Electronic Supplementary Information

Integrating Carbon Nanotubes to Silicon by means of Vertical Carbon Nanotube Field-effect Transistors

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Fabrication of planar CNTFETs

The top-gated planar CNTFETs have been fabricated on a silicon wafer which was thermally coated with a 500 nm thick SiO_2 layer. First, the source and drain contacts composed of 10-nm Ti and 50-nm Au were fabricated using electron beam evaporation (Denton, base pressure 4×10^{-6} Torr) and lithography. Then, SWCNTs were placed on top of SiO_2 by dropping SWCNT aqueous surfactant solution (Nanointegris, IsoNanotubes-S, semiconductor purity 99%) onto the Si wafer and evaporated the solution at 200 °C. To eliminate the surfactant contamination, the wafer was baked at 250 °C for 0.5 hr. Figure S1 shows the SEM images of the channel and the SWCNTs in the channel. The SWCNT density is 10~15 tubes/μm. Before the deposition of the gate dielectric layer, The SWCNTs beyond the transistor channels were etched using RIE to

isolate the CNTFETs from each other. The power, pressure, oxygen flow and etch time were 150 W, 50 mTorr, 30 sccm and 1 min, respectively. The channel length and width are 20 µm and 160 µm, respectively.

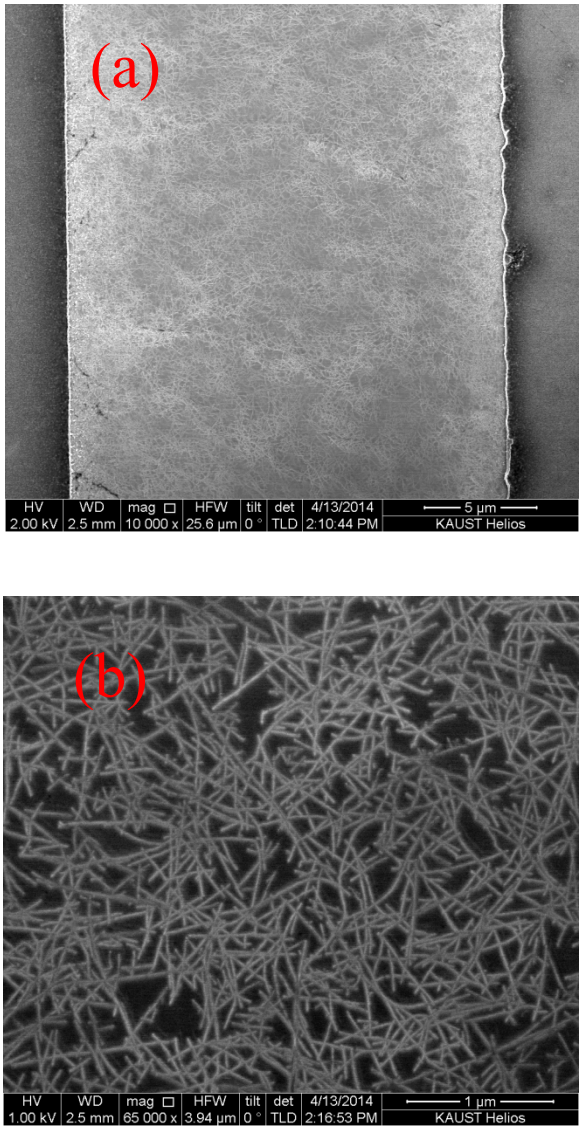

Figure S1. SEM images of a planar CNTFET before deposition of HfO_2 and gate (a) and the SWCNT network in the channel.

The gate dielectrics were of two layers of HfO_2, including 60 nm of electron beam evaporated HfO_2 and 30 nm of ALD HfO_2. After the gate dielectric deposition, the top gate electrode, 15 nm–Ti and 50 nm–Au, was subsequently deposited using electron beam evaporation and lithography. Finally, the source and drain contacts were exposed by etching the gate dielectric layer on top of the contacts using BOE.

