FIELD ELECTRON EMISSION PROPERTIES OF TIP BENDED CARBON NANOTUBES (CNTS)

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Article history

Received: 30 April 2024

Received in revised form: 27 June 2024

Accepted: 27 June 2024

Published online: 30 June 2024

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ABSTRACT

Field emission is a process of electron emission from a conductor using a strong electric field. The search for finding the best material for field emission has led to significant improvement, especially with nanomaterials. However, no study was conducted on the resultant structure of the M2B process as the material for field emission. In this study, we reported a field electron emission from micro-patterned Vertically Aligned Carbon Nanotubes (VACNTs). VACNTs have been successfully synthesized from an atmospheric CVD system with ethylene as a carbon source. Then, the sample was patterned with a method called micro-mechanical bending (M2B). The method used a rotated tool to move in X-, Y-, Z- direction to compact and bend the VACNTs in the direction of the tool. Interestingly, it could transform the bare VANCTs from black body absorber to become reflective. The surface of the resultant structure has shown a very low surface roughness value at 15 nm with trochoidal motion mark engraved on the surface. A field electron emission study of the CNTs exhibited a turn-on value of 2.76 V mm-1, corresponding to current densities of 100 µA cm-2. Maximum current density was found to be 0.453 mA cm-^{2}.

***Keywords**: CNT Forests, Field Emissions, Micro-Mechanical Bending (M2B) Method*

1.0 INTRODUCTION

The use of CNTs as field electron emitters is considered one of the most promising findings in technological application due to the structures and conductivity exhibited by CNTs. It is commonly known as a potential nanomaterial that has excellent electrical, mechanical, thermal, and optical properties for various scientific applications. Along with these unique properties, their inherent high aspect ratio, sharp tip, low work function, vigorous chemical and mechanical solidity also have made them recognised intensively as an excellent field emitter for electron emission [1]. The excellent field emission of CNTs is highly expected to be applicable in vacuum electronic devices such as X-ray sources [2], microwave devices [3], emission displays [4] and others. The field emission nature of CNTs depends on the deep coating process [5], in situ growth of CNTs tips [6] and electrophoretic process [7]. Moreover, various attempts have been proposed to enhance the field emission performance of CNTs as a potential cathode, such as reducing the field screening effect [8] and synthetization of vertically aligned CNTs [9]. However, no study was conducted on the resultant surface of the post-patterning of CNT forests. In our study, a field emission test has been carried out after surface modification by micro-mechanical processing [10] [11] [12] on CVD-grown vertically aligned CNTs. The main objective of this research is to investigate the field emissive nature of mechanically tip-bent VACNTs for different potential applications.

2.0 MATERIALS AND METHODS

The CNT forest samples were prepared using an atmospheric-pressure chemical vapour deposition (CVD) system on highly doped silicon substrates (<100> n-type, resistivity 0.008-0.015 Ωcm). Aluminium (Al) and Iron (Fe) of 10 and 2 nm, respectively, in thickness, were used as catalysts for the growth. The gases, 140 sccm of ethylene, 400 sccm of hydrogen and 100 sccm of argon were mixed at ~750°C for 15 minutes. The details of the preparation process with specific conditions have been demonstrated by Khalid et al. [12]. Vertically aligned multi-walled CNT array (100's of µm height) was fabricated with areas in the order of cm2 using the process demonstrated (the sample is shown in **Figure 1**).

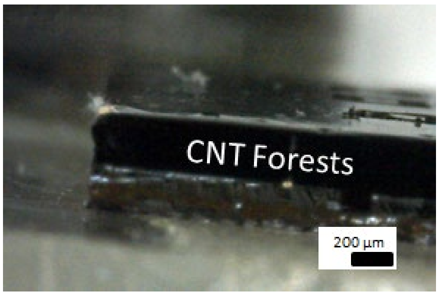

Figure 1: *The image shows grown CNT forests with a thickness of around 350 µm before undergoing the micro-mechanical bending (M2B) process.*

The micro-mechanical bending (M2B) [10-11] process was performed using a servo-controlled 3-axis Micro-CNC system (Mikrotools Ltd, Singapore) with the capability of 1 µm positioning resolution. First, the tool was positioned just above the CNT forest while rotated at 2000 rpm. The µtool (made of tungsten) was shaped with a defined diameter (in this case 300 µm) centrally on the rotational axis using a method called wire electro discharge grinding (WEDG) at various capacitances and voltages [4] of machining. Then, the µtool was programmed to move downward in the Z-direction with a defined step size before moving in the lateral (X- and Y-) directions, as shown in **Figure 2a)**. Step size could be described as the distance in the Z-direction taken by the µtool in each round of scanning (shown in **Figure 2b**)). This technique will create a pattern on the bare CNT forest by the local mechanical manipulation of the CNTs. Patterning parameters was set at 2000 rpm, 1 mm/min lateral speed in x-and y-direction and 1 µm step size until total depth of 60 µm.

