Extended Abstracts of the 2002 International Conference on Solid State Devices and Materials, Nagoya, 2002, pp. 416-417

**LP2-1**

# Modeling of Metal-Induced-Lateral-Crystallization Mechanism in High Performance Low Temperature Thin-Film-Transistor Application

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## 1. Introduction

Metal-Induced-Lateral-Crystallization (MILC) using nickel has been shown to be a low-cost, low-temperature and effective method for high performance System on Panel (SoP) and 3-dimension circuit integrations. The device performance strongly depends on the grain size, grain boundary and nickel impurity content of the resulted MILC polysilicon film. In this paper, the MILC growth mechanism is studied. A model has been proposed to predict the MILC growth rate, polysilicon grain size, location of MILC grain boundary and final metal impurity distribution. The model may give important information to optimize process conditions, such as annealing time and annealing temperature, for superior MILC device fabrication.

## 2. Mechanism of Metal-Induced-Lateral-Crystallization

The preparation of MILC polysilicon is shown in Fig. 1. The amorphous silicon (a-Si) layer is protected by a layer of low-temperature oxide (LTO) with some window openings where nickel can contact the a-Si for MILC formation.

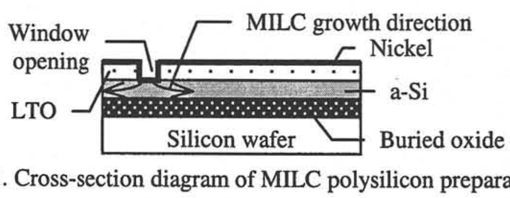


Fig. 1. Cross-section diagram of MILC polysilicon preparation.

At the beginning of MILC annealing, nickel deposited onto the seed window reacts with silicon to form a thin nickel silicide film. This silicide layer reduces the activation energy of a-Si crystallization. Thus, a-Si under the silicide is thermally crystallized into polysilicon before other part of the a-Si, and this polysilicon is called metal-induced-crystallization (MIC) polysilicon. The grain boundaries of the MIC polysilicon provide good locations for trapping nickel atoms and forming nickel silicide boundaries. At the MIC to a-Si interface, the nickel silicide boundary is reactive and will be responsible for the silicon grain growth, it is called nickel silicide reactive grain boundary (RGB); see Fig. 2(a). Further annealing leads the nickel atoms at the RGB leading-edge diffuse to the a-Si region and bond with silicon atoms as shown in eq. (1). Presence of nickel impurities lowers the activation energy of the a-Si crystallization.

$$\textit{Nickel} + \textit{Silicon}_{\,(from\ a\text{-}Si\ region)} \leftrightarrows \textit{Nickel Silicide} \qquad (1)$$

At the RGB rear-edge, the excess silicon atoms are dissociated from the nickel silicide and bond to the crystalline silicon region, refer to eq. (2). As a result, the a-Si is crystallized to polysilicon, which is called metal-induced-lateral-crystallization (MILC) polysilicon; refer to Fig. 2(b).

$$\textit{Nickel Silicide} \leftrightarrows \textit{Nickel} + \textit{Silicon}_{\,(to\ polysilicon\ region)} \qquad (2)$$

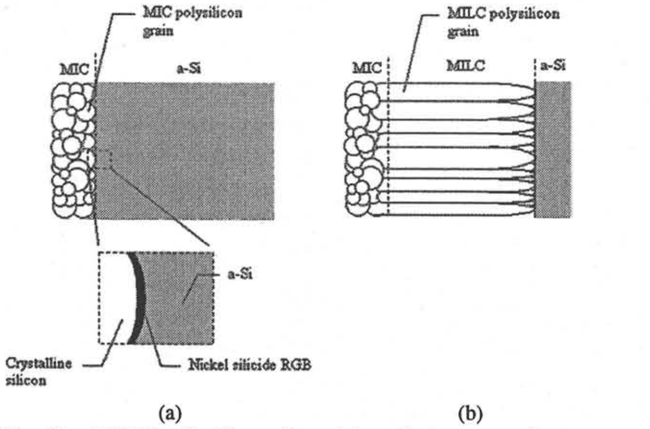


Fig. 2. MILC polysilicon formatrion during annealing process. (a) At the beginning, many nickel atoms are trapped and nickel silicide is formed at the grain boundaries of the MIC polysilicon region. (b) Further annealing leads the nickel silicide RGB absorbs silicon atoms from the a-Si region and rejects them to the MIC polycrystalline silicon region. MILC polysilicon is then formed.