Characterization of the planar CNTFETs

The transfer characteristics of the planar CNTFETs are shown in Figure S2 and Figure S3 for positive and negative V_d, respectively. It can be seen clearly that the planar CNTFETs exhibit ambipolar characteristics at any drain voltages, i.e., the transfer characteristics do not depend on the sign of the drain voltage.

The transconductance of the planar CNTFETs is in the range of 1.7~6 μS. Using L = 20 μm, W = 160 μm, $C_Q = 4\times10^{-10}$ F/m, Λ_0^{-1} = 10~15 tubes/μm, d = 1.4 nm, t_{ox} = 90 nm and ε_{ox} = 14 for mixed HfO_2, the mobility extracted from these CNTFETs using equation (1) and (2) is in the range of 5.9~15 $cm^2/V{\cdot}s$.

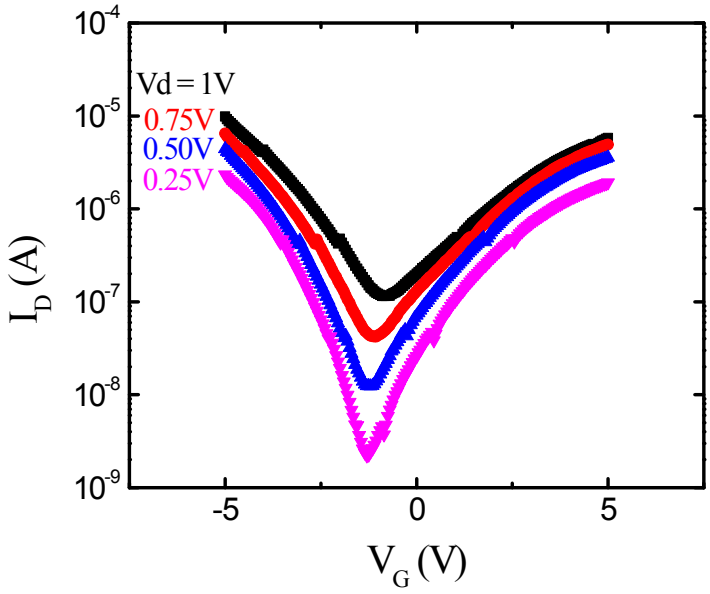

Figure S2. Transfer characteristics of the planar CNTFETs at positive drain voltage. The black, red, blue and purple curves are for V_d = 1 V, 0.75 V, 0.5 V and 0.25 V, respectively.

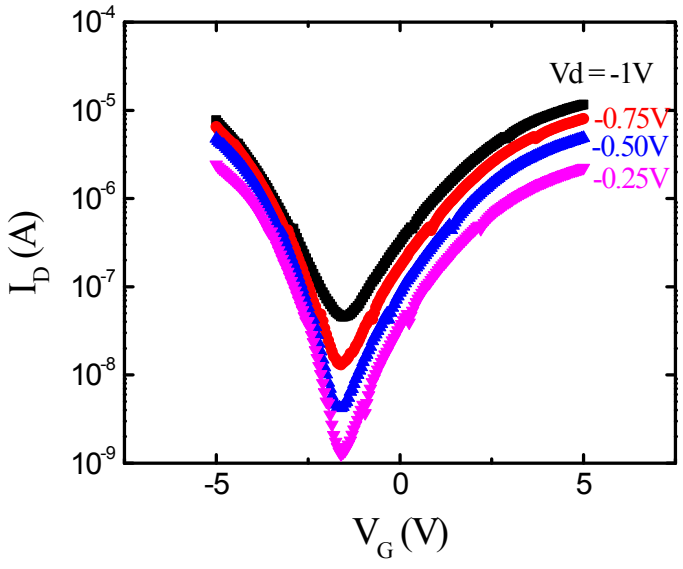

Figure S3. Transfer characteristics of the planar CNTFETs at negative drain voltages. The black, red, blue and purple curves are for V_d = -1 V, -0.75 V, -0.5 V and -0.25 V, respectively.