PERINTIS eJournal, 2024, Vol. 14, No. 1, pp. 1-7

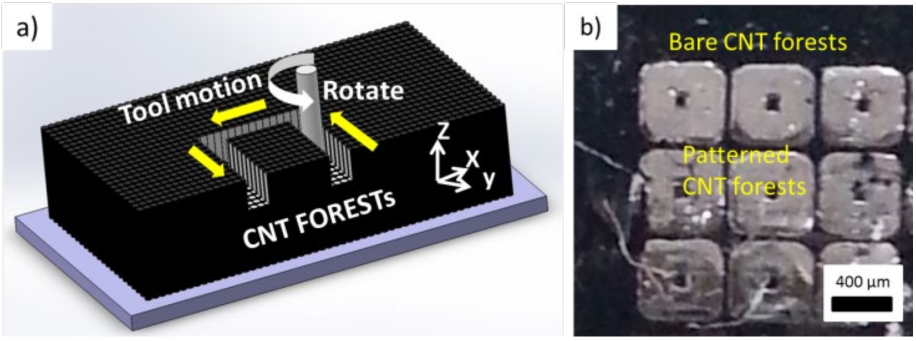

Figure 2: a) *Schematic diagram of the M2B method. b) The top view of the bare and patterned CNT forests shows the difference in surface morphology of the surfaces.*

The electron emission characteristics of the patterned CNT forest samples were conducted using Field Electron Emission (FEE) equipment at the Department of Frontier Materials, Nagoya Institute Technology (NIT), as shown in **Figure 3**. The in-house fabricated FEE equipment consists of a parallel electrode (anode and cathode) inside a vacuum chamber with a pressure of 10^{-4}Pa and a high voltage source measure unit (Hewlett Packard 34401A). This unit was PC-controlled and used to measure the emission current collected by the cathode and the applied voltage (1200 V) between the anode and the sample. The distance between the cathode and anode used was 100 µm.

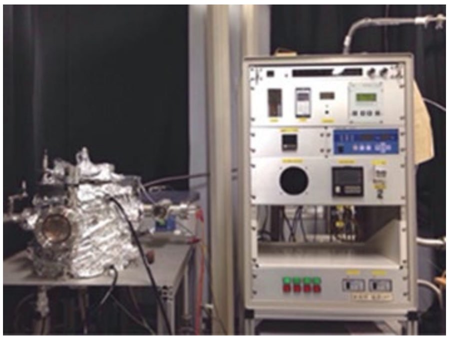

Figure 3: *In-house Field Electron Emission Equipment.*

The theoretical model for the field electron emission from cold cathodes are normally based on the Fowler-Nordheim model [5] which gives the relationship of the current density, J (A/cm^2) and the electric field, E (V/µm) as in **Equation-1**. The Fowler-Nordheim (F-N) plot was obtained by plotting ln J/E^2 as a function of 1/E, as in **Equation-2**.

$$J = A\beta^2 E^2 / \emptyset \exp\left(-\beta \emptyset^{3/2} / \beta E\right) \qquad (1)$$

$$\ln(J/E^2) = \ln(A\beta^2/\emptyset) - B\,\emptyset^{3/2}/\beta E \qquad (2)$$

Where J is the current density, E is the applied field and Ø is the work function (5 eV for carbon). A and B are constants (A = 1.54 x 10^6 A eV V^2 and B = 6.83 x 10^9 eV$^{3/2}$ V/m) and β is the field enhancement factor (FEF) which can be calculated using the slope of the linear part of the F-N plot.

The typical emission current density versus applied electric field (J-E) curve and the corresponding Fowler-Nordheim (F-N) plot of the patterned CNTs were displayed in **Figure 4**. From the J-E curve, the observed turn-on was approximately 2.76 V mm^{-1} which corresponded to current densities of 100 µA cm^{-2}. The maximum current density was found to be 0.453 $mAcm^{-2}$.

3.0 RESULTS AND DISCUSSION

The inset of **Figure 4** (**Figure 4a**) displayed a linear curve, consistent with the F-N equation. This verifies that the observed current is produced by field emitted electrons. The computed effective FEF for the sample was 11,500. Figure 4b displays the emission of light originating from the specifically designed region of carbon nanotube forests. The field emission data obtained, as depicted in **Figure 5**, suggest that the patterned carbon nanotubes (CNTs) achieved through tip bending have comparable field electron emission. This suggestion aligns with the characteristics of a high turn-on field, low maximum current density, and high value. The high turn-on field is due to the following cause. CNT forests without any covering have protrusions of CNT tips that promote electron emission. After performing the M2B method, the surface becomes flattened, and the tip no longer protrudes, instead facing sideways. This arrangement could be the reason for the high turn-on value of the patterned surface of CNT forests.

