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Enhanced electron field emission characteristics of single-walled carbon nanotube films by ultrasonic bonding

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HIGHLIGHTS

- A novel ultrasonic bonding process was used to fabricate the electron field emission.
- The mechanical and electrical contact between SWCNTs and metal layer was impoved.
- Electron field emission properties were improved remarkably.
- Turn-on voltage of bonded SWCNTs film showed significant decrease.
- The emission current of bonded SWCNTs film was much stabilized.

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ABSTRACT

A novel ultrasonic bonding process was used to fabricate the electron field emission cathode of single-walled nanotube film, which was deposited on an Al plate substrate by electrophoretic deposition. Electron field emission properties were improved remarkably after the cathode carbon nanotubes nanobonded with the Al substrate. Turn-on voltage showed a significant decrease and the emission current was much stabilized. This can be attributed to the reduction of the contact resistance in bonding area and easily moving electrons for field emission after ultrasonic bonding. In addition, the field emission performances of SWCNTs films formed at different bonding conditions were also studied. With a simple nano-bonding apparatus, this technique has low cost, and can be utilized for extensively roboticized fabrication of high performance field emission cathodes with short process time.

1. Introduction

Single-walled carbon nanotubes (SWCNTs) have received considerable attention because of their potential in applications and in new fundamental science. Due to their outstanding mechanical and electronic properties, high aspect ratios, chemical stability and small radii [1].of curvature at the tips, SWNTs are promising candidates, particularly, for cold cathode field emitter, and have exhibited great application as nanoscale building blocks for future nanoelectronics.

Many methods of preparing SWCNT emitter have been developed [2–4], such as direct growth [5], screen-printing [6,7], as well as electrophoretic deposition [8]. However, the disadvantages of uncontrollable experiment conditions in direct growth, organic residues for printing technologies [9], as well as weak adhesion between films and substrates for spraying and electrophoretic deposition hinder the improvement of field emission properties, so it is difficult to be further develop and apply these methods in nanoelectronic field [10]. More recently, researchers proposed that by using a rapid and simple ultrasonic bonding technique, MWCNTs could be firmly bonded to Ti substrate and stable field emitters were formed [11–14]. However, results showed that that turn-on voltage was relatively high, and the effect of bonding parameters on the field emission properties should be further discussed.

In this paper, we demonstrate how to solve the problems listed above efficiently by combining electrophoretic deposition with automatic ultrasonic bonding technology. This method improves the bonding strength, electrical conduction, and field emission properties of SWCNTs film. In addition, the field emission performances of

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SWCNTs films formed under different bonding conditions were also studied, which will provide the basis for the future large-scale manufacture of SWCNTs cathode.

2. Experimental details

For the fabrication of carbon nanotube cathode, the SWCNTs synthesized by the arc-discharge method [15]. were used as starting material. SWCNTs (Purity > 95%) were dispersed in iso-propanol which contained small amounts of dissolved $Mg(NO_3)_2$. The SWCNT electrophoresis suspension was ultrasonically dispersed for 3 h. Fig. 1(a) shows the electrophoresis deposition procedure. The Al plate acts as a cathode and the stainless steel plate acts as an anode. The two electrodes were kept at a constant distance of 2 cm for 15 min, under voltage of 20 V. The sample of sedimentary SWCNTs film was applied to ultrasonic nanobonding.

The automatic ultrasonic nanobonding was operated upon the Nano2000 ultrasonic bonder. The bonding head is made of Al_2O_3 single crystal with a 50 μm² pressing surface. Fig. 1(b) shows a schematic of the ultrasonic bonding process. After the sample was fixed on the workstation, a clamping force of 0.2 N was used to press the bonding head against nanotubes and Al plate. At the same time, an ultrasonic vibration with a frequency of 100 kHz was transferred to the soldering head through an ultrasonic transducer. The SWCNTs and metal were bonded together, which formed a bonding area of 25 mm^2 automatically. Ultrasonic frequency is fixed in the experiments, the bonding force and bonding time is adjustable.

Fig. 1(c) shows a schematic of the emitter. The bonded SWCNTs as the emitter were put at the cathode site. A Cu plate was used as the anode. Two electrodes were spaced 300 μm apart in parallel by mica. The field emission measurements were performed in a vacuum chamber at the pressure of 5.0×10^{-4} Pa. The field emitting area was approximately 25 mm^2. Furthermore, the *I–V* curves of the emitters were also recorded. The emission current density was calculated from the quotient of the obtained emission current divided by the emission area. The surface morphologies of the SWCNTs cathodes were studied using scanning electron microscopy (SEM; Carl Zeiss Ultra 55) at different processing stages.

