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Surface states related the bias stability of amorphous In–Ga–Zn–O thin film transistors under different ambient gasses

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A R T I C L E I N F O

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A B S T R A C T

This paper investigates the origin of the bias stability under ambient gas (oxygen, moisture and vacuum) of In–Ga–Zn–O thin film transistors with different annealing temperatures. In Zn-based TFTs, the electrical characteristic of device is a strongly function with the ambient gas, the simultaneous gas ambient and bias stresses are applied on devices annealed in atmosphere ambient to study this issue. The result shows the device which is annealed at temperature up to 330 °C has worst reliability. We suppose that the sensitivity of gas ambient depend the defect state, which is associated to the annealing temperature, of surface in a-IGZO.

1. Introduction

Since the first report was presented in 2004, amorphous oxide semiconductor has been intensively studied for the channel layer in thin film transistors (TFTs) during recent years [1]. Because of the large electron mobility (>10 cm^2/V.s) and uniformity with large area deposition even at room temperature, the amorphous oxide semiconductor-based materials such as amorphous indium gallium zinc oxide (a-IGZO) or amorphous hafnium indium zinc oxide are expected to be the driven-TFTs of organic light emitting diode (OLED), liquid crystal display (LCD) and innovative transparent electronics [2–4]. Among a variety of amorphous oxide semiconductors, a-IGZO TFTs are thought as the most promising device for practical applications.

The reliability of a-IGZO TFTs under bias stresses is vital before employing them into commercial electronic products. As the switching-TFT in pixel circuit of OLED, the gate voltage must be relatively high to sufficiently charge the capacitor [5]. On the contrary, the a-IGZO TFTs have most of the time experienced a negative bias to stay the "off" state as driving TFTs in operating LCD [6]. In the literature, the reliability of Zinc-based oxide TFTs with positive gate bias stresses and the negative bias temperature stresses under illumination on Zinc-based oxide TFTs have been proposed to be the influence of (i) gas ambient or (ii) charge trapping of electrons or photon-induced holes at the interface between gate insulator and semiconductor [7–10]. It is widely known that the electrical characteristic of Zinc-based oxide TFTs is a strong function with the ambient gas. The existence of water or oxygen molecules between the backchannel and passivation layer still affects the instability of a-IGZO TFTs under bias stress noticeably [7, 11]. Thus, the principal mechanism leading the bias instability of a-IGZO TFTs under ambient gas is necessary to study.

In this study, the effect of ambient gas on instability of a-IGZO TFTs with various post-annealing temperature under negative bias stress (NBS) has been investigated. For this purpose, the simultaneous bias stresses and different ambient gas (oxygen, nitrogen, moisture and vacuum) in environment are applied on a-IGZO TFTs to studies this issue. The shift of V_T during NBS is not only dependent on the ambient gas in environment but also related with the surface state of a-IGZO which is changed along with the post-annealing temperature. The stress condition without stress bias in moisture ambient is performed to verify the impact of electrical field on the a-IGZO TFTs. This eventually contributes to a better understanding of the instability mechanism of a-IGZO TFTs under NBS.

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2. Experiment

2.1. TFT fabrication

The fabricated a-IGZO TFTs have a bottom gate and bottom contract structure. The Ti/Al/Ti gate electrodes were deposited and patterned by standard photolithography on glass substrate with thickness 50/200/50 nm, respectively. Then, a 300-nm SiOx was capped on the gate electrodes by plasma enhanced chemical vapor deposition. After DC sputtered Ti/Al/Ti (50/200/50 nm) and patterned as the source/drain, the 30-nm a-IGZO (In_2O_3:Ga_2O_3 :ZnO = 1:1:1) was deposited to serve as the channel layer. The fabricating procedure of a-IGZO was deposited by DC magnetron sputtering system at room temperature in an ambient of gas mixture ratio of O_2/Ar = 6.7% with a working pressure of 5 m Torr. Finally, the TFTs were annealed at different temperature, 150 °C, 250 °C and 330 °C, for 30 min under atmosphere ambient.

2.2. TFT characterization

In this study, all the current–voltage (I–V) characteristics were measured at room temperature by an Agilent HP4156C semiconductor parameter analyzer. The probe station is settled in a vacuum chamber with gas flow control and a moisture feeding equipment [12]. Before supplying any gas, the vacuum chamber was evacuated to 1×10^{-4} Torr. The threshold voltage (V_T) is determined by using the constant current method as the gate voltage which induces a drain current of L/W × 1 nA at the V_{DS} of 5 V; While the subthreshold swing (SS) is extracted by the equation $SS = dV_{GS}/d(\log I_{DS})$ (V/dec) when the current is between 10^{-11} and 10^{-9} A. The stress condition of NBS is that the gate bias was kept at −50 V while source and drain were grounded.

