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# Field emission of vertically aligned single-walled carbon nanotubes patterned by pressing a microstructured mold

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ABSTRACT

We propose a method of patterning vertically aligned single-walled carbon nanotubes (VA-SWNTs) with the aim of increasing the emission current. We patterned regular arrays of VA-SWNTs by pressing a microstructured Si mold with $2.5 \times 2.5 \times 2.5\ \mu m^3$ cubic holes and a pitch of 5 μm on a VA-SWNT film. We observed that the substrate exhibited field-emission properties, and we determined the effectiveness of the substrate as an electron field-emission array.



## 1. Introduction

Single-walled carbon nanotubes (SWNTs) [1] are nanostructures with the appearance of seamless cylinders, a diameter of about 1 nm and various lengths depending on the synthesis conditions, it has been reported that SWNTs can be synthesized by catalytic chemical vapor deposition (CVD) [2–4]. They have been the subject of focused multi-disciplinary studies because their unique electrical, mechanical and thermal properties indicate their wide range of potential applicability, such as in electrochemical devices, hydrogen storage, field-emission devices, nanometer-sized electronic devices, sensors and probes [5]. Since SWNTs with high aspect ratios are easily fabricated, they have attracted considerable attention as field emitters [6,7]. SWNT vertical aligned on a substrate (VA-SWNT) have well aligned SWNTs with high density and very similar lengths, thus, the electric field at the tops of the SWNTs is too weak for them to be used as emitters. It is necessary to increase the emission current of VA-SWNTs to utilize them for field-emission displays. Concentrating an electric field on the top of VA-SWNTs is expected to increase their emission current. Here, we propose a method of patterning VA-SWNTs by pressing with the aim of increasing the emission current. The electric field at the top of SWNTs with a low density is higher than that for SWNTs with a high density owing to the screening effect [7–10]. Therefore, regular arrays of carbon nanotube blocks are useful for increasing field-emission. In this study, we pressed a mold on a flat VA-SWNT film and patterned regular arrays of SWNT blocks and showed that the patterned SWNT film exhibited field-emission properties.

## 2. Experimental

Fig. 1 shows the experimental procedure. First, we prepared a VA-SWNT film. The method of synthesis and the characterization of VA-SWNT films have been reported in Ref. [2]. Fig. 2 shows a cross-sectional scanning electron microscope (SEM) image of the film. We used a microstructured Si mold with $2.5 \times 2.5 \times 2.5\ \mu m^3$ cubic holes and a pitch of 5 μm to pattern this film (Fig. 3). The mold was pressed on the VA-SWNT film using a pressing machine. Fig. 4 shows a SEM image of the patterned VA-SWNTs. The pressure in the pressing process was 3 MPa. We observed that regular arrays of VA-SWNTs blocks were formed and that the other VA-SWNTs were compressed. To investigate the field-emission properties, we prepared two types of VA-SWNT film and set them in a vacuum chamber through glass coated with indium tin oxide (ITO glass) and connected with a high voltage dc power supply. One was a patterned VA-SWNT film obtained by pressing Si mold with a pressure of 5 MPa, the thickness of which after pressing was 10 μm. The gap between the patterned VA-SWNT film and ITO glass was estimated to be 140 μm. The other was a flat VA-SWNT film, the thickness of which was 30 μm. The gap between the flat VA-SWNT film and ITO glass was estimated to be 120 μm. The base pressure of the vacuum chamber was $1 \times 10^{-3}$ Pa. We compared the field-emission properties of the patterned VA-SWNT film and the flat VA-SWNT film in electric fields of 0–1.9 V/μm range.

## 3. Results and discussion

Fig. 5 shows a current density versus electric field (*I–V*) plots and a Fowler–Nordheim (F–N) plot of the samples with the two

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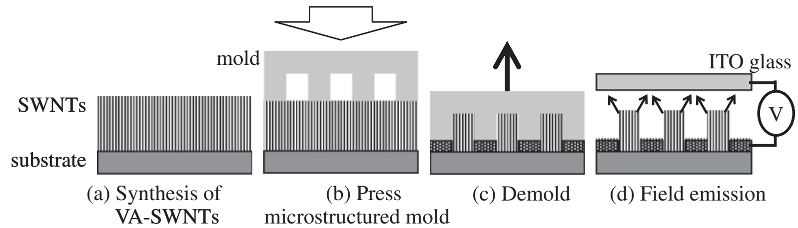


