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RESEARCH ARTICLE

Electroforming characteristics of SED emitter in Al-AlN granular films

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Abstract The Al-AlN granular film was proposed as a cathode emitter of surface-conduction electron-emission display (SED) and the effect of Al-AlN granular films' resistivity on electroforming in experiment and simulation methods was studied. Electroforming could be successfully completed with appropriate Al-AlN granular film resistivity between 1.98 and 15.10 mΩ·cm, and the corresponding turn-on voltage of electroforming increased from 6.2 to 10.5 V with the resistivity increasing. In addition, a temperature profile on Al-AlN emitter was simulated and the temperature decreased from middle to two sides, which were corresponding to surface morphology of Al-AlN emitter after electroforming.

Keywords electroforming, Al-AlN granular films, surface-conduction electron-emission display (SED), resistivity

1 Introduction

Surface-conduction electron-emitter display (SED) is a kind of high vacuum device, which consists of anode panel, cathode panel and spacer similar to that of plasma display panel (PDP) and field emission display (FED). Cathode panel is composed of base plate, electrodes and electron emitter, among which the electron emitter's material plays a key role in SED device. The pre-research of SED electron emitter's materials was concentrated on island metal films (IMF), discontinues semiconductor films and metal oxide films [1–10]. From the surface conduction emission (SCE) reported, we could summarize that it is necessary for obtaining SCE to form micrometer or sub-micrometer gap in the emitters. For IMF and discontinue semiconductor films, the micrometer or sub-micrometer gap were formed by controlling film thickness and post-annealing [1–4], and for double-layer electron emitter the bottom IMF and porous Al_2O_3 were used to form micrometer or sub-micrometer gap [7,8]. The nano-gap could be formed by applying a varying voltage on the PdO films [9]. The nano-gap on a Pd strip was attributed to special geometry and high-pressure hydrogen absorption treatment [10]. However, now only the PdO films were successfully used in display by Canon and a 36 inch SED prototype was exhibited in Consumer Electronics Show (CES) 2006, but there are no other SED prototypes shown until CES 2010.

For obtaining best performance SED, more attention should be paid to study different cathode emitter material and also to understand the electric properties of these material emitters. In our previous work, the Al-AlN granular films were suggested as a surface-conduction SED emitters' material. The SED prototypes in using granular films were fabricated and the green light from the anode proved the feasibility of the granular films' emitter [11]. The primary electric properties show a low driving-voltage of 10–20 V and driving-current of 0.06 mA for one unit (sub-pixel). Moreover, the main parameters affecting the device properties were determined to granular films, composition, electroforming process and device geometry. The granular films' composition varied with the films' deposition processes (especially with the inject N_2 gas flow) due to changing ratio of Al and AlN phase. According to the granular theory, the granular films' properties show three distinct regimes of metallic regime, transition regime and dielectric regime. In the metallic regime, the films' structure is discontinue dielectric phase embedded in continue metallic phase net. In the dielectric regime, the films' structure is discontinue metallic phase embedded in dielectric phase net. In transition regime, the films, structure is an inversion between the metallic and the dielectric regime. So the granular films' resistivity shows a giant difference from dialect to conductor with the ratio changing.

Before the application of granular films SED cathode

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emitters, much work could be made to understand that how much resistivity range could the granular films' emitter be completely electroformed to form nano structure for electron emission? In this paper, we prepared different resistivity Al-AlN granular films under different N_2 gas flow and the electric properties of electroforming were reported in experiment and simulation.

2 Experiments

Al-AlN granular films were deposited by sputtering a pure Al (99.99%) target in using Ar gas with a flow rate of 25 sccm and N_2 gas with different flow rate of 2.2, 2.8 and 3.4 sccm under working pressure of 1.3×10^{-1} Pa. The sputtering power was maintained at 150 W and the distance between Al target and substrate was fixed at 15 cm. Al-AlN films of 100 nm thickness were obtained after 10 min of deposition.

Figure 1 shows a schematic of electroforming. Rectangular Al-AlN granular films with dimensions of 100 μm × 400 μm were patterned on middle of two electrodes with 150 μm space by lithography progress. Three-layer (Cr/Cu/Cr) electrodes with a total thickness of 100 nm were deposited in thermal evaporation. Before deposition, the glass substrate was cleaned by Ar gas sputter for 5 min. Electroforming was carried out with the pressure less than 3.0×10^{-4} Pa and anode voltage of 2000 V. The varying device cathode voltage (*Vf*) was applied on the two electrodes including 18 measurement units.

