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RESEARCH PAPER

Field emission properties of carbon nanocoils synthesized on stainless steel

Li-li Li, Lu-jun Pan*, Da-wei Li, Qin Zhao, He Ma

School of Physics and Optoelectronic Technology, Dalian University of Technology, Dalian 116023, China

Abstract: Carbon nanocoils (CNCs) were synthesized by a thermal chemical vapor deposition (CVD) method over tin-coated type 202 stainless steel (SS) plates (Cr 15%, Mn 10%, Ni 1%). It is considered that the calcination at 900 °C leads to the crazing of the SS surface, which causes the Fe (Ni) and Sn to be fully mixed and forms active Fe (Ni)-Sn-O catalyst particles suitable for the growth of CNCs. However, the Cr in the catalyst particles is below the limitation of detection, and its role is currently not understood. The electron field-emission properties of as-grown CNCs dispersed on an n-type Si substrate were also investigated. It is found that the CNCs exhibit a low turn-on electric field of 1.6 V/m. The distributions of electric fields on a stand-up and a laid-down CNC successfully explain the behavior of the Fowler-Nordheim (*F-N*) plot. The field enhancement factor for the laid-down CNC is 2.25 times larger than that for a laid-down multiwall carbon nanotube (CNT). This is because the helical morphology of the CNCs can reduce the screening effect produced by the surrounding substrate. In this case, CNCs can more easily emit electrons, and show promise for use in X-ray sources, field emission displays and other micro- or nano-devices.

Key Words: Carbon nanocoils; Stainless steel; Calcination temperature; Field emission; Finite element method

1 Introduction

Carbon nanocoils (CNCs) have attracted much attention because of their excellent mechanical and electrical properties [1,2]. They were mostly synthesized by chemical vapor deposition (CVD) method [3,4]. Generally, CNCs were synthesized on Fe-Sn-coated Si/SiO_2 substrates, or Fe-coated indium-tin-oxide glass substrates [5-7] etc. In the mass production of CNCs, it is too expensive to use these substrates. Recently, Chang et al [3] have synthesized CNCs with a high yield on a low price 304 stainless steel plate (Cr 18%, Ni 8%) with Sn spin-coated on it. In this work, Sn-coated ordinary SS plate（Cr 15.27%, Mn 10.11%，Ni 1.32%）, which is cheaper than 304 SS plate, has been used to synthesize high-yield CNCs. The influence of the calcination temperature on the CNC growth was also investigated.

It is known that carbon-based nanomaterials, especially carbon nanotubes (CNTs) have excellent field emission properties, which are expected to be applied in electron guns, field emission displays and other electronic devices [8-11]. So far, there are two main methods to fabricate CNT emitters. One is directly growth of CNT array on patterned electrodes [12]. However, the distribution of electric fields on these CNT arrays are not uniform and strongly concentrated at the edge of the arrays [12,13]. The other is screen-printing method that prints the mixture of CNTs and binders on electrodes [14], but, most of the CNTs are laid down on the substrate when using the screen-printing method. The laid-down CNTs cannot easily emit electrons, and the turn-on voltage is high [15] that largely limit their applications. CNCs, another kind of carbon nanomaterials, also possess excellent field-emission properties owing to their unique spiral morphologies. It is considered that the electrons can be emitted not only from the tip of a CNC, but also from its side body and the outstanding performance is also attributed to the high aspect ratio of the CNCs [16-19]. Therefore, the efficiency of field emission from CNCs is considered to be higher than CNTs and is suitable for wide applications. In this work, we have studied the field-emission properties of the CNCs dispersed on an n-type Si substrate by considering the case of screen-printing. The distributions of electric fields on a stand-up /a laid-down CNC and a laid-down CNT were calculated by a finite element method.

2 Experimental

An ordinary SS plate with a thickness of 360 μm was selected as the substrate. A $SnCl_2{\cdot}2H_2O$ ethanol solution with a concentration of 0.025 mol/l was used as the catalyst precursor and dropped to the SS substrates. Then the samples were calcined at temperatures of 700, 800 and 900 °C in air for 30 min. Finally, the calcined SS samples were put into a CVD chamber to synthesize the CNCs at 700 °C for 60 min under the flow of acetylene and argon with flow rates of 17 and 323 mL/min, respectively. The carbon deposits and the calcined samples were observed and analyzed by a scanning electron microscope. The field-emission properties of

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***Corresponding author.** E-mail: lpan@dlut.edu.cn
†These authors equally contributed to this work.

