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Probing the transport properties of each individual wall within a multiwall carbon nanotubes by electric breakdown

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Conventional transport studies of multiwall carbon nanotubes (MWCNTs) with only the outmost wall contacted to the electrode via *side-contact* (Fig. 1a) shows that a MWCNT is a ballistic conductor with only the outmost wall carrying current. Here we report, using *end-contact* (Fig. 1b) and in high vacuum, the atomic-scale imaging with concurrent transport measurements of the wall-by-wall breakdown of individual MWCNTs inside a high resolution transmission electron microscope (HRTEM) equipped with a scanning tunneling microscope (Nanofactory TEM-STM system). We found unexpectedly three distinct breakdown sequences, namely, from the outermost wall inward, from the innermost wall outward, and alternatively between the innermost and the outmost walls [1]. Remarkably, a significant amount of current drop was observed when an innermost wall is broken, proving unambiguously that every wall is conducting, and a MWCNT is the smallest parallel resistor. Moreover, the breakdown of each wall in any sequence initiates in the middle of the nanotube, not at the contact, proving that the transport is not ballistic but diffusive.

Figure 2 shows that a six-wall nanotube was peeled off layer-by-layer in a sequence from the outmost wall to the innermost wall by high-bias induced thermal breakdown [1]. When passing a current of 240 μA, breakdown occurs midway of the MWCNT, resulting in the formation of a clean 6-wall nanotube segment, which was eliminated wall-by-wall. The loss of one wall under a constant bias of 3 V results in an instant current drop (Fig. 2f). The current drops are approximately: 13, 17, 25, and 31 μA for the 6th, 5th, 4th, and 3rd wall breakdown (the innermost wall is labeled as the 1st wall), respectively. HRTEM indicates that the breakdown eventually results in the formation of either a double-wall nanotube or a single-wall nanotube junction [1-3]. Remarkably, HRTEM detects that each breakdown initiates in the *middle* of the nanotube, *not* at the contact (Fig. 2).

The temperature distribution in the nanotubes is parabolic, with the highest temperature being in the middle of the nanotube, which is estimated to be over 2000 °C at the breakdown voltage of 3 V. We suggest that the breakdown is triggered by resistive heating, thus it is not difficult to understand the breakdown occurs in the middle of the nanotube, starting either from the outermost wall or from the innermost wall.

References

[1] J. Y. Huang et al., Phys. Rev. Lett. 94 (2005) 236802.
[2] S. Chen et al., Appl. Phys.Lett. 87 (2005) 263207.
[3] J. Y. Huang et al. Nature 439 (2006) 281.

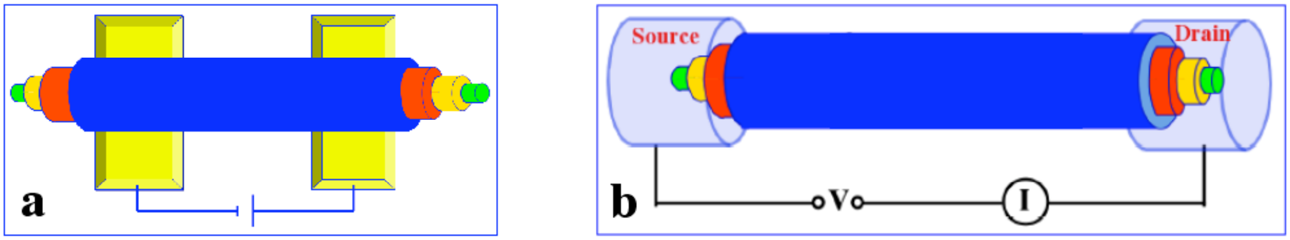

Fig. 1 A schematic drawing showing a side-contact (a) and an end-contact (b) geometry. In the side-contact configuration, only the outmost wall is contacted to the electrodes, while in the end-contact configuration, each wall is contacted to the electrodes.

