Electronic Supplementary Material

Imaging Electronic Structure of Carbon Nanotubes by Voltage-Contrast Scanning Electron Microscopy

Aravind Vijayaraghavan[1,*], Sabine Blatt[1,2], Christoph Marquardt[1,2], Simone Dehm[1], Raghav Wahi[1,§], Frank Hennrich[1], and Ralph Krupke[1,*]

[1] Institut für Nanotechnologie, Forschungszentrum Karlsruhe, D-76344 Eggenstein-Leopoldshafen, Germany

[2] Physikalisches Institut, Universität Karlsruhe, D-76021 Karlsruhe, Germany

[§] Present address: Rice University, Houston, TX 77251, USA

Supporting information to DOI 10.1007/s12274-008-8034-3

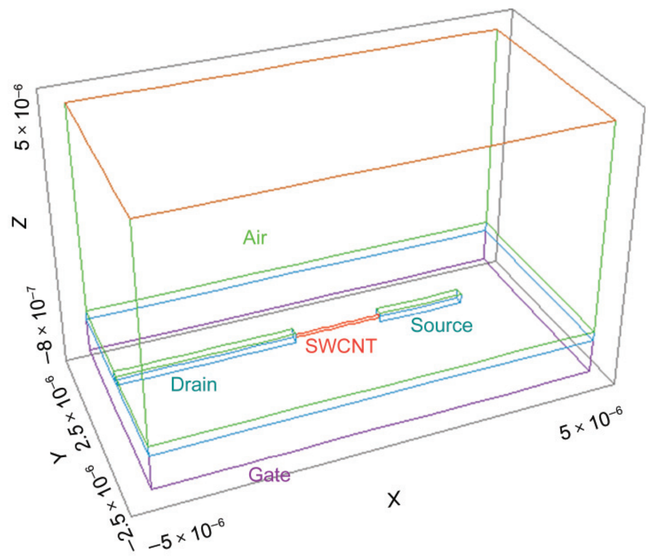

Figure S-1 The layout and dimensions of the simulation space used to model SWCNT device electrostatics. All dimensions are in meters. The drain is assigned a potential of 0 V (grounded), the gate bias is assigned various values (V_G) and the source is floating, and treated as a dielectric with a high dielectric constant ($\varepsilon_r = 10^8$). The gate dielectric (SiO_2) is assigned $\varepsilon_r = 3.9$, air is assigned $\varepsilon_r = 1$ and the nanotube is assigned $\varepsilon_r = 10^8$ for metallic and $\varepsilon_r = 30$ to 10^8 for semiconducting nanotubes to mimic various gate bias conditions