3. Experiment result and discussions

Fig. 1(a) and (b) shows the evolution of I_D–V_G transfer characteristics of a-IGZO TFTs which post-annealed at 330 °C under NBS for 2000 s in atmospheric ambient, and vacuum, respectively. A large negative shift of V_T and increasing of SS for the device under NBS in atmospheric are observed. By contrast, the V_T and SS of device after NBS in vacuum are without negative shift and without degradation, as shown in Fig. 1(b). To analyze the different degradation of transfer characteristics under NBS between in atmospheric ambient and vacuum, the NBS was performed in the oxygen, nitrogen and moisture ambient. Fig. 1(c) shows that the NBS in moisture ambient affects the V_T obviously like the result that under NBS in atmospheric ambient does, but in O_2 and N_2 ambient does not. The delta V_T of 330 °C post-annealed TFTs under NBS in different ambient are depicted in the Fig. 1(d). The negative V_T shift is attributed to the charge trapping in the channel/insulator interface or the defect creation in the channel layer. Because of the negative V_T shift and degradation in SS both happen in our experiment. It is thought that the defect creation must dominate the mechanism for a-IGZO TFT under NBS. In the literature, the negative shift of V_T suggested the adsorption of moisture in atmosphere to form positively charged spices (H_2O^+) which resulted from the combination of increased hole and water molecules during NBS [13]. Although this conclusion cannot explain the significant change in SS completely.

Next, the simultaneous gas ambient and NBS are applied on devices which were post-annealed at 150 °C. Under NBS in the same