3 Results and discussion

3.1 Results

Figures 2–4 show curves of device *Vf* and device conduction current (*If*) with different Al-AlN granular films' resistivity of 1.98, 7.00 and 15.10 mΩ·cm, respectively. The inset pictures in Figs. 2 and 3 show details of a voltage period, respectively. It was found that the maximum value of *If* decreased from 635 mA with 1.98 mΩ·cm resistivity in Fig. 2 to 220 mA with 7.00 mΩ·cm resistivity in Fig. 3, and then reduced to 110 mA with 15.10 mΩ·cm resistivity in Fig. 4. Furthermore, the peak value of *If* with 1.98 mΩ·cm resistivity in Fig. 2 decreased rapidly at second period and then decreased gradually from second period. However, the *If* peak value with 7.00 mΩ·cm resistivity present a gradually decrease with *Vf* amplitude steeply increasing. The *If* peak value with 15.10 mΩ·cm resistivity slowly increased before ten electroforming periods and decreased after the tenth electroforming period.

In addition, during the second electroforming period, the *If* of 1.98 mΩ·cm resistivity Al-AlN films increased with the *Vf* increasing from 0 to 6 V, and inversely decreased with *Vf* more than 6 V from the inset picture of Fig. 2, which was an obvious voltage control negative resistance (VCNR) property. When the film resistivity reached to 7.00 mΩ·cm, VCNR could be also observed during the seventh electroforming period with device cathode voltage more than 8 V from the inset picture of Fig. 3. No VCNR properties, however, could be observed with 15.10 mΩ·cm resistivity during electroforming from Fig. 4.

In order to quantities present electroforming, the turn-on voltage of electroforming ($V_{\text{turn-on-e}}$) was determined to a *Vf* corresponding to first inflection point of *If* when *Vf* increasing. According to this definition, the $V_{\text{turn-on-e}}$ were determined to 6.2 and 8 V corresponding to 1.98 and 7.00 mΩ·cm resistivity from the inset pictures of Figs. 2 and 3, respectively. Because of no clear VCNR properties, the $V_{\text{turn-on-e}}$ of an Al-AlN granular film with 15.10 mΩ·cm could be determined to a *Vf* after which the peak value of *If* begins to decrease. According to this definition, the $V_{\text{turn-on-e}}$ could be determined to 10.5 V.

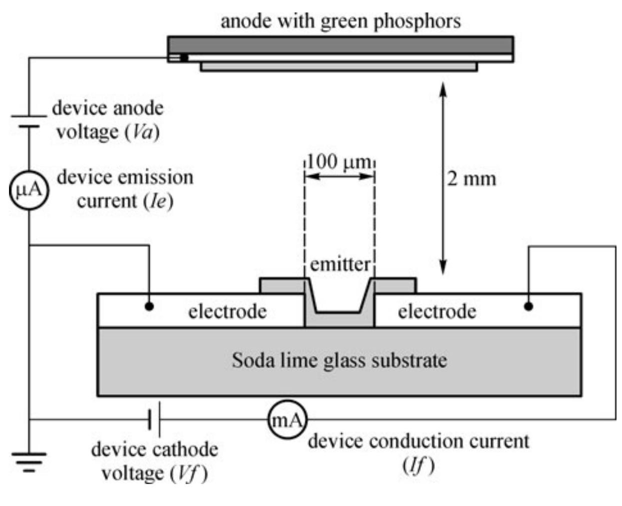

Fig. 1 Schematic of electroforming set-up

3.2 Discussion

At beginning of electroforming, according the granular conductive theory electrons more easily flowed the granular films through Al conductive net for lower resistivity, so the *If* peak value for lower resistivity of Al-AlN films was larger than that of higher resistivity of films.

In our previous work, electroforming mechanism could be determined to Al granular evaporated from Al-AlN granular films due to accumulation of Joule heat. For Al-AlN films with lowest resistivity of 1.98 mΩ·cm, a 635 mA *If* peak current in the first period was enough to generate lots of heat to destroy most Al conductive net which lead to a sharply decrease of the *If* peak value at the second electroforming. For Al-AlN films with resistivity of 7.0 mΩ·cm, part of Al conductive net were damaged due to relative lower *If* peak current. So the *If* peak value