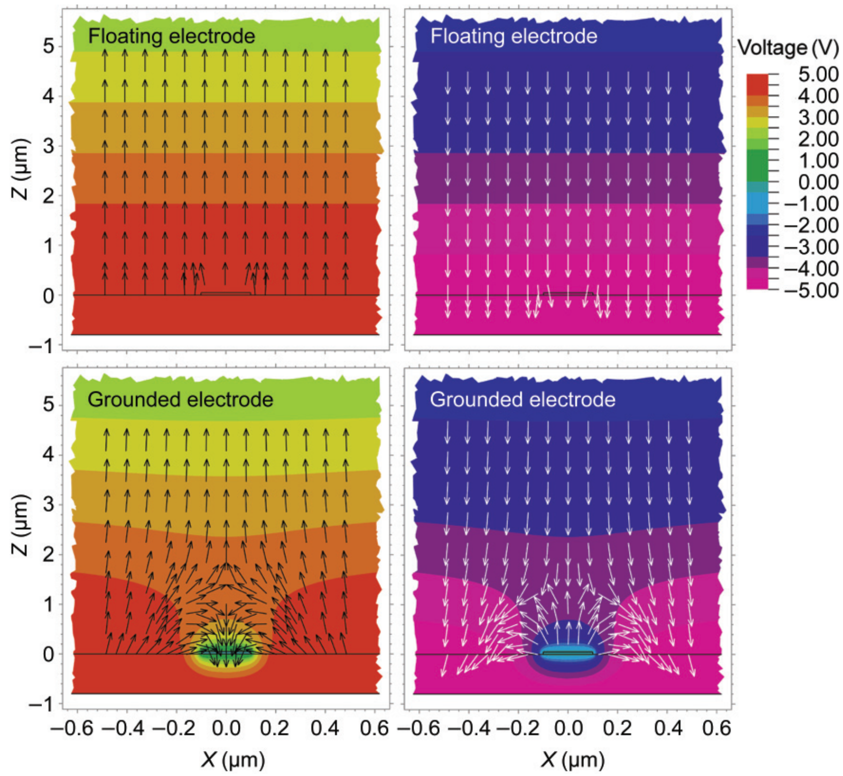

Figure S-2 Potential Φ (background color) and electric field E (arrows) distribution around floating ($V_S = V_G$) and grounded ($V_S = V_D = 0$) surface electrodes (seen in cross-section). The electrodes extend perpendicular to the plane of the image. The force on the electrons is opposite to the direction of the electric field. Positive substrate bias causes electrons to be retarded and shifts their energy distribution to lower energies and reduces the SE yield. Negative gate bias shifts the SE energy distribution to higher energies and increases the SE yield. Floating electrodes acquire a potential similar to that of the substrate and do not significantly distort the electric field distribution. Grounded electrodes are at a different potential compared to the substrate and cause large distortions in the electric field distribution. A region around the electrodes is also affected due to the field distortion

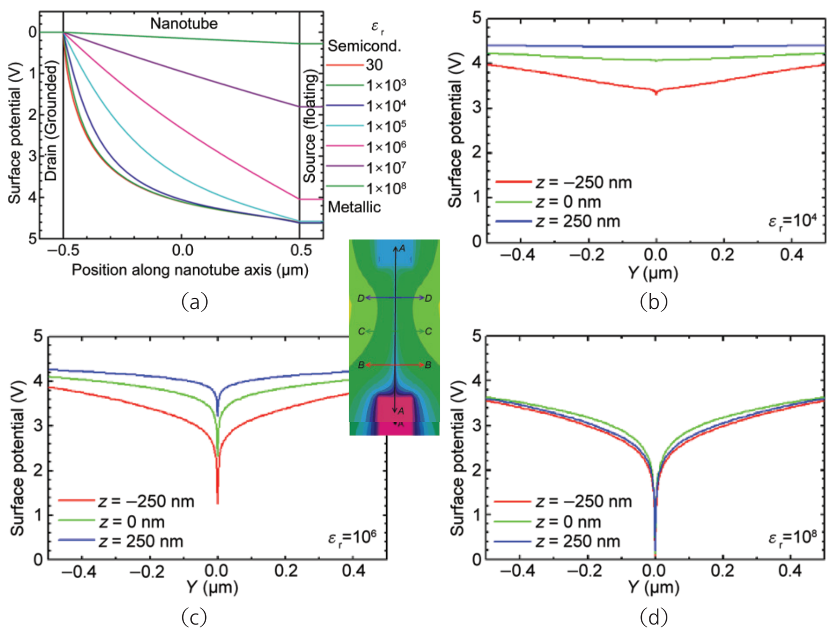

Figure S-3 Simulated surface potential profiles along different sections (shown in the inset). (a) Along the axis of the nanotube (section *AA*) for different values of ε_r ranging from 30 (semiconducting SWCNT at low gate bias) to 10^8 (metallic SWCNT or semiconducting SWCNT at high bias). Intermediate values mimic the transition from insulating to conducting behavior of a semiconducting SWCNT under gate bias. (b)–(d) Across the axis of the nanotube at various positions along its length (sections *BB, CC, DD*), for $\varepsilon_r = 10^4$, 10^6, and 10^8

