Al-doped Zinc Oxide Field Emitter Array Controlled by High-Voltage Poly-Si Thin Film Transistor

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1. Introduction

Carbon nanotubes (CNTs) have attracted considerable attention as a field emission source due to the small tip radii of curvature, high electrical conductivity, good chemical inertness, and high mechanical strength [1]. However, Fowler–Nordheim field emission is very sensitive to the work function of the emitter surface and the nanometer structure of the emitter, bringing the problems of instability and nonuniformity on anode currents [2]. A long-channel thin film transistor (LC-TFT) has been used to reduce the current fluctuation and driving voltage of CNTs field emission arrays (FEAs) [3]. Nevertheless, the LC-TFT occupies large substrate area and shows a drawback for fine pixel. Furthermore, the reported CNTs FEAs fabricated by microwave plasma-enhanced chemical vapor deposition with high power (~1500 W) and high substrate temperature (~800 °C) inside a vacuum facility during manufacture, resulting in the seriously degraded field-effect mobility and on/off current ratio of LC-TFT due to the plasma damage and high-temperature process. The required high temperature and vacuum facility of CNT growth, resulting in the difficulty over the fabrication of large-area FED using direct deposition of CNTs. Hence, a structure of a high-voltage thin-film transistor with integrated Al-doped ZnO (AZO) nanostructures FEAs are considered to solve the mentioned issues of LC-TFT controlled CNT FEAs. The high-voltage TFT can be realized by excimer laser crystallization technique with an offset design of undoped region in the drain side, which can achieve excellent transistor performances under low-temperature process and ensure a high-breakdown voltage between the drain and the gate/source. In this study, a fully low-temperature fabrication of offset-TFT-controlled AZO nanostructures arrays is proposed for high stable field emitter arrays. The according field emission characteristics and current stability of FEAs will be systematically addressed.

2. Result and discussion

Figure 1 shows the fabrication procedures of offset-TFT-controlled AZO nanostructures FEAs. Fig. 2 presents the FE-SEM images of the AZO nanostructures field emitter arrays synthesized on AZO seed layer. The morphology of AZO nanostructures FEAs reveals the shape of nanowires (NWs), which were well ordered and vertically aligned on the AZO seed layer/poly-Si substrate. The top view FE-SEM image of the AZO NWs FEAs is shown in the inset of Fig. 2. It reveals that aligned AZO NWs FEAs with an average diameter of ~100 nm and controllable length of ~1 μm. The NWs outline can be seen as well-defined hexagons, probably attributed to the wurtzite structure of ZnO single crystal.

Figure 3(a) presents the anode current and gate voltage characteristics of the offset-TFTs-controlled AZO NWs FEAs. A schematic diagram of the experimental measurement setup is shown in the inset of Fig. 3(a). A large on/off current ratio of 3.05 × 10^6 was achieved for the gate voltage (Vg) switching from 0 V to 30 V, indicating that the driving voltage of AZO NWs FEAs can be significantly suppressed. Fig. 3(b) demonstrates the comparison of field emission characteristics for AZO NWs FEAs with or without offset-TFT-control. The anode currents (Ia) were measured as a function of the anode voltage (Va) with various gate voltages of offset-TFTs. The turn-on electric field of uncontrolled AZO NWs FEAs is ~2.17 V/μm. Normally, the anode current of uncontrolled AZO NWs FEAs was increased markedly with the anode voltage. Contrastively, the anode currents were observed to be controlled by the offset-TFTs and showed saturated behaviors at high anode voltages. The saturated anode currents of 82.4 μA, 197.5 μA, and 397.5 μA were obtained when the offset-TFT gate voltage of 15 V, 20 V, and 25 V, respectively. It suggests that the saturated anode current can be modulated by the TFT gate voltage. However, the anode current of the offset-TFT-controlled AZO NWs FEAs were unstable at low anode voltages due to the offset-TFTs under linear-region operation. In addition, the turn-on fields of the offset-TFT-controlled AZO NWs FEAs were raised to 2.4 V/μm owing to the high resistance of the offset region between the gate and drain.

The current stability is a key issue for field emission devices to be applied for flat panel displays. Fig. 4 evaluates the anode current stability of the uncontrolled AZO NWs FEAs and offset-TFT-controlled AZO NWs FEAs over an operation period of 1 hour. The current fluctuation was defined as ΔI/Iave (ΔI = Imax−Imin) under constant applied anode voltage. It is apparent that the uncontrolled AZO NWs FEAs show a comparatively larger current fluctuation of about 15.6 %. In contrast, all of the stress conditions exhibit very stable emissions achieved via the offset-TFT control. The different current levels of offset-TFT-controlled AZO NWs FEAs are according to the different gate voltages. Essentially, the current fluctuation


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of offset-TFT-controlled AZO NWs FEAs was less than 2%. This result recommends that offset-TFT-control significantly can improve the field emission stability of AZO NWs FEAs.

3. Conclusion
A new field emission device composed of an offset-TFT and AZO NWs FEAs has been demonstrated in this study. In addition, the offset-TFT showed better device performances than the LC-TFT [3], such as lower operation gate voltage and higher ON/OFF current ratio. An ON/OFF current ratio of $3.05 \times 10^5$ was achieved while the gate voltage of offset-TFT switching from 0 to 30V. It convinces that the offset-TFTs-controlled AZO NWs FEAs can be operated by the low gate voltage under 30V. Moreover, the saturated anode current can be modulated by the gate voltage of offset-TFT. The stable anode current can be obtained via the offset-TFT control over a period of 1h and the current fluctuation of offset-TFT-controlled AZO NWs FEAs can be reduced to less than 2%.

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Fig. 1 The fabrication procedures of offset-TFT-controlled AZO nanostructures FEAs.

Fig. 2 The FE-SEM images (45° tilt view) of AZO NWs arrays synthesized on the drain region of the offset-TFT. The inset is the related top view.

Fig. 3 (a) Anode current and gate voltage characteristics of the offset-TFT-controlled AZO NWs FEAs. The inset presents the schematic diagram of a high-vacuum field emission measurement for offset-TFT-controlled AZO NWs FEAs. (b) Field emission characteristics of the uncontrolled and offset-TFT-controlled AZO NWs FEAs with different gate voltages.

Fig. 4 Anode current stabilities of uncontrolled and offset-TFT-controlled AZO NWs FEAs over 1h.

References