Available online at www.sciencedirect.com
ScienceDirect
Thin Solid Films 515 (2006) 1210–1213
www.elsevier.com/locate/tsf

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

Shih-Che Huang [a,*], Yen-Pang Chou [a], Ya-Hsiang Tai [b]

[a] Department of Photonics and Institute of Electro-Optical Engineering, National Chiao Tung University, Hsinchu, Taiwan, 300
[b] Department of Photonics and Display Institute, National Chiao Tung University, Hsinchu, Taiwan, 300

Available online 8 September 2006

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.

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

* Corresponding author.
E-mail address: hansley.eo92g@nctu.edu.tw (S.-C. Huang).

0040-6090/$ - see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.tsf.2006.07.125

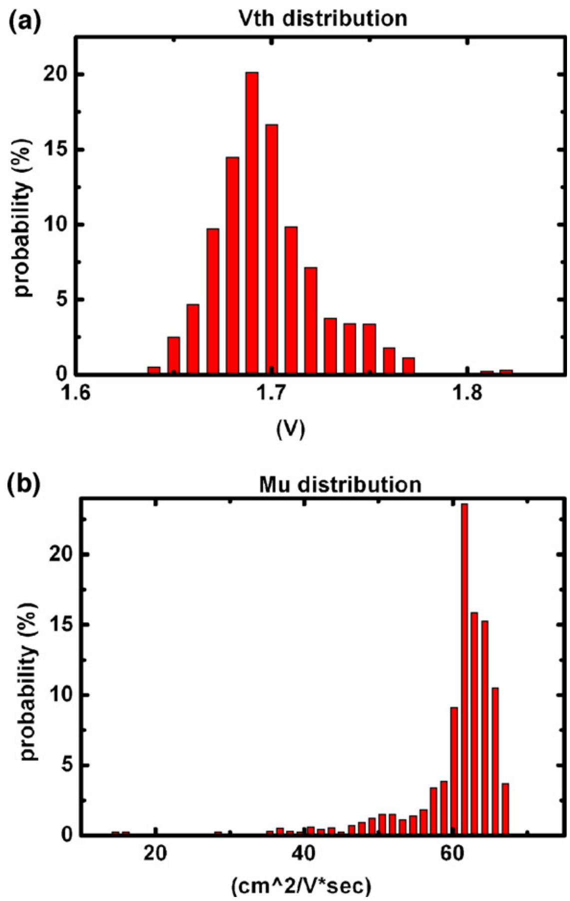

Fig. 1. The distributions of (a) V_{th}, and (b) Mu of the measured devices.