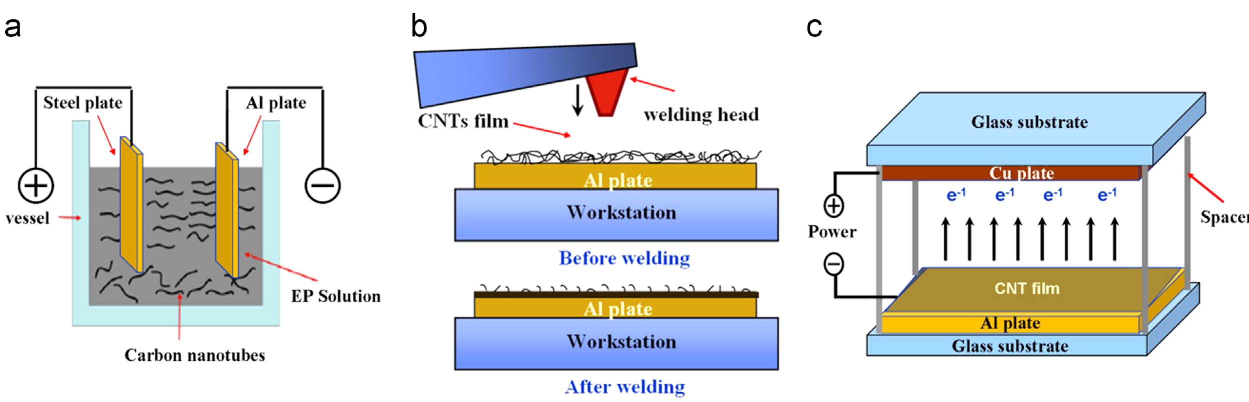

Fig. 1. (a) Electrophoresis deposition process; (b) ultrasonic bonding process; (c) schematic of the emitter.

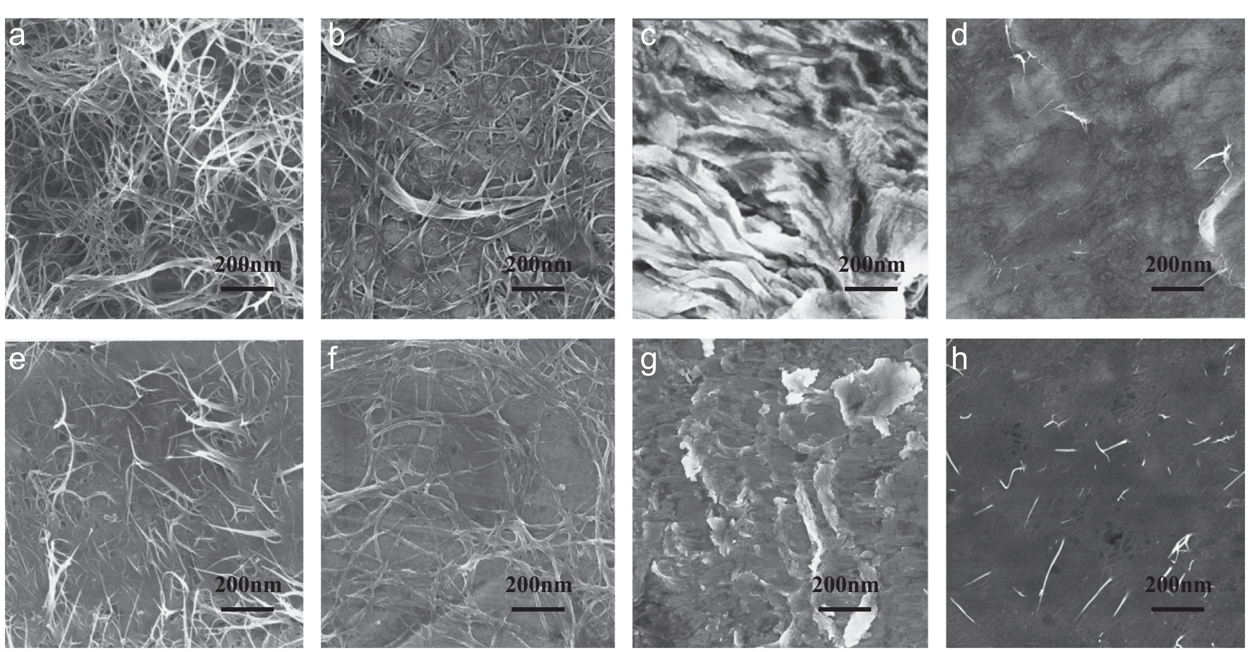

Fig. 2. SEM images of SWCNT–Al: (a) unbonded (b) 50 gf, 200 ms; (c) 250 gf, 200 ms; (d) 250 gf, 100 ms; (e) 150 gf, 200 ms; (f) 150 gf, 100 ms; (g) 150 gf, 300 ms (h) 50 gf, 300 ms.