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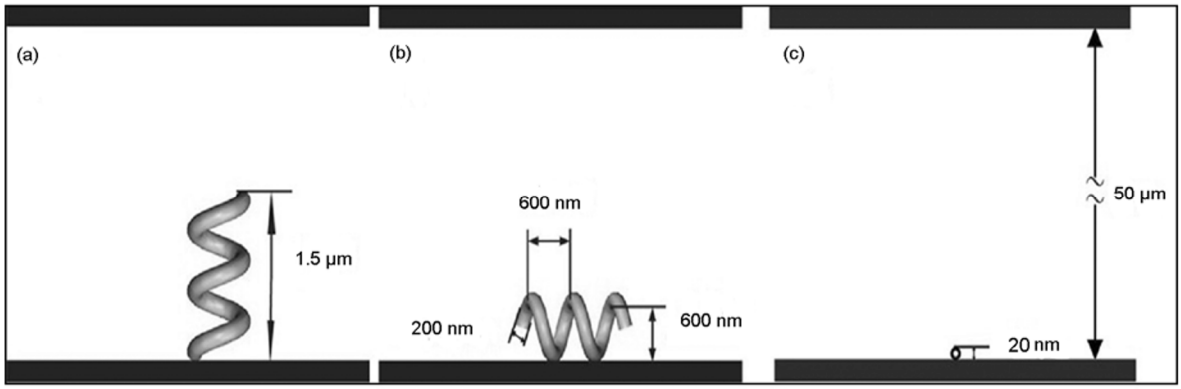

Fig. 1 Simulation models for the field-emission devices using (a) a stand-up CNC, (b) a laid-down CNC and (c) a laid-down CNT as the emitters.

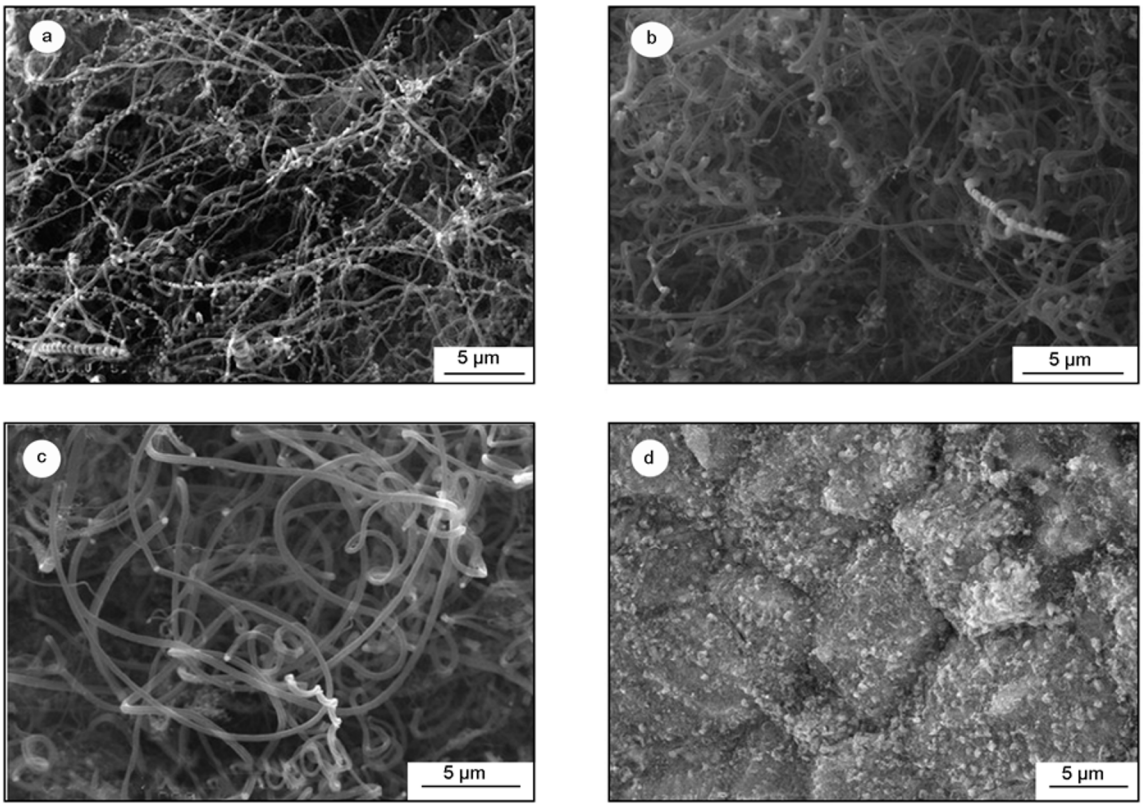

Fig. 2 SEM images of carbon deposits grown on the Sn-coated SS substrates which were initially calcined at (a) 900 °C, (b) 800 °C, (c) 700 °C and (d) 1000 °C.

as-grown CNCs were studied by using a diode-type configuration in a vacuum chamber at a base pressure lower than 4×10^{-5} Torr. An n-type Si substrate with CNCs uniformly dispersed on its surface was used as the cathode and an indium tin oxide (ITO) glass plate as the anode. The gap between the anode and cathode was set to be 350 μm.

In addition, the distributions of electric fields on a stand-up CNC, a laid-down CNC and a laid-down CNT were calculated by a three-dimensional finite element method. The model used is shown in Fig. 1, where the space between the two parallel electrodes was set to be 50 μm, and the applied voltage ranged from 75 to 305 V. Line diameter, coil diameter and pitch of the CNC are 200, 600 and 600 nm, respectively, which correspond to the parameters of the actually grown CNCs, and its length is set to be 1.5 μm. For comparison, the CNT diameter is set to be 20 nm, which is the same as the diameter of CNT synthesized in the general experiment conditions.

3 Results and discussion

Figs. 2a, 2b and 2c show the SEM images of the deposits