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

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

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

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

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

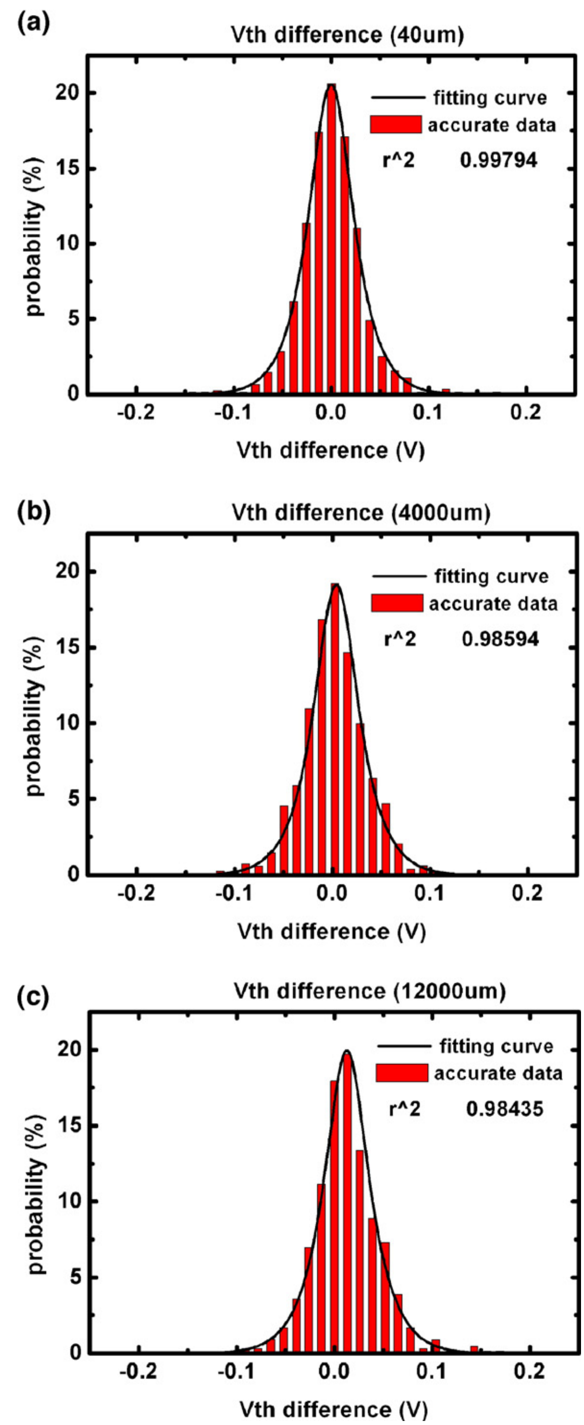

Fig. 2. The distributions of the difference of V_{th} for device pairs with different distance.

these two distributions are more centered than the commonly known Gaussian distribution.

4. Discussion

The electrical characteristics of TFTs correspond to the states of the poly-silicon film. Because deep and tail states are composed of defects existing inside the region of grain boundaries, the electrical characteristics of TFTs depend on the grain number of the poly-Si film in the device channel. In other words, V_{th} and Mu also relate to the grain number in the active film of the TFT. In this work, the statistical model describing the relationship between the distribution of Mu and the number of grains is described below. The proportion of different sizes of grains in the poly silicon film can be calculated approximately from the SEM (Scanning Electron Microscope) image, as shown in Fig. 4. For a statistical study of the grain number inside the poly-Si film, it is essential to randomly generate the corresponding values of grain size according to the distribution. In this work, a method of range mapping was used. We take the distribution consisting of four variables as example, as shown in Fig. 5. Based on the probability, a table of range mapping can be established, as shown in Table 1. For a series of uniformly random values in the range from 0 to 1 generated by the computer,