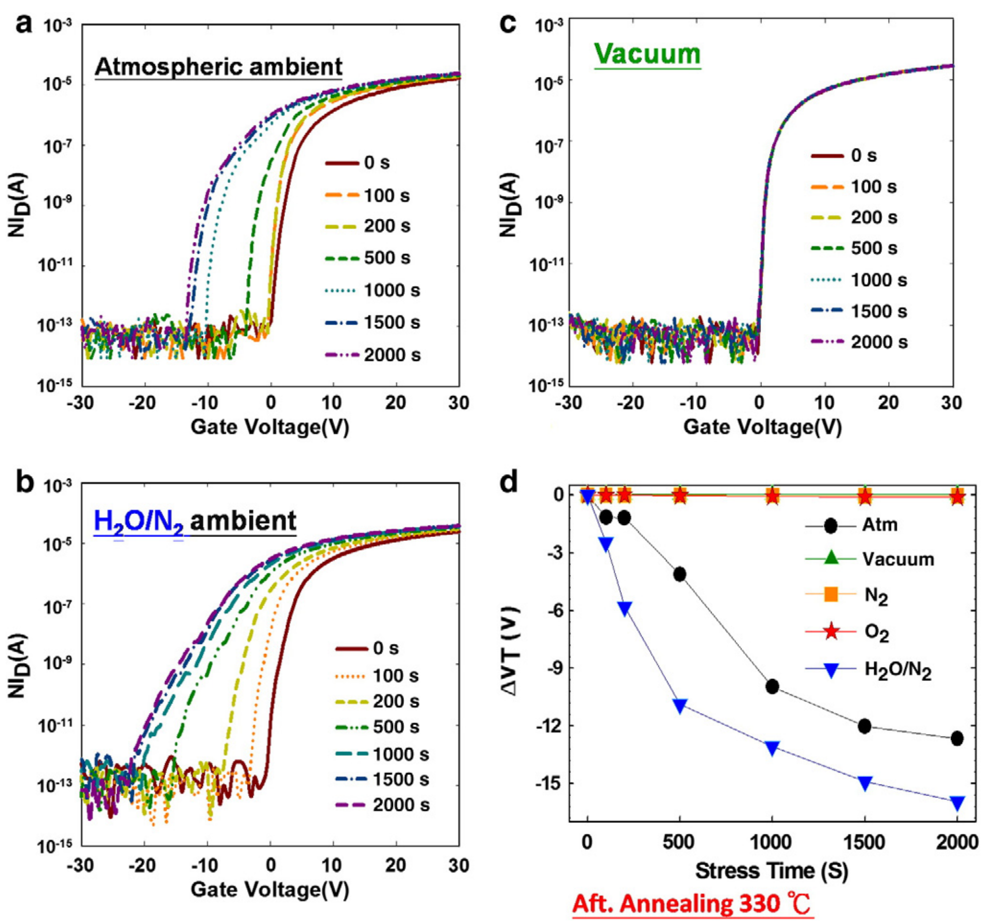

Fig. 1. Transfer I_D–V_G characteristics of a-IGZO TFTs under NBS for 2000 s for devices post-annealing at 330 °C in (a) atmospheric ambient, (b) vacuum, (c) moisture, respectively. Figure (d) shows V_T shift with time for the 330 °C annealing TFTs under NBS in different gas ambience (atmosphere, vacuum, O_2, N_2 and moisture).

ambient, the similar tendency on I_D–V_G transfer characteristics of devices annealed at 150 °C as devices annealed at 330 °C are observed in Fig. 2(a)–(c). Comparing the delta V_T of devices annealed at 150 °C under NBS with in different gas ambient in Figs. 1(d) and 2(d), it indicates that the instability of a-IGZO TFTs under NBS is worsened by the post-annealing at >330 °C. In the literature, the improvement of a-IGZO TFTs' electrical stability under positive gate bias stress in moisture ambient was caused by the out-diffusion of water from device [14]. Hence, it also suggests that the moisture in the environment governs the instability of a-IGZO TFTs under NBS. The result of negative shift in V_T is regarded as the moisture-induced increment in donor concentration of a-IGZO during NBS [15].

Fig. 3(a) shows the I_D–V_G transfer characteristics of a-IGZO TFT with post-annealing at 330 °C under NBS in the moisture ambient with pressure of 1 Torr. Fig. 3(b) shows the time evolution of V_T for device with post-annealing at 330 °C under NBS in moisture ambient with pressures of 1 Torr, 250 Torr and 550 Torr. The threshold voltage shift seems to be closely connected to the amount of water molecules in environment.

The SS is extracted for TFT with post-annealing at 150 °C and 330 °C during NBS in atmospheric and moisture ambient, as shown in Fig. 4. The device annealed at 330 °C presents a more increase in SS during NBS in moisture and atmospheric ambient. The degradation in SS indicates the presence of electron trap states between the interface of a-IGZO and insulator [16, 17]. It can be expected that the moisture reaching the a-IGZO film induces an increase in carrier density within a-IGZO and enhances the generation of shallow donor state.

As the result of our experiment, the instability of a-IGZO TFTs is not only dependent on the moisture in environmental gas but also inseparable from post-annealing temperature. To further investigate

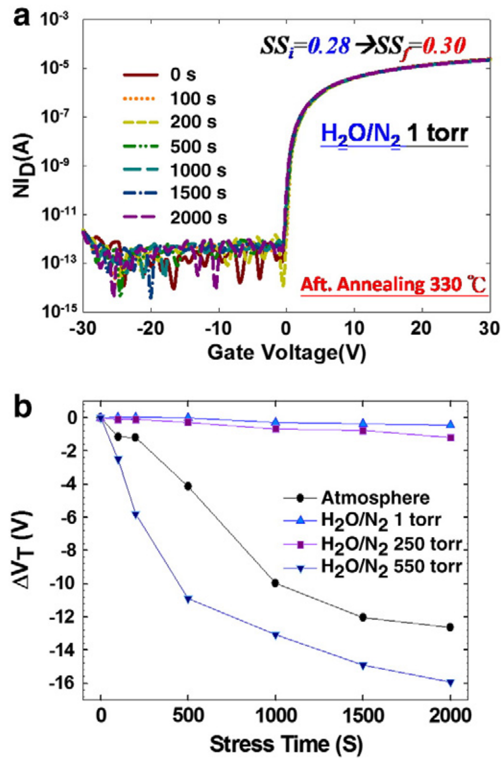

Fig. 3. (a) The evolution of the transfer curve for the devices post-annealing at 330 °C under NBS in moisture ambient pressures of 1 Torr. (b) The Time evolution of the delta threshold voltage after NBS in atmospheric and moisture ambient with different partial pressures (1 Torr, 250 Torr, and 550 Torr).

