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Efficient surface-conduction field emission electron sources from tin oxide film

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ABSTRACT

This paper describes a study on the surface-conduction field emission (SCFE) electron sources based on island-like tin oxide (SnO_2) film by magnetron sputtering, conventional photolithography and lift-off method. The images of island-like SnO_2 film were characterized by the optical microscopy and atomic force microscopy (AFM). Field emission (FE) characteristics of SCFE electron sources with SnO_2 film were also investigated. The AFM images show that the diameter of island-like SnO_2 film is approximately 100–300 nm and the gap of most island-like SnO_2 film is around 10–30 nm. FE properties reveal that the emission current and conducted current are completely controlled by gate voltage. The electron emission efficiency is around 0.95% when the anode voltage and gate voltage was fixed to be 3.2 kV and 238 V, respectively, at the anode–cathode gap of 500 μm. The emission images obviously become brighter and more uniform with the increases of the gate voltage and the maximum brightness can reach 850 cd/m^2. The emission current fluctuation is smaller than 5% for 4 h, which indicated that the fabricated electron sources have an efficient field emission performance.

1. Introduction

Electron sources operating on the basis of Field Emission (FE) are nowadays a basic component of many technological tools [1–3]. Further, in the field of vacuum micro- and nano electronics [4–7], field emitter arrays (FEAs), integrated with microscale and nanoscale field-emission-type electron sources, have been developed for various applications using the advantage of field emission electron beams, such as field emission displays [8,9], field emission lamps [10,11], small X-ray sources [12–14], high-frequency devices [15], and electric power switching devices [16,17]. To date, semiconductor nanofabrication processes have been used to fabricate different types of field emission electron sources to achieve better FE characteristics and stability, such as the Spindt type [18] and Si type [19] which were suitable for mass production, normal-gate type [20,21], under-gate type [22,23], planar-gate type [24,25] and surface-conduction field emission electron sources [26–28]. Compared with other electron sources, the surface-conduction field emission electron sources based on a planar-gate-type triode have many advantages such as simple structure and fabrication processes, which have been paid much attention due to a lower driving voltage and excellent field emission characteristics.

Up to now, one key challenge is to choice field emitters and develop efficient deposition technique to assemble electron emitters on the triode structure. FE properties of many materials, including diamonds, carbon nanotubes (CNTs), SiC, ZnO and SnO_2 films have been extensively investigated due to their fascinating physical and chemical properties, and potential applications in the past years [29–35]. Among them, tin dioxide (SnO_2), as a kind of n-type semiconductor with a wide band gap (3.6 eV, at 300 K), has attracted extensive attention [36,37]. Due to its low electrical resistivity, high optical transparency in the visible range (up to 97%), high or low porosity, high thermal and chemical stability, and low cost, SnO_2 has been widely investigated as an electron emitter and demonstrated an enhanced FE property in comparison with ZnO and other field emitters [38–41]. We know, there are many ways to prepare SnO_2 electron emitter, such as screen printing [25], hydrothermal methods [42], rapid oxidation [43], chemical vapor deposition (CVD) [44], and thermal evaporation [45]. Compared with other methods, magnetron sputtering is employed to fabricate SnO_2 film, (used as surface-conduction electron emitters) and has many advantages, including the controllable size, shape, and thickness of SnO_2 film.

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Surface-conduction field emission (SCFE), also called surface conducted emission (SCE), is a field emission electron source based on a planar-gate type structure, which refers to electron emission from a thin-emitter near the cathode. Few electrons are absorbed by anode plate and most electrons are conducted between thin-emitter under the modulation of gate electrode. These conducted electrons bombard on the other thin-emitters and secondary electrons are generated. As known, the field emitters of a conventional planar-gate-type electron sources are deposited on the surface of cathode electrode. However, the surface-conduction electron emitters of SCFE electron sources are deposited the gap between the cathode and gate electrode (C-G gap). The advantage of SCFE as compared with conventional field emission electron source can be a low drive voltage when the C-G gap becomes nanoscale. In this study, our aim was to fabricate a SCFE electron source based on a planar-gate-type triode with SnO_2 film carefully deposited on the gap between the cathode and gate electrode by magnetron sputtering. In addition, its FE characteristics were also investigated.

