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Statistical study on the states in the low-temperature poly-silicon films with thin film transistors

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Abstract

Laser recrystallized low temperature poly-silicon films have attracted attention for their applications in thin-film transistors (TFTs), which are widely used in active matrix displays. The electrical characteristics of the poly-silicon film may vary because of its grain boundaries. In this work, the variation is statistically studied with respect to the threshold voltage and mobility of the TFTs. The threshold voltage and mobility of many closely-located TFTs are measured. These two parameters correspond to the deep states and tail states of the poly-silicon film, respectively. The mutual difference of two threshold voltages exhibits the distribution in a Gaussian–Lorentzian cross product form. On the other hand, the mutual difference of two mobility exhibits the distribution of Lorentzian function. This result directly reflects the local fluctuations and the spatial trends of the deep and tail states in a poly-silicon film.
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Keywords: Thin film transistor; Poly-Si; Model; Statistical distribution

1. Introduction

Low-Temperature Polycrystalline Silicon (LTPS) thin film transistors (TFTs) have attracted much attention in the application on the integrated peripheral circuits of display electronics such as active matrix liquid crystal displays (AMLCDs) and active matrix organic light emitting diodes (AMOLEDs) [1–4]. The significant advantages over amorphous silicon TFTs are the higher driving capability and better reliability. However, diverse grain boundary distribution in poly-Si film also leads to the non-uniformity of device characteristics and the difficulty in predicting the reliability behavior [5–9]. Therefore, the yield control of the poly-Si TFTs is very difficult due to the poor uniformity of poly-Si TFTs compared with single crystal silicon transistors. In this work, the device characteristics are studied in a statistical approach to investigate the relationship between variation in electrical behavior and states in the low-temperature poly-silicon films.

2. Experimental

The process flow of TFTs is described below. Firstly, the buffer oxide and a-Si:H film with thickness of 50 nm were deposited on glass substrates with PECVD. The samples were then put in the oven for dehydrogenation. The XeCl excimer laser of wavelength 308 nm and energy density of 400 mJ/cm^2 was applied. The laser scanned the a-Si:H film with the beam width of 4 mm and 98% overlap to recrystallize the a-Si:H film to poly-Si. After poly-Si active area definition, 100 nm SiO_2 was deposited with PECVD as the gate insulator. Next, the metal gate was formed by sputter and then defined. The lightly doped drain (LDD) and the n$^+$ source/drain doping were formed by PH_3 implantation with dosage 2×10^{13} cm^{-2} and 2×10^{15} cm^{-2} of PH_3 respectively. The LDD implantation was self-aligned and the n$^+$ regions were defined with a separate mask. Then, the interlayer of SiN_x was deposited. Subsequently, the rapid thermal annealing was conducted to activate the dopants. Meanwhile, the poly-Si film was hydrogenated. Finally, the contact hole formation and metallization were performed to complete the fabrication work.

I–V characteristics of the TFTs with channel width $W=20$ μm and length $L=5$ μm were measured using an Agilent 4156 semiconductor parameter analyzer. The threshold voltage is extracted by the constant current method, which is defined by the voltage at the

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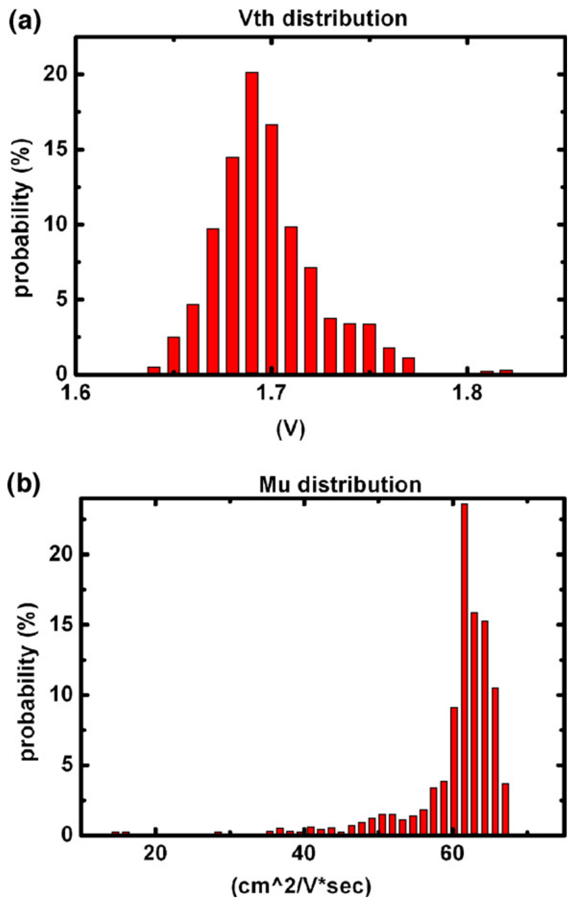

Fig. 1. The distributions of (a) V_{th}, and (b) Mu of the measured devices.

specified drain current of 10 nA × (W/L) for a drain voltage (Vd) of 0.1 V. The electron field effect mobility is determined from the maximum transconductance g_m at the same Vd.