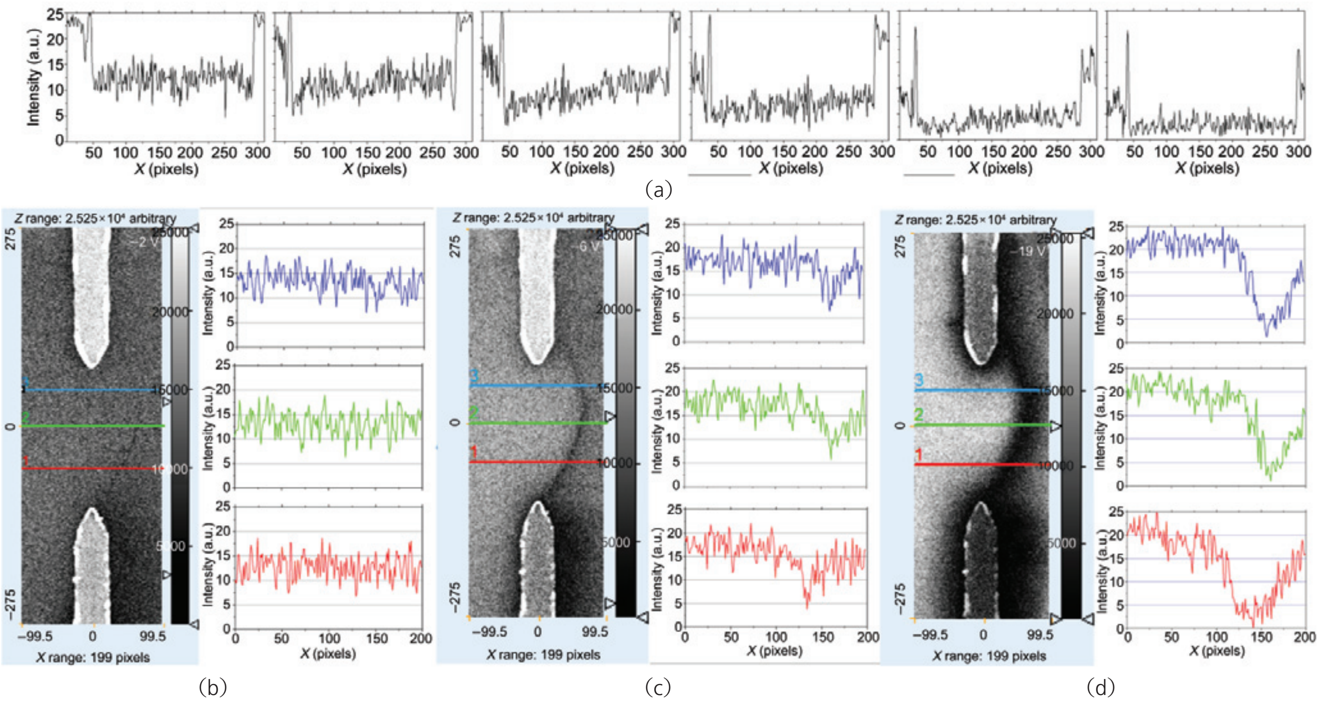

Figure S-4 Experimental contrast profiles at different V_G: (a) along the nanotube for V_G = 0 V, −2 V, −6 V, −9 V, −15 V, −19 V; (b)–(d) across the nanotube at various cross-sections for V_G = −2 V, −6 V, −19 V. The nanotube contrast is broader than the simulated potential profile due to the transverse electric fields around the nanotube that deflect the electrons. The contrast saturates at higher potentials due to the limited width of the energy spectrum (FWHM ~2 eV) of secondary electrons emitted from SiO_2

Supplementary Movie Captions

Movie 1 Sequence of VC-SEM images taken at gate voltage V_G = 0–20 V in steps of 1 V of a representative region of the device array consisting of 10 functional nanotube devices. The common drain (bottom electrode) is grounded and the independent sources (top electrodes) are floating. Devices 2, 4, 7, and 8 are metallic; devices 1, 3, 6, and 9 are semiconducting

Movie 2 Sequence of VC-SEM images taken at gate voltage V_G = 0–20 V in steps of 1 V of a representative region of the device array consisting of 10 functional nanotube devices. The common drain (bottom electrode) is grounded and the independent sources (top electrodes) are floating. Devices 2, 4, 7, and 8 are metallic; devices 1, 3, 6, and 9 are semiconducting

Movie 3 Sequence of VC-SEM images taken at gate voltage V_G = 0–−20 V in steps of 1 V, when zoomed in to device 4 (metallic device) of Supplementary Movies 1 and 2. The common drain (bottom electrode) is grounded and the independent source (top electrode) is floating

Movie 4 Sequence of VC-SEM images taken at gate voltage V_G = 0–20 V in steps of 1 V, when zoomed in to device 4 (metallic device) of Supplementary Movies 1 and 2. The common drain (bottom electrode) is grounded and the independent source (top electrode) is floating

Movie 5 Sequence of VC-SEM images taken at gate voltage V_G = 0–−20V in steps of 1 V, when zoomed in to device 6 (semiconducting device) of Supplementary Movies 1 and 2. The common drain (bottom electrode) is grounded and the independent source (top electrode) is floating

Movie 6 Sequence of VC-SEM images taken at gate voltage V_G = 0–20 V in steps of 1 V, when zoomed in to device 6 (semiconducting device) of Supplementary Movies 1 and 2. The common drain (bottom electrode) is grounded and the independent source (top electrode) is floating