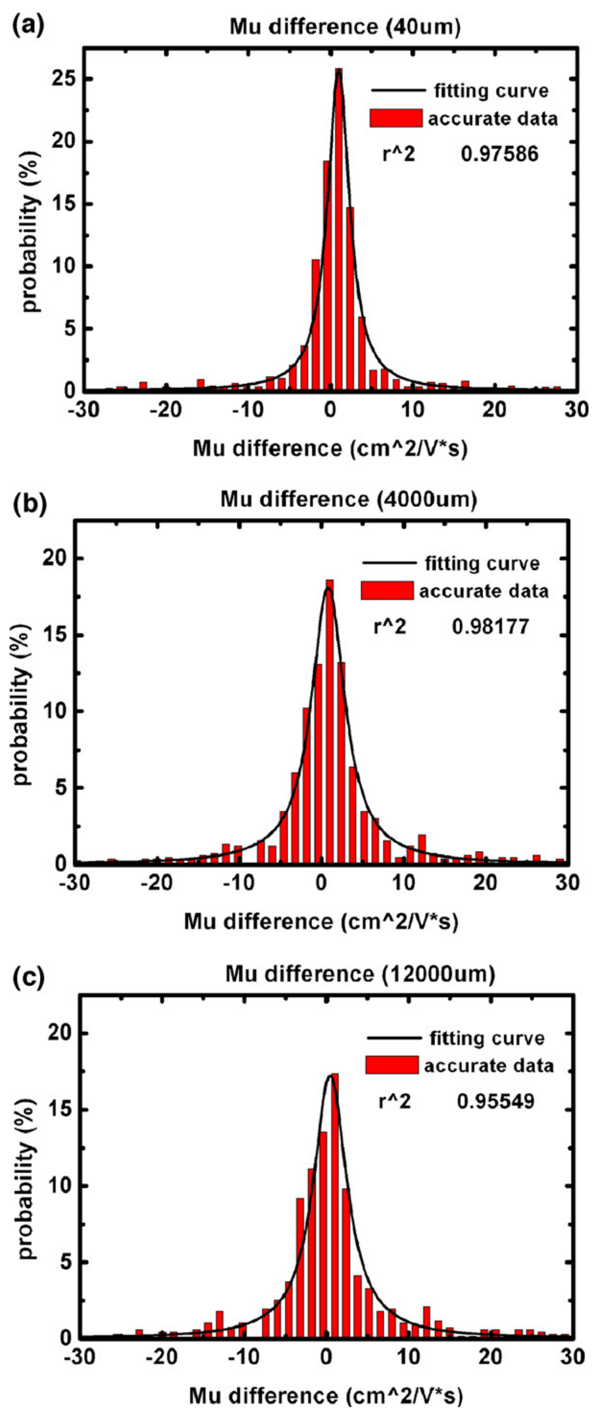

Fig. 3. The distributions of the difference of Mu for device pairs with different distance.

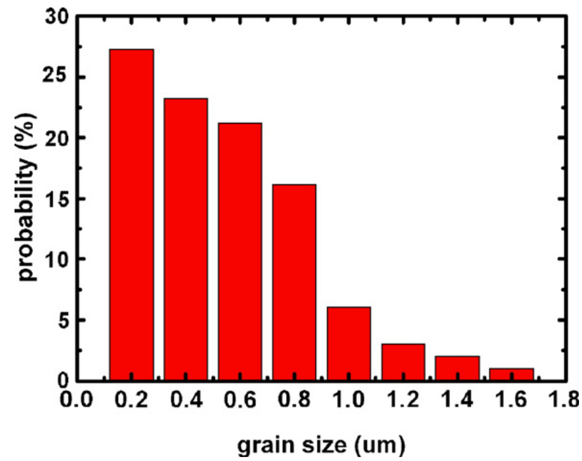

Fig. 4. The distribution of grain size in the channel.

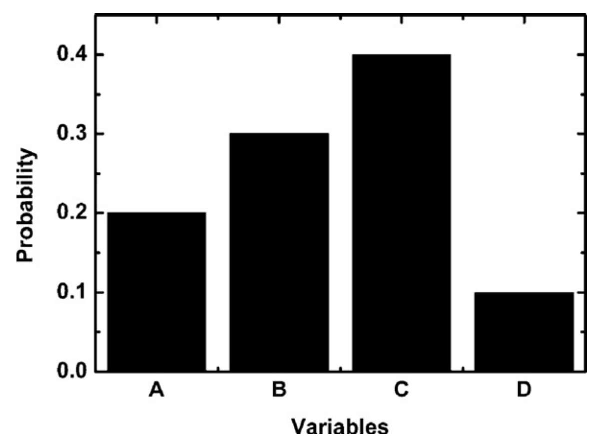

Fig. 5. Simple distribution with four variables.

Table 1
A look up table for the range mapping base for Fig. 5

Random value	Probability (%)	Corresponding variable
0–0.2	20	A
0.2–0.5	30	B
0.5–0.9	40	C
0.9–1	10	D

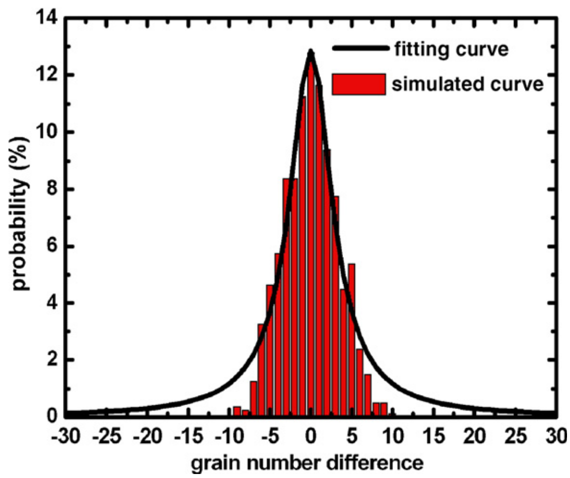

Fig. 6. The distribution of the simulated difference of grain boundary.

the corresponding series can be obtained by looking up Table 1. Thus, the distribution of the looked-up values will match that shown in Fig. 5. Similarly, the grain size distribution can be generated for a certain number of data in order to get the stable and reliable statistical base. In this experiment, more than 1000 times of data mapping for each distribution were executed and a converged distribution was obtained.

