Superlattices and Microstructures 84 (2015) 144–153

Contents lists available at ScienceDirect

Superlattices and Microstructures

journal homepage: www.elsevier.com/locate/superlattices

Field emission property of ZnO nanowires prepared by ultrasonic spray pyrolysis

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ARTICLE INFO

Article history:
Received 23 April 2015
Accepted 5 May 2015
Available online 14 May 2015

Keywords:
ZnO
Nanowire
Field emission
Oxide semiconductor
Ultrasonic spray pyrolysis

ABSTRACT

The field emission property of cold cathode emitters utilizing the ZnO nanowires with various conditions prepared by ultrasonic spray pyrolysis technique was discussed. It is found that the emission current was enhanced in the emitters having higher aspect ratio as well as smaller sheet resistance. Applying of post-annealing process, utilization of additional Mo back electrode in the cathode, and coating of Mo on the ZnO nanowires resulted in the improvement of the emission current and lowering the threshold voltage. A threshold voltage of about 5.5 V/μm to obtain 1.0 $\mu A/cm^2$ was achieved in the sample prepared at the growth temperatures varying continuously from 250 °C to 300 °C.

1. Introduction

Electron emission phenomenon observes at the surface of a solid material under an applied electric field in vacuum is well explained by the following expression known as Fowler–Nordheim (F–N) equation.

$$J = A\frac{(\beta E)^2}{\phi}\exp\left(\frac{-B\phi^{3/2}}{\beta E}\right) \tag{1}$$

Here, E represents an applied electric field, β is defined as a field enhancement factor which is depending on the morphological aspect ratio of the solid emitter, ϕ is the work function of the emission

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http://dx.doi.org/10.1016/j.spmi.2015.05.003

surface, and A and B are the constants respectively [1,2]. This equation can be rearranged in the form as shown in Eq. (2), which is usually used for evaluating the β directly from the experimental measurement results.

$$\mathrm{Ln}\left(\frac{J}{E^2}\right) = \frac{-B\phi^{3/2}}{\beta}\cdot\frac{1}{E} + \mathrm{Ln}\left(\frac{A\beta^2}{\phi}\right) \tag{2}$$

From these equations it can be clearly understood that the emission current density J is depending on the applied electric field as well as the surface morphology of the emitter. Since one dimensional nano-structure such as nanowire has higher morphological aspect ratio than that of a flat surface thin film of the same material, β is significantly increase and it is possible to enhance the electron emission under an applied electric field even at room temperature by utilizing the structural advantage of nanowire. Accordingly, one dimensional material such as ZnO nanowires (abbreviated as ZNs) is know to be one of the promising materials for application in the cold cathode emitter due to its structural property of high aspect ratio [2–19]. In addition, ZNs has advantages in the environmental issue since it has no toxicity, no limitation in the resource, and it could be synthesized by various processes including non vacuum processes such as solution based reaction techniques and ultrasonic spray pyrolysis, in which only relatively low energy is required for the growth process [20–38]. Up to now, several researches have been focusing on the development of cold cathode field emission devices based on ZNs [2–19]. Recently, we also reported an economically viable synthesis technique of ZNs on a soda-lime glass (SLG) substrate utilizing ultrasonic spray pyrolysis (USP) [22–25]. In this paper, we focused on the field emission property of ZNs prepared by this USP technique in relation to various material parameters.

2. Experimental methods

The ZNs were prepared by utilizing our original USP system with some minor modifications, the detailed structure and processes of which were described in our previous reports [22–25,39]. In preparing the ZNs, a precursor solution containing zinc acetate dihydrate (abbreviated as ZA, Wako, 99%), indium (III) nitrate trihydrate (abbreviated as IN, Wako, 98%), and ammonium acetate (abbreviated as AA, Wako, 97%), which were dissolved in 1 L of deionized water by a specific molar ratio, was used. In our USP technique, ZNs with wurtzite crystal structure are usually obtained and the majority growth direction of one dimensional nanowire structure is observed to be along the [002] axis or c-axis. The details of material properties such as crystal structure, growth orientation, optical characteristics and etc. of the ZNs prepared by this USP technique were already reported in our previous reports [22–25]. For the field emission measurements, a device configuration as shown in Fig. 1 was used. A cathode emitter was formed by growing the ZNs emitter on the SLG substrate directly by USP. A self-assembled seeding layer with or without additional Mo back electrode was utilized as the back electrode of ZNs emitter. The details of self-assembled seeding layer were discussed in

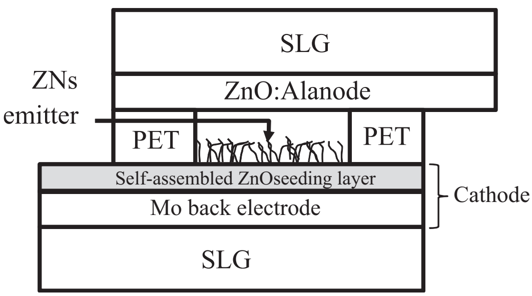

Fig. 1. The cross-sectional schematic of the device used for testing the field emission property. The Mo back electrode layer was not applied in some conditions, i.e., only the ZnO seedling layer was used as the cathode. The thickness of the films were not drawn to scale.