## 3. Modeling of MILC Growth

At the RGB leading-edge, presence of abundant nickel atoms increases the rate of the forward mechanism of eq. (1). At the RGB rear-edge, nickel atoms contribute to the backward reaction of eq. (2) and retard the MILC growth. So the MILC growth rate is proportional to the nickel concentration at the leading-edge, $[Ni]_{RGB\ leading\text{-}edge}$, and inversely proportional to that at the rear-edge, $[Ni]_{RGB\ rear\text{-}edge}$.

$$\textit{MILC Growth Rate} = A_0 \frac{[Ni]_{RGB\ leading\text{-}edge}}{[Ni]_{RGB\ rear\text{-}edge}} \exp\left(-\frac{E_a}{kT}\right) \qquad (3)$$

where $A_0$ and $E_a$ are the rate coefficient and the activation energy of MILC growth respectively. k is the Boltzmann constant and T is the annealing temperature in K. During the annealing, solid-phase-crystallization (SPC) also occurs throughout the entire a-Si film and the value of $E_a$ varys.

$$E_a = E_a'\left(1 + B_0 \exp\left(-\frac{E_b}{kT}\right)\right) \qquad (4)$$

$B_0\exp(-E_b/kT)$ is the SPC factor where $B_0$ and $E_b$ are the growth coefficient and the activation energy of SPC process respectively. $E_a$' is the activation energy of MILC without SPC effect. Eq. (4) shows that the SPC effect increases the activation energy of a-Si crystallization and retards the MILC growth. As a lower temperature T is used, the SPC effect becomes less dominant. When T tends to zero, the SPC factor can be omitted and the MILC growth rate equation changes to a simple model without the SPC effect. In the proposed model, the value of $E_b$ was equal to 3.12 eV which is same as the activation energy of intrinsic a-Si crystallization. $E_a$' was found to be 2.57 eV. This showed that presence of nickel impurity the activation of a-Si crystallization could be reduced by 0.55 eV. Using eq. (3) & (4), the MILC growth rate at different annealing temperature can be modeled. In Fig. 3, the predicted results were well-matched with the experimental results.

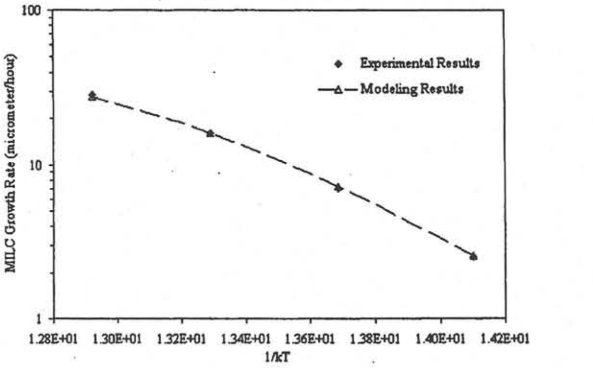


Fig. 3. Temperature effect on MILC growth rate (Using 2-hour MILC annealing).

During the MILC formation, the silicon layer can be divided into 4 regions; MIC, MILC, nickel silicide RGB and a-Si regions. Due to nickel trapping, the nickel diffusivities are relatively lower in the MIC and RGB regions, whereas fast nickel diffusion can be obtained inside a MILC crystalline silicon grain. With the nickel diffusion profile obeying the Gaussian distribution, the nickel concentration from a source at a point ξ, $N(x, t)$, can be estimated by:

$$N(x,t)=\frac{N_\xi}{2\sqrt{D\pi t}}\exp\left[-\frac{(x-\xi)^2}{4Dt}\right] \quad (5)$$

Base on the MILC growth rate and the diffusion mechanism proposed, the nickel distribution can be obtained as shown in Fig. 4. The nickel profile model was validated by experimental calibration by SIMS analysis and that of Wang et al [1].