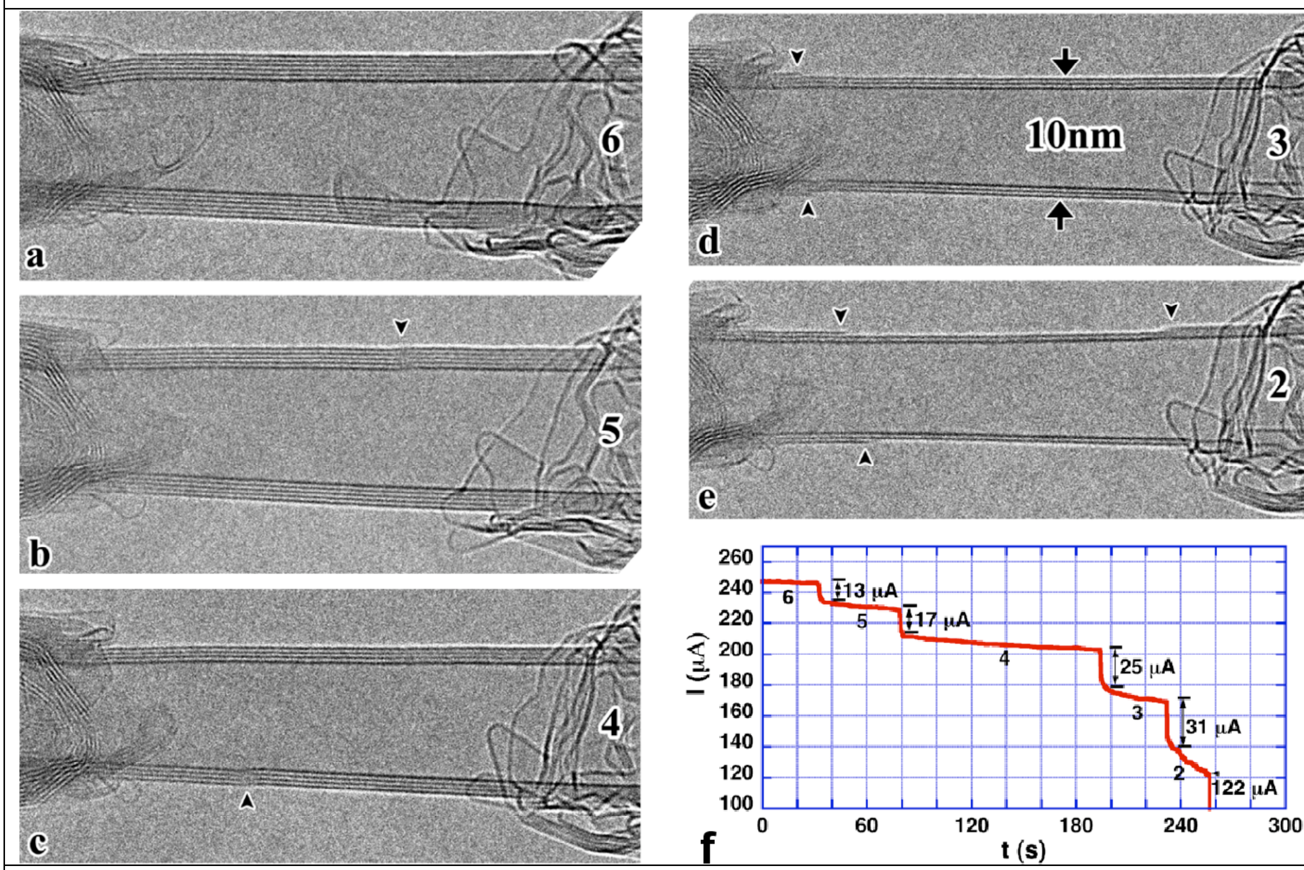

Fig. 2 Sequential HRTEM images showing that the six-wall nanotube is removed wall-by-wall from the outermost wall (a) to the innermost wall (e). The bias voltage is 3 V, and the current flowing in the nanotube is about 240 μA. The numbers indicate the total number of walls. The arrows mark kinks. The arrowheads denote the residue of the 4th and the 3rd walls after breakdown. (f) The elimination of each wall causes a current drop in the I-t curve.

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