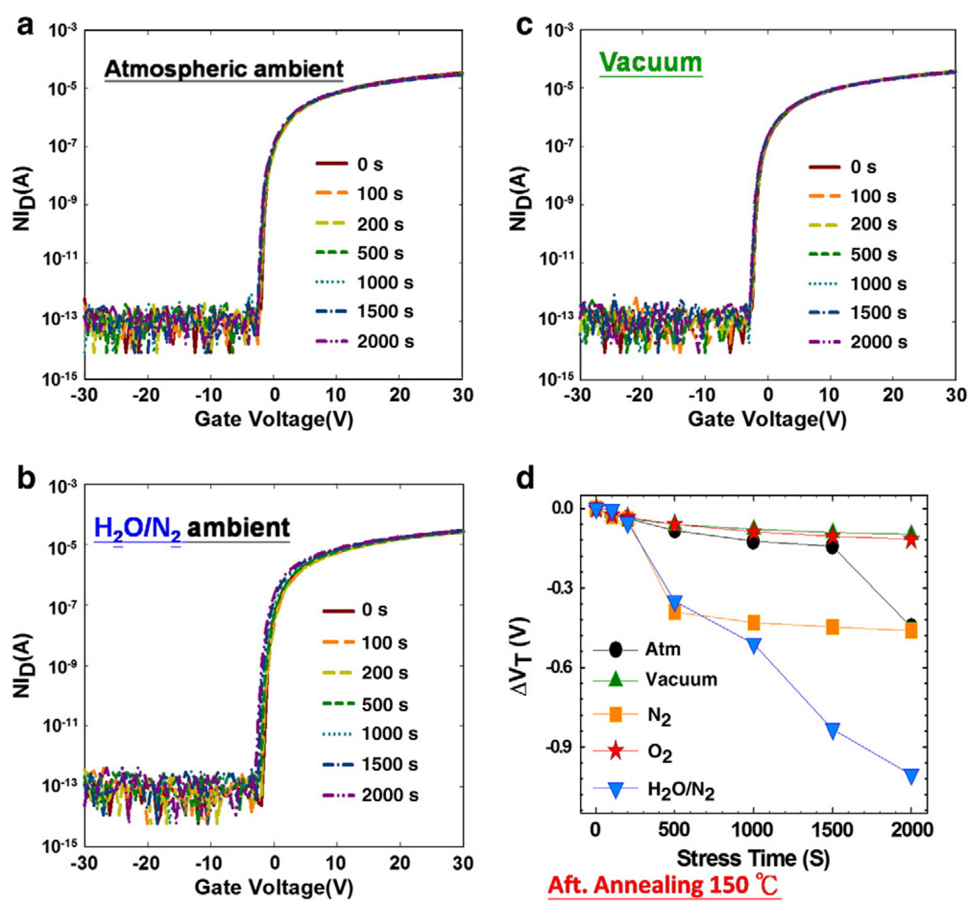

Fig. 2. Transfer I_D–V_G characteristics of a-IGZO TFTs under NBS for 2000 s for devices post-annealing at 150 °C in (a) atmospheric ambient, (b) vacuum, (c) moisture, respectively. Figure (d) shows V_T shift with time for the 150 °C annealing TFTs under NBS in different gas ambience (atmosphere, vacuum, O_2, N_2 and moisture).

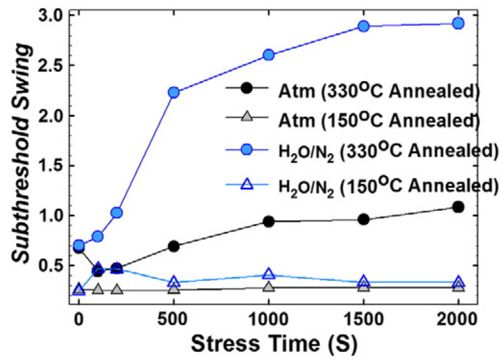

Fig. 4. Time evolution of the SS after NBS in atmospheric and moisture ambient for devices which post-annealed at 150 °C and 330 °C.

the impact of post-annealing temperature on the instability of a-IGZO TFTs, the NBS was performed on the device which was post-annealed at 250 °C. The comparison of delta V_T between device with post-annealed at 150 °C, 250 °C and 330 °C during NBS in moisture ambient is illustrated in Fig. 5. It suggests that the negative V_T shifts are not linear dependence with post-annealing temperature. The superior instability on V_T of device annealed at 330 °C than the device annealed at 150 °C or 250 °C is observed under the same NBS condition. This result can be associated to the variation of electrical parameters before and after post-annealing in the inset of Fig. 5. In the literature, the increment of SS after annealing is attributed to the formation of defect as the annealing temperature up to >300 °C [18]. The smaller V_T shift observed for the device annealed at 150 °C or 250 °C is attributed the less defect state underlying a-IGZO. Therefore, it can be understood that the devices with post-annealing at 330 °C exhibit the worse electrical characteristics without improving SS after post-annealing in atmospheric ambient.