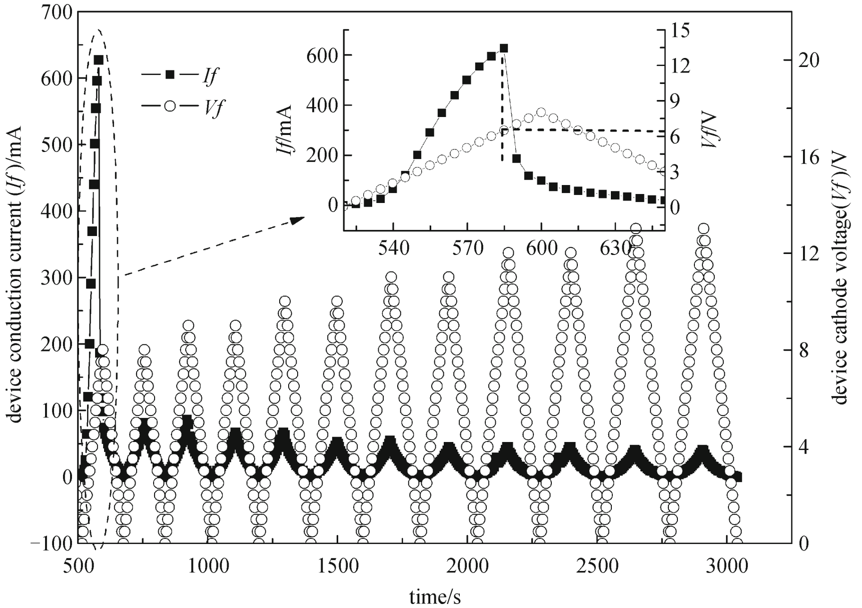

Fig. 2 Relation of device conduction current and device cathode voltage with resistivity of 1.98 mΩ·cm

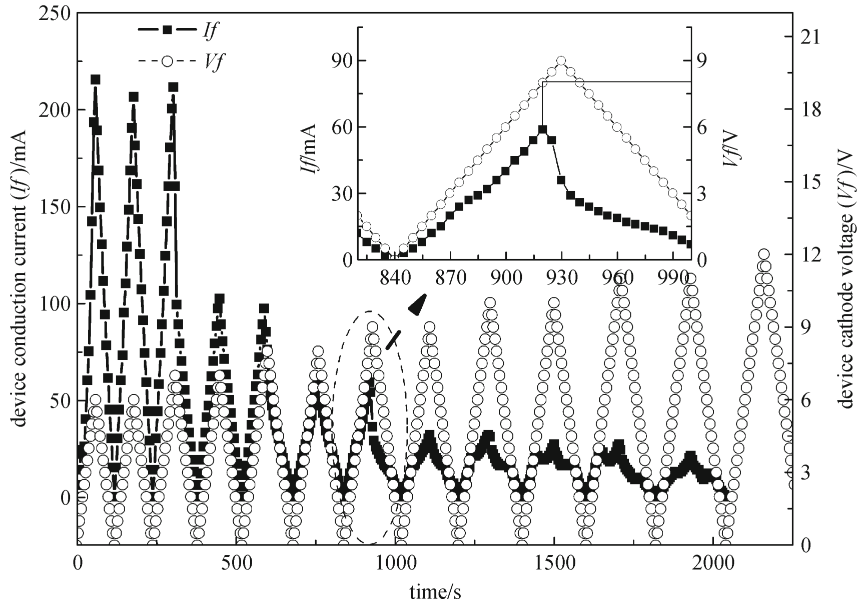

Fig. 3 Relation of device conduction current and device cathode voltage with resistivity of 7.00 mΩ·cm

present a gradually decrease. When the resistivity reaching to 15.10 mΩ·cm, the Al conductive net were damaged slowly due to lowest *If* current, which corresponding to the *If* tendency.

For lower resistivity larger *If* in first period could not only destroy the Al conductive net, but also could evaporate Al from the Al-AlN granular films, which lead to the present of the VCNR properties for the Al-AlN films with 1.98 and 7.00 mΩ·cm resistivity. However, there are no VCNR for Al-AlN films with 15.10 resistivity because the heating generated by *If* during electroforming was not enough to evaporate Al granular and only destroyed the Al conduction net.

The morphology of Al-AlN films before and after electroforming will prove the mentioned above discussion. Figure 5 shows morphology of Al-AlN granular films with 1.98 mΩ·cm resistivity after electroforming. We could observe large number of re-deposition materials glued to Al-AlN granular surface which have been proved to be Al materials in our paper [6]. However, no any glued materials on the surface of Al-AlN granular films with 15.10 mΩ·cm resistivity after electroforming could be