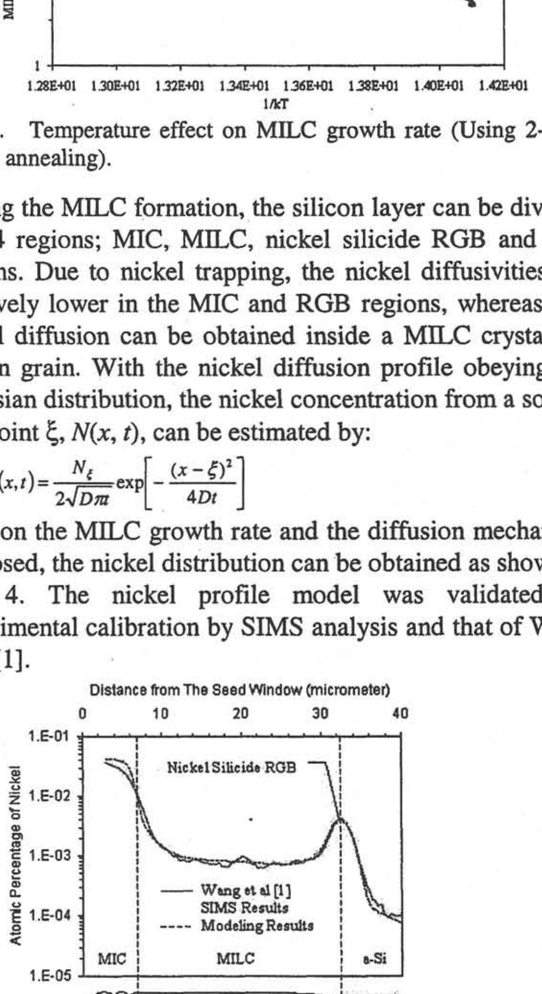


Fig. 4. Nickel distribution profile along the MILC polysilicon grain growth direction.

The effect of annealing temperature on the nickel distribution and the time evolution of the MILC growth at 575 °C are shown in Fig. 5 and Fig. 6 respectively. In the MILC device fabrication region, the nickel concentration increased with the annealing temperature, but was almost insensitive to the annealing time. All these observations were well consistent with the MILC growth mechanism proposed before and the accuracy of the model was further confirmed by experimental resulted.

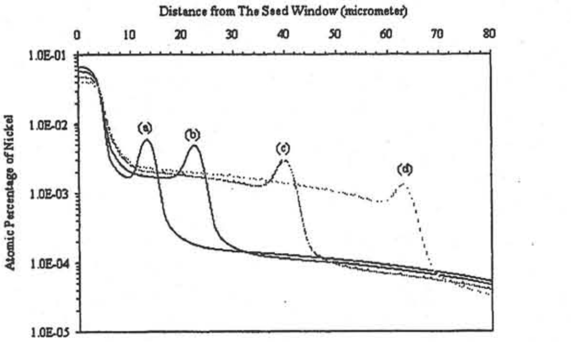


Fig. 5. Effects of annealing temperature on the nickel distribution with 2-hours annealing. (a) 550 °C annealing, (b) 575 °C annealing, (c) 600 °C annealing, and (d) 625 °C annealing.

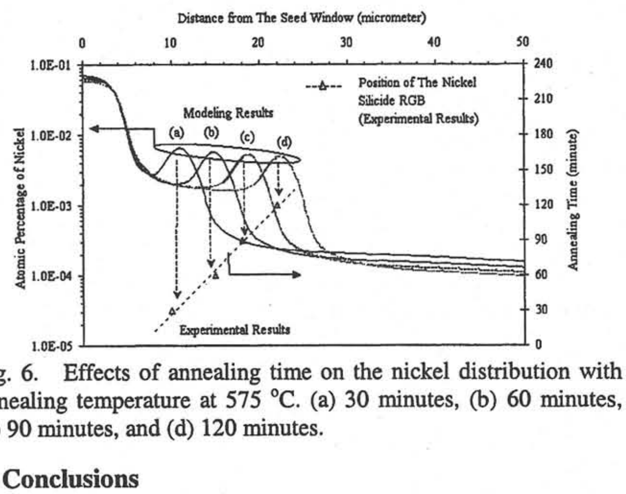


Fig. 6. Effects of annealing time on the nickel distribution with annealing temperature at 575 °C. (a) 30 minutes, (b) 60 minutes, (c) 90 minutes, and (d) 120 minutes.

## 4. Conclusions

This paper has proposed a model to predict the crystallization growth rate, polysilicon grain size and final metal impurity distribution of MILC using nickel. SIMS analysis has been employed to validate the accuracy and reliability of the model. From the modeling results, it was observed that the final nickel concentration in the MILC region depended on the annealing temperature, but was not sensitive to the total annealing used. To minimize the metal impurity left in the TFT fabrication region, a lower annealing temperature is preferable to form higher quality and lower nickel concentration MILC polysilicon film, in the expense of longer annealing time to achieve the same grain size in the MILC region.


## Acknowledgments

This work was sponsored by the research grant of the Research Grant Council of Hong Kong.


## References


[1] M. Wang, et. al., *IEEE TED*, pp.1655-1660, Aug. 2001.