# Selection of isolated and individual single-walled carbon nanotube from a film and its usage in nanodevices*

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Individual and isolated single-walled carbon nanotubes (SWNTs) are important for fabricating relevant nanodevices and studying the properties of the SWNT devices. In this work, we demonstrate that individual and isolated SWNT can be selected and obtained from a film containing a huge number of SWNTs. By using both the polymethylmethacrylate (PMMA) as a negative resist and the electron beam lithography, the selected SWNT can be fixed on a substrate, while the other SWNTs in the film can lift off. The selected SWNT can be used to fabricate nanodevice and a gas sensor of oxygen is demonstrated in this work.

**Keywords:** single-walled carbon nanotube, electron beam lithography, sensor

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## 1. Introduction

Single-walled carbon nanotubes (SWNTs) have aroused great interest due to their potential applications in nanoscale materials and devices since their discovery.[1] The properties of SWNTs, especially the electrical properties (metallic or semiconducting), are very sensitive to their diameter and chirality.[2−6] In the usual growth methods reported, however, SWNTs are usually mixed, entangled and poorly ordered with different kinds of SWNTs by arc discharge,[7] laser ablation[8] or chemical vapour deposition.[9] Thus, a main challenge to the growth of SWNT is how to control its diameter and chirality of SWNT.[10−12] In this work, we demonstrate that an individual and isolated SWNT can be selected and obtained from a film containing a huge number of SWNTs. By using the electron beam lithography combined with thermal metal evapouration or polymethylmethacrylate (PMMA), the desired SWNT can be used to fabricate nanodevices with multiterminals. Its usage as nanosensor of oxygen is demonstrated in this work.

## 2. Experiment

The SWNTs used in this work were grown by floating catalytic chemical vapour deposition (CVD) similar to the methods reported previously.[13−15] A mixture of ferrocene and sulfur (molar ratio = 16 : 1) was used as the catalyst source and sublimed in a temperature range of 60 °C–80 °C. The reaction temperature was 1100 °C and the pressure in the quartz tube was kept constant at ∼ 1 atm (1 atm=1.01325 × $10^5$ Pa). After growing for about 6 h, SWNT films can be obtained to be 20 mm×10 mm in size.

## 3. Results and discussion

Figure 1(a) shows a typical scanning electron microscope (SEM) image of SWNT film. It can be seen clearly that all the SWNTs in the SWNT film are entangled and randomly oriented in the central area of SWNT film. Meanwhile, there are some isolated, straight individual SWNTs on the edge of SWNT film as shown in Fig. 1(b). These individual SWNTs are useful and suited for the fabrication of nanodevices. The main challenge here is how to separate them from the film.

Here in this work, we show that these SWNTs can be obtained and separated from the film by using polymethylmethacrylate (PMMA) and electron beam lithography. As is well known, PMMA is usually used as a positive resist. However, if the PMMA is exposed to a very high dose, it can respond as a negative resist. When it is highly exposed, the PMMA will crosslink such that it becomes a negative resist. When PMMA is used as a negative resist, acetone can be used as the developer and all the uncrosslinked resist will be removed.

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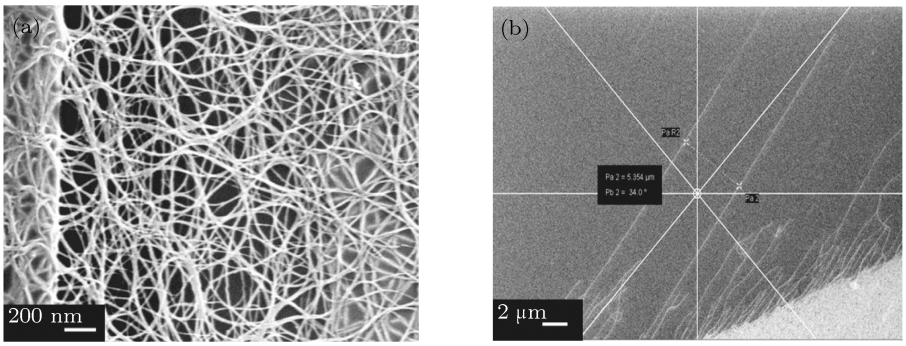



**Fig. 1.** The SEM images of SWNT film: (a) the central area of SWNT film and (b) the edge of SWNT film.

Figure 2 is a schematic diagram showing how to fix the desired individual SWNT onto a substrate. In order to avoid the SWNT film sticking to the substrate, a 150-nm-thick PMMA layer is first spin-coated onto a silicon wafer with a thin insulating $SiO_2$ layer (Fig. 2(a)) and the SWNT film is located on the wafer which is on the PMMA. Then, the individual, isolated and desired SWNT on the edge of SWNT film is selected by using the electron beam lithography system (Raith 150). For simplicity, only the isolated SWNT on the edge of SWNTs film is shown in Fig. 2(b). Finally, another layer of PMMA is coated onto the SWNT film; and the two parts of PMMA across the desired SWNT are exposed to a very high dose as shown in Fig. 2(c).