The distribution of grain sizes in the channel of more than one thousand TFTs was calculated for many times. The results showed the similarity in the centrality, but the inconsistency in the tail distributions. However, for the distribution of the grain number difference, as in shown in Fig. 6, the profile is consistent. Furthermore, it is similar to Lorentzian distribution, which corresponds to the proposed distribution describing the Mu difference. This indicates the distribution of the difference in Mu may reflect the difference of grain boundary number inside the poly-Si film. On the other hand, the distribution of V_{th} difference is not so similar, although both distributions are narrower than the Gaussian distribution. The wider distribution of the V_{th} difference, which follows the distribution of Gaussian–Lorentzian cross product, may be attributed to the effect of the interface charge and defect in the oxide.

The major difference between the crystalline silicon and the poly silicon is that the poly silicon consists of crystalline grains separated by grain boundaries. The effect of grain boundaries can be accounted for by using the "effective medium" approach and introducing an effective density of states in the bandgap of poly-Si. The similarity of Figs. 3 and 6 reveals that the fluctuation of states inside the poly-Si film follows the distribution of Lorentzian function, which is almost the same with different device distances. However, the difference in the Mu distribution of the measured data and the proposed model may also indicate that Mu may as well be affected by other factors such as surface states and parasitic resistance, in addition to the effect of grain size distribution. This may require further study for the understanding and modeling of the relationship between the distribution of the device behavior and the states inside the poly-Si film.

5. Conclusion

The difference of V_{th} and Mu between two devices exhibits the distribution of Gaussian–Lorentzian cross product and Lorentzian respectively. The coefficient of determination (R square) for these two distributions can reach above 0.95, which indicates the fitness of the proposed model and the real data. The distribution of device behavior differences in V_{th} and Mu of the TFTs is closely related to the grain structure of the poly-Si film. This reasserts the importance of the poly-Si film quality in the performance of the TFTs. The statistical analysis of the device parameters will be very helpful in the comprehension of the relationship between poly-Si film structure and the device behavior.

Acknowledgements

We would like to thank the Chunghwa Picture Tubes, LTD. for their technical support. This work was partially supported by MOE ATU program and the MOEA Technology Development for Academia Project #94-EC-17-A-07-S1-046.

References

[1] Woo-Jin Nam, Sang-Hoon Jung, Jae-Hoon Lee, Hye-Jin Lee, Min-Koo Han, SID Tech. Dig. (2005) 1046.
[2] S.-H. Jung, W.-J. Nam, M.-K. Han, SID Tech. Dig. (2002) 622.
[3] S.H. Yeh, W.T. Sun, C.S. Yang, IDW Tech. Dig (2004) 345.
[4] C.C. Pai, Y.H. Tai, IDMC Tech. Dig (2005) 483.
[5] Yoshiyuki Kitahara, Shuichi Toriyama, Nobuyuki Sano, Jpn. J. Appl. Phys., Part 2 42 (6B) (2003) L634.
[6] Albert W. Wang, Krishna C. Saraswat, Tech. Dig. - Int. Electron Devices Meet. (1998) 277.
[7] Albert W. Wang, Krishna C. Saraswat, IEEE Trans. Electron Devices 47 (5) (2000) 1035.
[8] Shigenobu Maeda, Hirotada Kuriyama, Takashi Ipposhi, Shigeto Maegawa, Yasuo Inoue, Masahide Inuishi, Norihiko Kotani, Tadashi Nishimura, IEEE Trans. Electron Devices 50 (6) (2003).
[9] S. Maeda, H. Kuriyama, T. Ipposhi, S. Maegawa, M. Inuishi, IEDM Tech. Dig. (2001) 759.