3. Results

The distributions of threshold voltage (V_{th}) and mobility (Mu) of more than one thousand TFTs arranged in a constant pitch of 40 μm are shown respectively in Fig. 1 (a) and (b). The average and standard deviations of V_{th} are 1.69 V and 0.03 V, and those of Mu are 59.66 cm^2/Vs and 7.84 cm^2/Vs , accordingly. It can be seen that Mu exhibits obvious asymmetric behavior. The asymmetric behavior may be attributed to the difference in grain number of the poly-Si film in the TFTs.

The distributions of the difference in V_{th} and Mu between two devices with different distances are shown in Figs. 2 and 3, respectively. Two models are proposed to fit these two distributions and the coefficient of determination (R square) can reach above 0.95, which indicates the fitness of the proposed model and the real data. The proposed models fit the variation in behavior quite well, even for different device distances.

In the proposed models, the difference in V_{th} follows the distribution of Gaussian–Lorentzian cross product, which is

$$y = \frac{a}{\left(1 + d\left(\frac{x-b}{c}\right)^2\right) * \exp\left((1-d) * \frac{1}{2}\left(\frac{x-b}{c}\right)^2\right)} \quad (1)$$

On the other hand, the difference of Mu follows Lorentzian distribution, which is

$$y = \frac{a}{1 + \left(\frac{x-b}{c}\right)^2} \quad (2)$$

The parameters a, b, c, and d in Eqs. (1) and (2) are fitting parameters, which may vary slightly with distance. The peaks of

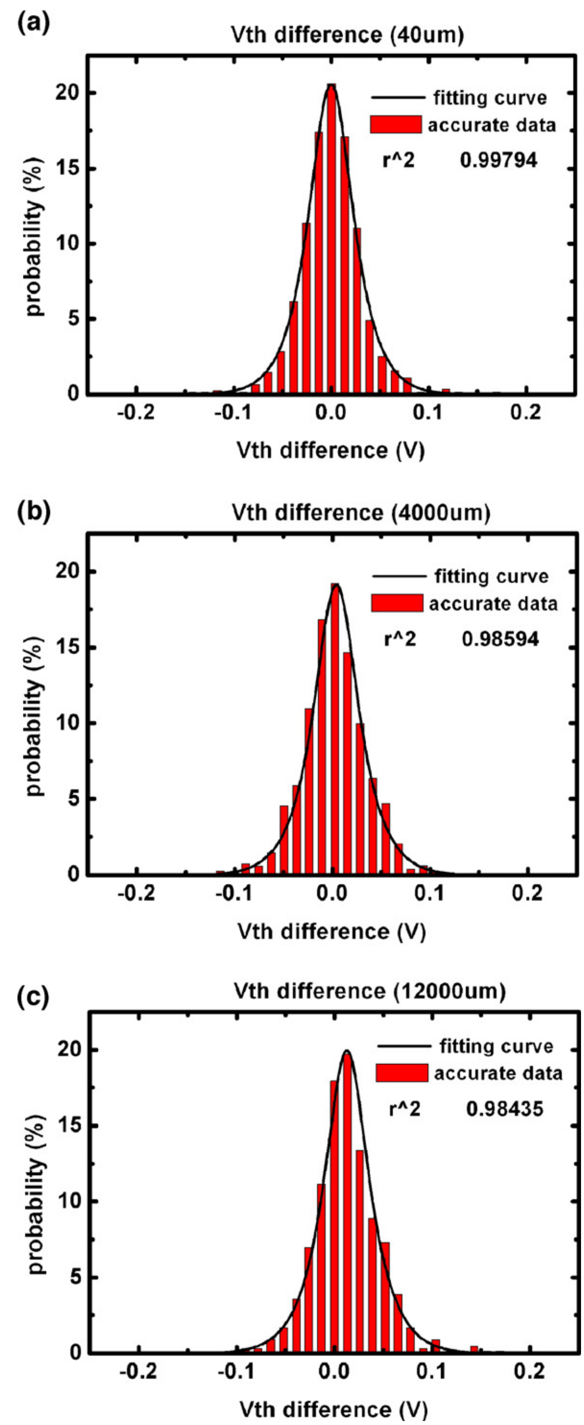

Fig. 2. The distributions of the difference of V_{th} for device pairs with different distance.

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