growth rate: 25 μm/h. In Fig. 4, a large growth variation of Ni/Cu-induced poly-Si, especially when the anneal

<table>
<thead>
<tr>
<th>Thickness (nm)</th>
<th>Growth rate (μm/h)</th>
<th>Adherence to glass substrate</th>
</tr>
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<tbody>
<tr>
<td>Ni/Cu 4/4</td>
<td>≥25</td>
<td>Excellent</td>
</tr>
<tr>
<td>Cu/Ni 4/4</td>
<td>6~8</td>
<td>Good</td>
</tr>
<tr>
<td>Ni/Cu alloy (40:60)</td>
<td>≥25</td>
<td>Poor</td>
</tr>
</tbody>
</table>

![Fig. 3. Photographs showing the (a) Ni/Cu, (b) Cu/Ni, and (c) NiCu alloy-induced polysilicon after annealing at 550 °C for 6 h.](image)

![Fig. 4. Lateral growth width of poly-Si induced by Ni/Cu (Ni on Cu) after 550 °C for different times.](image)
time was short (1 to 2 h), occurred. This probably occurs for two reasons: first, the annealing time at 550 °C was harder to define at shorter annealing time because it took 1 to 2 h to raise the furnace temperature from 200 to 550 °C. Second, the Ni/Cu bars were exposed to the atmosphere after preparation; therefore, various oxides on the surface tended to result initially in nonuniform growth of poly-Si. The bright- and dark-field images of transmission-electron microscopy

**TABLE II.** The heat conduction formula and the parameters used in the simulation. \( \rho \frac{\partial u}{\partial t} = \nabla (k \nabla u) \); \( \rho \): density; \( c \): heat capacity; \( k \): thermal conductivity; \( f \): radiant heat source; \( u \): surface temperature; \( n \cdot (k \nabla u) = q \) (with boundry condition); \( n \): direction vector; and \( q \): heat flux.

<table>
<thead>
<tr>
<th>Materials</th>
<th>Si</th>
<th>Cu</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \rho ): Density ( (\text{kg/m}^3) )</td>
<td>2330</td>
<td>8700</td>
</tr>
<tr>
<td>( c ): Heat capacity ( (\text{J/kg °C}) )</td>
<td>703</td>
<td>385</td>
</tr>
<tr>
<td>( k ): Thermal conductivity ( (\text{W/m °C}) )</td>
<td>163</td>
<td>360</td>
</tr>
</tbody>
</table>

**FIG. 5.** TEM images of Ni on Cu (Ni/Cu)-induced poly-Si. (a) Bright-field, (b) dark-field, and (c) diffraction patterns.

**FIG. 6.** Simulation of polysilicon induced by (a) one or (b) two copper bars.

"Materials Si Cu
\( \rho \): Density \( (\text{kg/m}^3) \) 2330 8700
\( c \): Heat capacity \( (\text{J/kg °C}) \) 703 385
\( k \): Thermal conductivity \( (\text{W/m °C}) \) 163 360"
and the transmission-electron diffraction of thermal-enhanced Ni-induced polysilicon prepared by Ni on Cu (Ni/Cu) metal structure are shown in Figs. 5a–5c, respectively. The average grain size is 1.5 μm, which is 1.5 times larger than that of nickel-induced polysilicon, and more than 30 times larger than that in the copper-induced case.14

According to the results of the above experiment, the heat-conduction model was used to simulate the shape of the poly-Si region under copper-induced lateral crystallization. It is assumed that the latent heat released from a-Si to poly-Si transformation is represented by the fixed heat sources at the perimeter of the Cu bar. The initial simulation results were obtained by using FEMLAB commercial software. Table II displays the heat-conduction formula and the material properties used in the simulation: the densities, heat capacities, and thermal conductivities of Si and Cu. Figure 6a shows the simulation result of temperature distribution of poly-Si at the time of 4 h induced by a single copper bar and experimental data. Since the heat of formation of copper silicide CuSi3 is not known, the radiant heat source f Table II was chosen to create a 20 °C temperature difference between the metal bars and environment. The assumed critical temperature (843 K) that can provide enough heat to form poly-Si (the deep red part) does not encompass the copper bar. Figure 6b shows the case of two copper bars at the time of 4 h, where the deep red region (843 K) can clearly be seen to encompass the body of the bars. Apparently, the simulation can fit the experimental results of Cu-induced lateral crystallization of poly-Si.

The drain-current versus the drain-voltage characteristics of the device are shown in Fig. 7a. The width/length ratio of the devices is 30 μm/20 μm. Figure 7b shows the transfer curves of the TFT with $V_{DS}=10$ V. The $10^6$–$10^7$ on/off current ratio can be obtained from this figure. The relationship between the square root of $I_D$ and $V_{DS}$ of the TFT biased in the saturation region ($V_{GS}=V_{DS}$) is shown in Fig. 7c. The field-effect mobility of 25 cm$^2$/V s can be obtained by evaluating the slope of Fig. 7c. The threshold voltage of 22 V is extracted from the intercept of the square root of the $I_D$ line and the $V_{DS}$ axis.

**IV. CONCLUSIONS**

Evidence is provided that the Ni/Cu-induced lateral crystallization of poly-Si is uniform, as in the case of Ni, and is fast as in the case of Cu. The crystallization is attributed to Cu-enhanced Ni silicide migration. This technology can apparently shorten the process time of lateral crystallization of poly-Si and is suitable for industrial applications. It is demonstrated as a practical method for fabricating polysilicon TFTs by Ni/Cu-induced crystallization.

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