Fig. 6 (a) and (b) shows the evolution of I_D–V_G transfer characteristics of a-IGZO TFTs with post-annealing at 330 °C and 150 °C without negative gate bias for 1000 s in moisture ambient, respectively. The transfer characteristics of a-IGZO TFTs show a significant difference in the behavior of V_T shift between with or without NBS in moisture ambient. According to this result, it is suggested that the negative gate bias helps the adsorption of moisture molecules during NBS.

Hence, a possible explanation for the difference of degradation under NBS is as follows. The generated weak bonds break on the surface of a-IGZO to act on the defect state by post-annealing. From the result of thermal desorption spectrum measurements, the H_2O desorption processes to generation processes of free electrons and oxygen vacancy happened at 280–310 °C [18]. During NBS, the negative bias repels the trapped electron in the defect of channel layer and induces the adsorption of H_2O molecules on the defect state of a-IGZO.

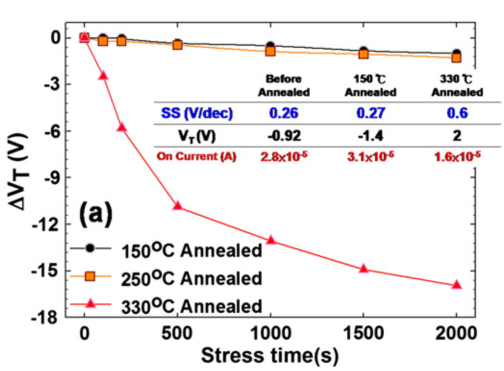

Fig. 5. Time evolution of the delta threshold voltage after NBS in moisture ambient for 150 °C, 250 °C and 330 °C post-annealing devices. The inset shows the typical electrical parameters (SS, threshold voltage and on current) of the devices before and after post-annealing at 150 °Cor 330 °C.

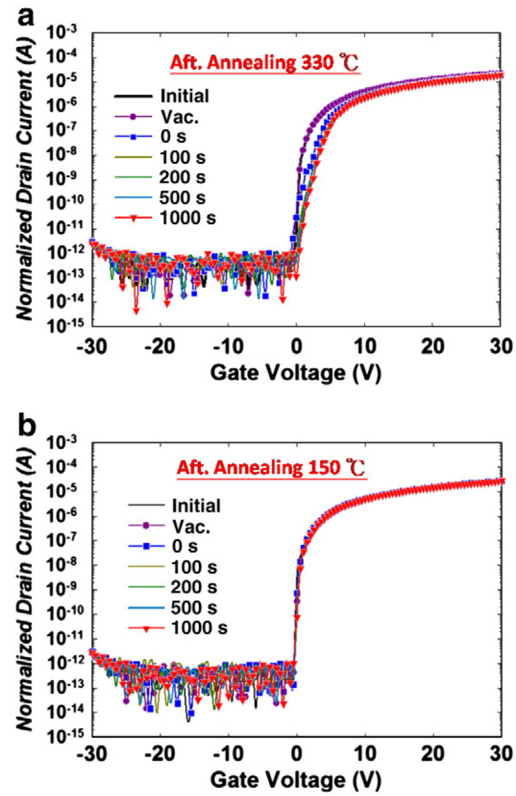

Fig. 6. The time evolution of transfer curve without NBS in moisture ambient for the devices post-annealing at 330 °C and (b) 150 °C, respectively.

Hydroxylating a surface O atom and forming O–H species on the metal atom of a-IGZO occurred from the dissociation of H_2O molecules under NBS [19]. This adsorbed H_2O reaction can be expressed in the form of $H_2O + M\text{-}O\text{-}M \rightarrow M\text{-}OH + M\text{-}OH + V_o^+ + e^-$, where M is the metal cation and V_o^+ is the oxygen vacancy. For 330 °C post-annealing devices, the negative shift of V_T and increase of SS under NBS reflect that the generation of O–H species and oxygen deficiency in a-IGZO are both presented. It is expected that the degradation under NBS was caused by more defect generation due to the defect from post-annealing up to >300 °C.