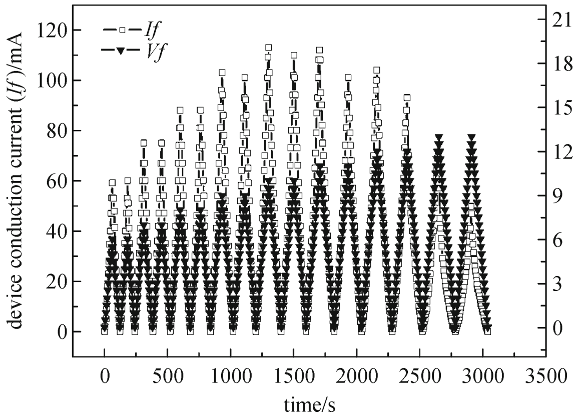

Fig. 4 Relation of device conduction current and device cathode voltage with resistivity of 15.10 mΩ·cm

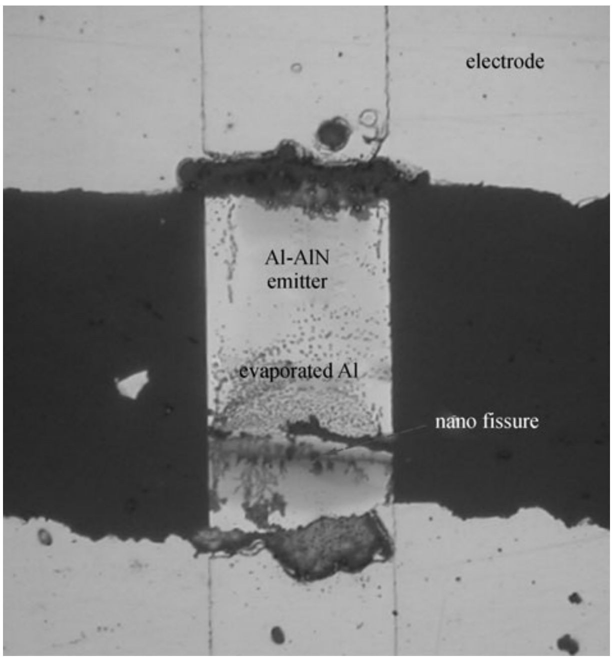

Fig. 5 Surface morphology of Al-AlN emitter after electroforming

observed. Joule heating produced by *If* was not enough to evaporate Al from granular films and only to destroy Al conductive net. Moreover, theory simulation also proves Al evaporation and the simulation results were shown in Fig. 6 with Al-AlN films' resistivity of 2 mΩ·cm and applied *Vf* of 10 V. It was found that temperature in the middle of Al-AlN granular films reached to 2234 K which is enough to evaporate the Al materials in vacuum, and also found that the temperature decreased from middle to two edges which was in agreement with Al-AlN films morphology after electroforming.

The $V_{\text{turn-on-e}}$ of Al-AlN granular films decreased from 6.2 to 10.5 V with resistivity increasing which also could

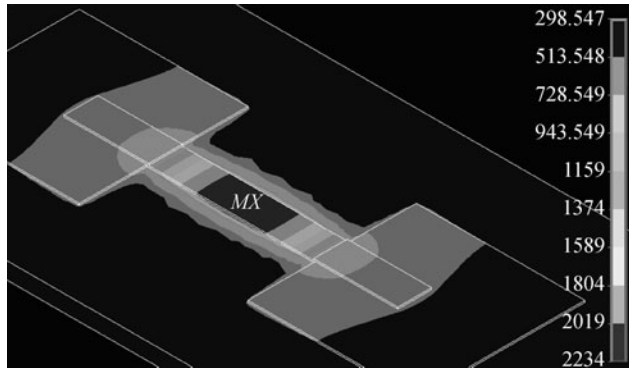

Fig. 6 Temperature profile on Al-AlN granular films emitter

be attributed to accumulation heating produced by *If* due to different resistivity.

4 Conclusions

The effect of different resistivity on electroforming was studied in using Al-AlN granular films' emitters. It was found that electroforming could be successfully completed with appropriate resistivity range. The device would be destroyed because of much more Joule heating with resistivity less than 1 mΩ·cm and the device was not electroformed successfully due to much less Joule heating with resistivity more than 15.10 mΩ·cm. The turn-on voltage of electroforming increased from 6.2 to 10.5 V with resistivity increasing from 1.98 to 15.10 mΩ·cm. The surface morphology of the Al-AlN emitter showed a nano fissure near to the middle after electroforming, which was corresponding to temperature profile on the Al-AlN granular emitter in simulation.

We also found that $V_{\text{turn-on-e}}$ decreased with electroform period increasing and reached lowest voltage of 3 V in Fig. 2. This lower drive voltage could benefit developing SED device, and deep research would be on the drive voltage, drive current and efficiency.

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