**Fig. 1.** Experimental procedure for achieving field-emission of patterned VA-SWNTs.

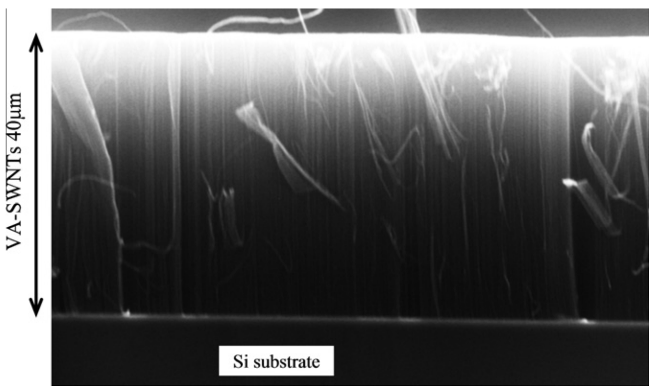


**Fig. 2.** Cross sectional SEM image of a VA-SWNT film.

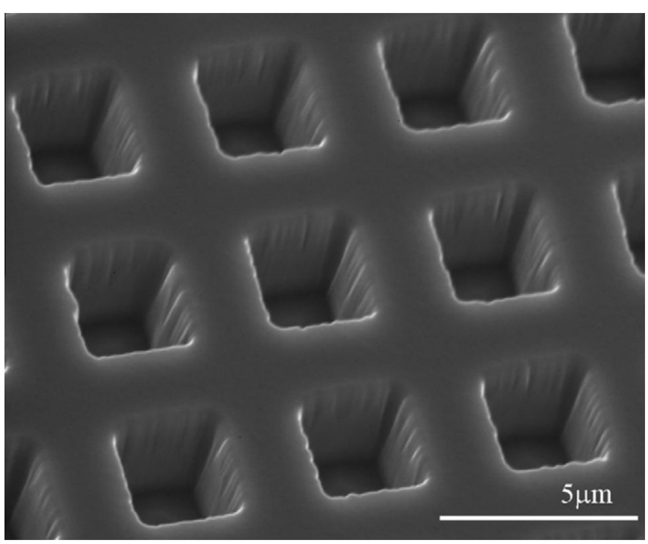


**Fig. 3.** SEM image of Si microstructured mold with $2.5 \times 2.5 \times 2.5\ \mu m^3$ cubic holes and a pitch of 5 μm (tilt angle: 30°).

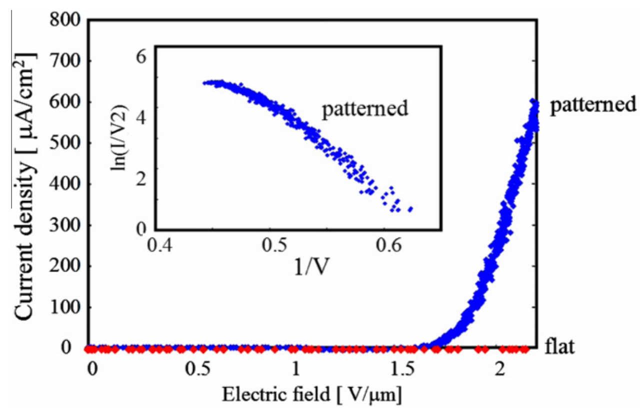


**Fig. 5.** Current density versus electric field (*I*–*V*) plots for VA-SWNT films. The inset shows the Fowler–Nordheim (F–N) plot of the patterned film.

types of the VA-SWNT films. In the case of the patterned VA-SWNT film, typical field-emission current density a carbon nanotube cathode in versus applied electron field characteristics for the diode configuration was observed. The linear F–N plot indicates that the electron emission of VA-SWNTs proceeded from a field-emission process such as the tunneling of electrons through a potential barrier. On the other hand, we observed that the flat VA-SWNT film does not exhibit field-emission properties. This result shows that the patterned VA-SWNT film had obtained field-emission properties.

## 4. Conclusions

We have proposed a method patterning of VA-SWNTs by pressing with the aim of increasing the emission current. We pressed a microstructured Si mold on a VA-SWNT film to form regular arrays of VA-SWNT blocks on the substrate. Then we determined the effectiveness of the substrate as an electron field-emission array and confirmed that the substrate exhibited field-emission properties. Therefore, our method is useful for VA-SWNT films to obtain field-emission properties.

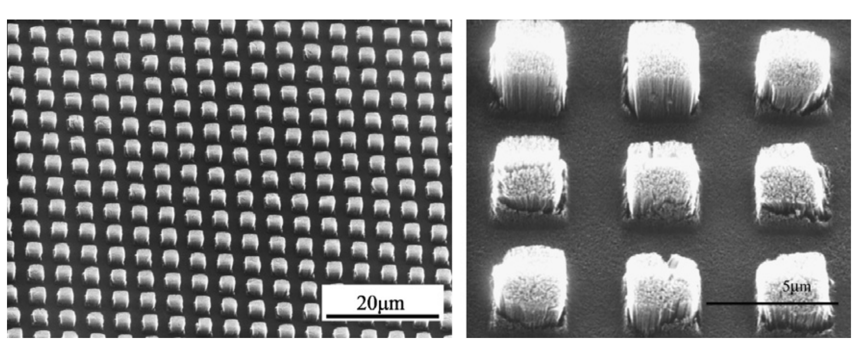


**Fig. 4.** (a) SEM image of patterned VA-SWNTs obtained by pressing of the Si microstructured mold (tilt angle: 40°). (b) Enlarged SEM image of VA-SWNT blocks (tilt angle: 40°).

## Acknowledgments

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