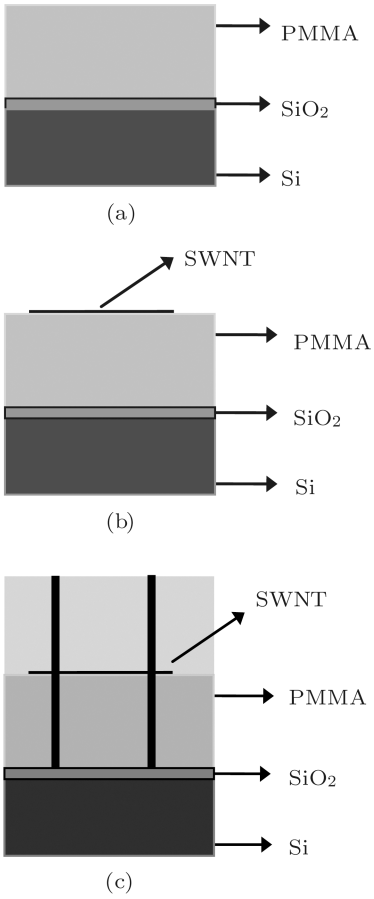



**Fig. 2.** Schematic diagram showing how to fix the desired SWNT onto a substrate. (a) A layer of PMMA that is spin-coated on a silicon wafer with a thin insulating $SiO_2$. (b) The SWNT film that is located on the wafer and is above the PMMA layer. The black line indicates the individual SWNT. (c) Another layer of PMMA that is coated on the SWNT film and the two vertical black columns that represent PMMA.

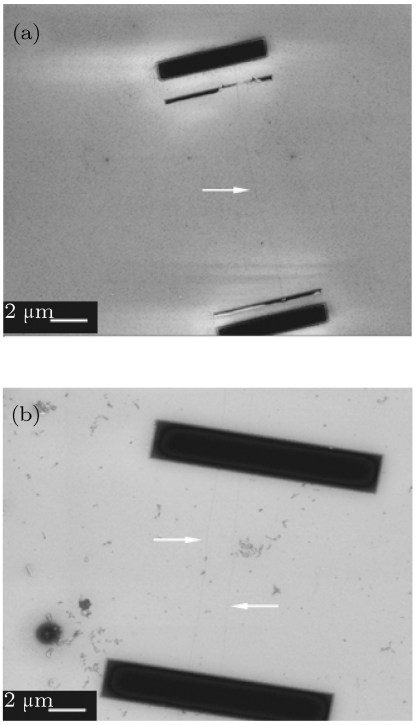



**Fig. 3.** Typical SEM images showing the selected SWNTs and PMMA rectangles after developing by acetone. (a) An individual SWNT that is selected and separated from SWNT film with four PMMA pillars. (b) Two individual SWNTs that are parrallel to each other and obtained by two PMMA pillars.

After exposure, the sample is immersed into acetone for several minutes and blown dry with nitrogen gas. All the uncrosslinked resist will be removed and the exposed parts will be left together with the desired SWNT. Figure 3 shows typical SEM images of the selected SWNT and PMMA rectangles after developing by acetone. In Fig. 3(a), it can be seen that an individual SWNT spans four black PMMA pillars. In Fig. 3(b), another sample of two individual SWNTs is shown, which are parallel to each other and obtained by two black PMMA pillars.

The fabrication of nanodevice by using the selected SWNT is similar to that reported previously.[14] Electron beam lithography patterning, metal evaporation and lift-off process are carried out, and devices with the SWNT are fabricated (Fig. 4). Then, the device is loaded into a steel chamber (0.8 L in volume) that is evacuated to about $10^{-4}$ Pa. The current–voltage ($I$–$V$) characteristic of the device in vacuum is shown in Fig. 5. When high pure oxygen gas of $\sim 1$ atm is introduced into the chamber, the $I$–$V$ characteristic changes, indicating that this device acts as a gas sensor.

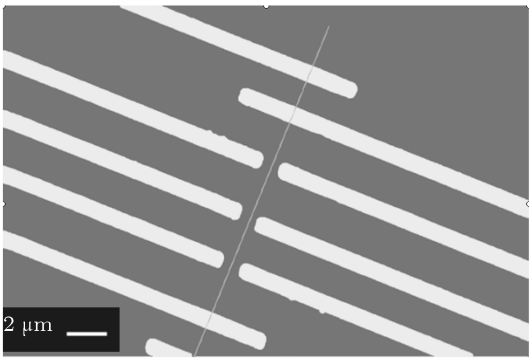



**Fig. 4.** Typical SEM image of nanodevice composed of an individual SWNT and 10 gold electrodes.

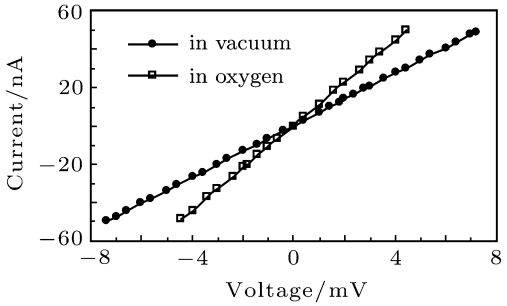



**Fig. 5.** The $I$–$V$ characteristics of the nanodevice when it is exposed to oxygen.

## 4. Summary

In summary, when PMMA is highly exposed, it responds as a negative resist. By using this characteristic of PMMA and the electron beam lithography, the selected SWNT can be fixed on a substrate and the remaining SWNTs can lift off after acetone developing. The selected, individual and isolated SWNT can be used to fabricate nanodevices, which is important and useful for studying carbon nanotubes.

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