4. Conclusions

This work demonstrates the influence of gas ambient on the instability of a-IGZO TFTs under NBS. It is found that the post-annealing temperature as up to >300 °C affects the surface state of channel layer and worsens the stability of a-IGZO under NBS. These results propose that appropriate post-annealing temperature will help to improve the surface state of channel layer and suppress the sensitivity of gas ambient on the electrical instability of a-IGZO TFTs. The origin of instability under NBS for a-IGZO is dependent on gas ambient in environment and the applied electrical field during a stress. A model that the negative bias-induced adsorption of water results the OH-related species on the backchannel and generates the V_0 in channel layer is proposed. These findings lead us to know that the proper post-annealing temperature should be used in order to obtain the better electrical reliability of a-IGZO TFTs.

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Reference

[1] K. Nomura, H. Ohta, A. Takagi, T. Kamiya, M. Hirano, H. Hosono, Nature 432 (2004) 488.
[2] Min-Chen Chen, Ting-Chang Chang, Sheng-Yao Huang, Shih-Ching Chen, Electrochem. Solid-State Lett. 13 (2010) H191.
[3] M.-C. Hung, W.T. Lin, J.J. Chang, P.-L. Chen, C.-Y. Wu, C.-J. Lin, 2010 Int. Workshop on Transparent Amorphous Oxide Semiconductors (25–26 January 2010, Tokyo, Japan), 2010.
[4] Chen Min-Chen, Chang Ting-Chang, Huang Sheng-Yao, Li Hung-Wei, Appl. Phys. Lett. 94 (2009) 162111.
[5] Kimura Mutsumi, Imai Shinji, IEEE Electron Device Lett. 31 (2010) 963.
[6] Te-Chih Chen, Ting-Chang Chang, Tien-Yu Hsieh, Wei-Siang Lu, Appl. Phys. Lett. 99 (2011) 022104.
[7] J.K. Jeong, H. Won Yang, J.H. Jeong, Y.-G. Mo, H.D. Kim, Appl. Phys. Lett. 93 (2008) 123508.
[8] Te-Chih Chen, Ting-Chang Chang, Chih-Tsung Tsai, Tien-Yu Hsieh, Appl. Phys. Lett. 97 (2010) 112104.
[9] Yu-Chun Chen, Ting-Chang Chang, Hung-Wei Li, Shih-Ching Chen, Appl. Phys. Lett. 96 (2010) 262104.
[10] T.-C. Chen, T.-C. Chang, T.-Y. Hsieh, C.-T. Tsai, S.-C. Chen, C.-S. Lin, M.-C. Hung, Appl. Phys. Lett. 97 (2010) 192103.
[11] Sheng-Yao Huang, Ting-Chang Chang, Min-Chen Chen, Shih-Ching Chen, Electrochem. Solid-State Lett. 14 (2011) H177.
[12] K.-H. Lee, J.S. Jung, K.S. Son, J.S. Park, T.S. Kim, R. Choi, J.K. Jeong, Appl. Phys. Lett. 95 (2009) 232106.
[13] Po-Tsun Liu, Yi-Teh Chou, Li-Feng Teng, Appl. Phys. Lett. 95 (2009) 233504.
[14] M.E. Lopes, H.L. Gomes, M.C.R. Medeiros, P. Barquinha, L. Pereira, E. Fortunato, R. Martins, I. Ferreira, Appl. Phys. Lett. 95 (2009) 063502.
[15] Jin-Seong Park, Jae Kyeong Jeong, Hyun-Joong Chung, Yeon-Gon Mo, Hye Dong Kim, Appl. Phys. Lett. 92 (2008) 072104.
[16] J.-S. Park, J.K. Jeong, H.-J. Chung, Y.-G. Mo, H.D. Kim, Appl. Phys. Lett. 92 (2008) 072104.
[17] Wan-Fang Chung, Ting-Chang Chang, Hung-Wei Li, Chi-Wen Chen, Electro-chem. Solid-State Lett. 14 (2010) H114.
[18] Nomura Kenji, Kamiya Toshio, Ohta Hiromichi, Hirano Masahiro, Hosono Hideo, Appl. Phys. Lett. 93 (2008).
[19] Y. Wang, M. Muhler, Ch. Woll, Phys. Chem. Chem. Phys. 8 (2006) 1521.