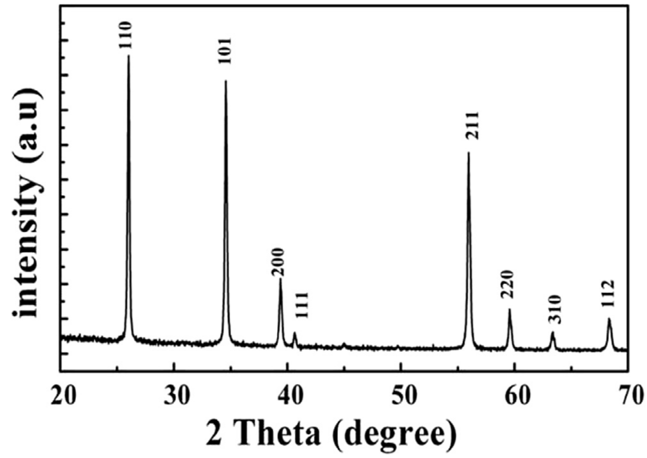

Fig. 2. XRD pattern of the sample deposited on the C-G gap.

2. Experimental methods

2.1. Fabrication of SCFE electron sources with SnO_2 films

The whole manufacture process of a surface-conduction field emission electron sources based on island-like SnO_2 film is shown in Fig. 1. Firstly, Cr/Cu multilayer films with a thickness of 100 nm were deposited the glass substrate (10 cm × 10 cm) by magnetron sputtering. The substrate was coated by positive photoresist (RZJ-304) using spin coating and then photoresist patterns were formed by developer after UV exposure. After etching of Cr layer was carried out in the solution with 6:3:100 weight ratio of concentrated $KmnO_4$, NaOH and H_2O and etching of Cu layer was completed in the 4 wt.% $FeCl_3$ solution, the cathode and gate electrodes coated by the photoresist were formed. Secondly, SnO_2 film was deposited the substrate by magnetron sputtering, in which the distance between the substrate and the Sn source was about 10 cm and the substrate temperature was kept at 150 °C under a flow rate of 75 standard cubic centimeter per minute (SCCM) of Ar and 75SCCM of O_2 for 6 min. The size and thickness of tin oxide islands can be easily modified by changing the sputtered Sn quantity, O_2 flow, sputtered power and time. SnO_2 film with the thickness of 60 nm, deposited in the gap between cathode and gate electrode (C-G gap) was obtained after the photoresist was removed by acetone. Finally, island-like SnO_2 film was formed after AC voltage was applied between cathode and gate electrodes for 15 min. A surface-conduction field emission (SCFE) electron sources based on island-like SnO_2 film was fabricated.

2.2. Characterization of SCFE electron sources

The typical image of the SCFE electron sources with SnO_2 film deposited in the C-G gap, was observed by the optical microscopy. The morphology of deposited SnO_2 film was characterized by atomic force electron microscope (AFM, Nano ScopeIIIa), and the crystal structure of the samples was characterized by X-ray diffraction (XRD, Philips X'Pert Pro) with the incident radiation of Cu Kα (i.e., λ = 0.154 nm). The composition and chemical bonding states were analyzed by X-ray photoelectron spectroscopy (XPS) using an ESCALab250Xi electron spectrometer (Thermo Scientific) with the incident radiation of Al Kα, the binding energies were referenced to the C 1s line at 284.8 eV of carbon.

2.3. Field emission characteristics of SEFC electron sources

To investigate the field emission characteristics of the SCFE electron source based on island-like SnO_2 film, ITO glass coated green phosphor was used as an anode plate and the SCFE electron

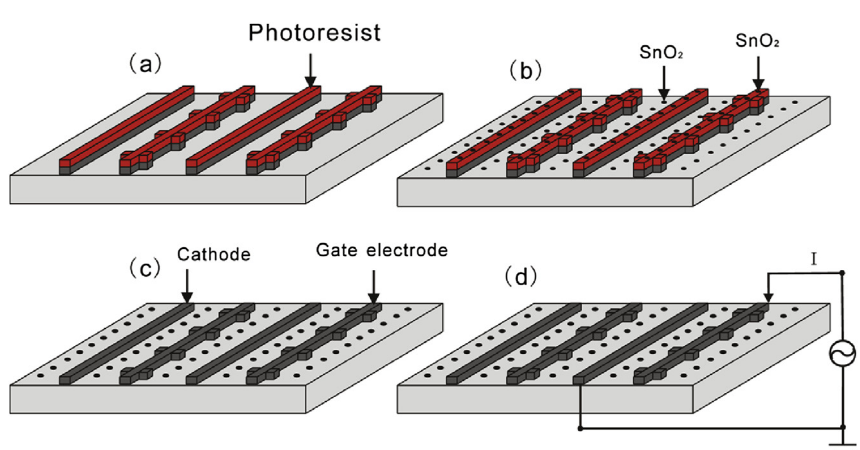

Fig. 1. The whole manufacture process of a surface-conduction field emission electron sources based on island-like SnO_2 film: (a) fabrication of gate and cathode electrodes, (b) deposition of SnO_2 film by magnetron sputtering, (c) removing photoresist by acetone and (d) formation of island-like SnO_2 film.