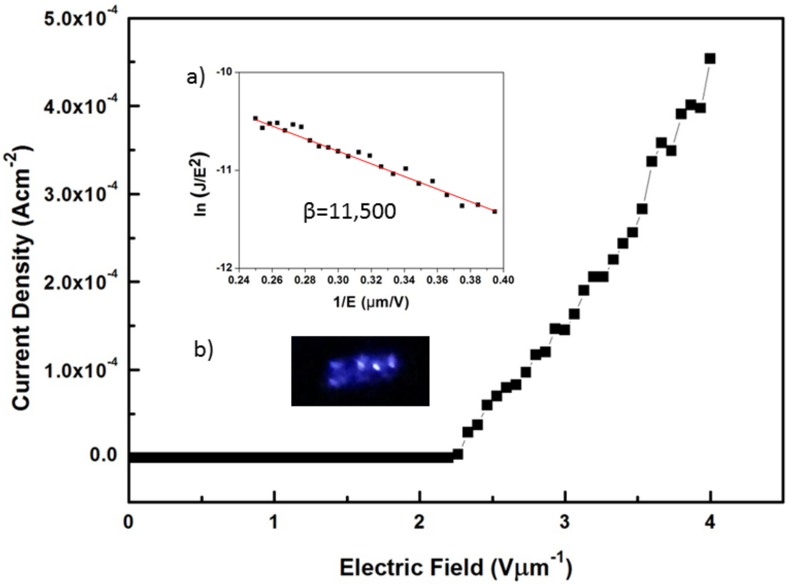

Figure 4: *The J-E property of micro-patterned of CNT forests. The inset figures are (a) the F-N plot and (b) the light emission from the micro-patterned area.*

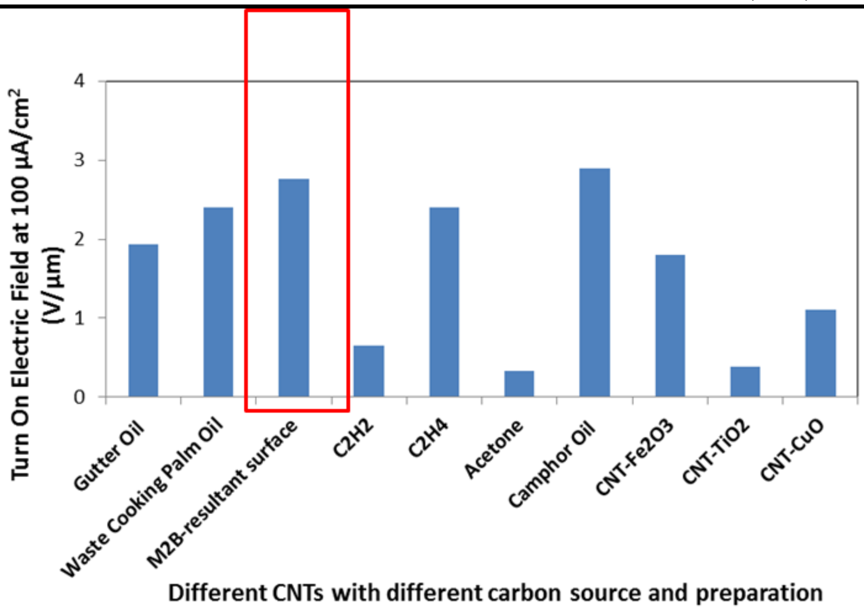

Figure 5: Turn on electric field at 100 μA/cm^2 (V/um) for different CNTs produced from different sources ad preparation.

5.0 CONCLUSION

This is the first time a field emission study has been conducted on the patterned area of CNT forests. CNT forests has been prepared with the post processing technique with M2B process. The turn on value was studied and J-E curve was plotted. The value obtained is comparable to those obtained from the CNTs synthesized from gutter oil [16], waste cooking palm oil [17], C_2H_2 [18], C_2H_4 [19], acetone [20], camphor oil [21] and CNTs-metal oxide composite [22]–[24]. The result is summarized in **Figure 5**. This study is important to explore the potential of patterned CNT forests as field electron emitters.

Acknowledgement

Authors would like to acknowledge IIUM, UPSI, UiTM, and MIMOS for all their invaluable assistance to carry out this research work. This work was financially supported by MOHE (FRGS21-248-0857).

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