Supporting Information for

**Electronically Pure Single Chirality Semiconducting Single-Walled Carbon
Nanotube for Large Scale Electronic Devices**

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Experimental Details

Materials: Single-walled carbon nanotubes raw powder was produced by Rice University Mark III high pressure carbon monoxide reactor using less catalyst in a yield of 1 gram per hour.

In a 100 mL beaker, the mixture of 100 mg SWCNTs raw powder and 100 mL of 2% sodium dodecyl sulfate (SDS, 99+% pure) aqueous solution were dispersed into 1 mg/mL solution using an ultrasonic processor (Cole Parmer, 20 W) equipped with a 0.5-inch Ti flat tip for 20 hours under continuous water cooling. The residue catalyst, large nanotube bundles and other impurities were removed via ultracentrifugation using a Beckman TL-100 ultracentrifuge equipped with a TLS-55 rotor. The top 90% of the supernatant was collected as the starting solution for gel chromatography.

Gel chromatography purification of SWCNTs was performed using in-house packed columns packed with allyl dextran-based gel beads following a similar protocol in the literature.⁷ Briefly, a 50 mL of supernatant SWCNT solution was loaded to a column packed with 6 mL gel. The unabsorbed SWCNTs were washed off with 2% SDS solution and the adsorbed SWCNTs on the column were eluted using 5 % SDS solution. The unabsorbed SWCNTs were then load to the column and eluted in the same way for four times. The (6,5) enriched fractions from the elution was then subjected to fine purification by repeating gel chromatography 4-6 times using gradient SDS/SC elution system. Roughly about 50 mL of pure (6,5) SWCNT purple solution was collected in a concentration of 6 µg/mL within 1 day.

The molar extinction coefficient of the S_{11} exciton in (6,5) SWCNTs is around $4400 \text{ M}^{-1}\text{cm}^{-1}$,^{1,2} the S_{11} peak height of our stock solution is ~ 2.1 , so the concentration is $\sim 6 \mu\text{g/mL}$ for the stock solution suspended in 10:1 surfactant mixture. For the 5% SC (6,5) solution used for coating, the concentration would be ~ 3 times higher than the surfactant mixture system.

$$\text{Concentration} = \frac{\text{Abs cm}^{-1}}{4400 \text{ M}^{-1}\text{cm}^{-1}} \times 12 \text{ g} \cdot \text{mol}^{-1} = \frac{2.1}{4400} \times 12 \text{ g/L} = 5.7 \mu\text{g/mL}$$

The 2% SDS dispersed (6,5) SWCNT solution (15 mL, 6 µg/mL) was then converted into 5% sodium cholate (SC) dispersed (6,5) SWCNT solution (6 mL, 15 µg/mL) on allyl dextran-based gel column.

Device Fabrication: Substrates including Borofloat 33 glass (Diameter: 100 mm, Thickness: 500 µm), Silicon wafer (SiO₂ thickness: 500 nm) and quartz were treated with UV Ozone Cleaner (Jelight Model 42) for 15 minutes. After poly(L-Lysine) aqueous solution (0.1weight%) flew through the substrates, the substrates were extensively washed with de-ionized water. The substrates were blown dry and further had 5% SC dispersed (6,5) SWCNT solution (15 µg/mL) to flow through. Then the substrate was baked on hotplate at 110 °C for 10 minutes and followed with extensively washing with de-ionized water. The substrates were again blown dry and annealed in vacuum oven at 200 °C for 2 hours. Thus clean (6,5) SWCNT was uniformly coated on substrates. The size of substrates can be as large as 120 inch in diagonal for Gen10 manufacturing line.

Drain/Source electrodes were patterned with photolithography using AZ2020 photo resist gel. The 10 nm Cr (0.5 A/s rate, 16% power) and 40 nm Au (3A/s rate, 22% power) were deposited in sequence using Sloan E-Beam, and lift-off using acetone. For Pd electrodes, 40 nm Pd (3A/s rate, 22% power) was deposited using Sloan E-Beam, and lift-off using acetone.

The (6,5) SWCNT thin film was patterned with photolithography using AZ 5214 photo resist gel. The unpatterned (6,5) SWCNT thin film was etched with O₂ plasma (100 sccm flow, 100 W) using Oxford RIE and then patterned photo resist were stripped off using acetone immediately.

The 170 nm SiN_x was deposited with plasma enhanced chemical vapor deposition (225°C, N₂ 100sccm, He 400sccm, NH₃ 10sccm, SiH₄ 5.3 sccm). The 30 nm HfO₂ was deposited with atomic layer deposition (CH₃-TEMAH-200-H₂O at 200 °C, 0.1 nm/cycle rate).

Gate electrodes were patterned with photolithography using AZ2020 photo resist gel. The 10 nm Cr (0.5 A/s rate, 16% power) and 90 nm Au (3A/s rate, 22% power) were deposited in sequence using Sloan E-Beam, and lift-off using acetone. For Pd electrodes, 90 nm Pd (3A/s rate, 22% power) was deposited using Sloan E-Beam, and lift-off using acetone.

Drain/source pads were opened with photolithography using AZ 5214 photo resist gel. The deposited SiN_x or HfO₂ above drain/source pads were dry etched using Oxford RIE (3 sccm O₂, 30 sccm CHF₃).

Gold electrodes were aerosol jet printed using 4 nm gold nanoparticles in xylene (40weight%) and cured at >200 °C for 30 minutes. Silver paste (SPI Chem ERL 4221 Epoxy Plasticizer) was used to bond copper wire (0.5 mm in diameter) on substrates.

SiN_x top-gated (6,5) SWCNT TFTs were wire-bonded with HfO₂ top-gated (6,5) SWCNT TFTs using wedge bonder of the center for high frequency electronics at University of California Los Angeles.

Measurements: The Vis-NIR absorption, NIR fluorescence emission (excited at 532 nm) and Raman spectroscopy (excited at 532 nm) of (6,5) SWCNT purple solution were measured on NS3 NanoSpectralyzer.

SEM image of (6,5) SWCNT thin film was imaged with Stanford Nova NanoSEM.

The current-bias curves, transfer characteristics, output characteristics and voltage output characteristic of Schottky diodes, NMOS and PMOS TFTs and CMOS inverters were measured with Keithley 4200 SCS on SemiProbe PS4L M12 probe station. The current-bias curves of copper wire (0.5 mm in diameter) bonded Schottky diodes were tested with alta DCA Pro from PEAK Instruments.

Fig S1. The measured current versus bias curve showing linear curve when probed on two electrodes on Nanointegris 99% semiconducting single-walled carbon nanotubes.

Figure S2. The histogram of (6,5)SWCNT lengths extracted from SEM images.

Figure S3. The SEM and AFM images of coated (6,5) SWCNT thin films.

Fig S4. The typical transfer characteristics of SiN_x top-gated Nanointegris 99% semiconducting SWCNT TFT with channel width of 50 μm by sweeping V_{Gate} from -5 V to 20 V (right I_{DS} is linear scale and left I_{DS} is log scale) under $V_{\text{DS}}=0.1$ V.

Fig S5. The output characteristics of SiN_x top-gated (6,5) SWCNT TFT with channel width of 50 μm showing downward bending curves by sweeping V_{DS} from 0V to 5V.

Figure S6. The statistical analysis of $I_{\text{ON}}/I_{\text{OFF}}$ ratio for NMOS (6,5) SWCNT TFTs with different channel widths.

Figure S7. The transfer characteristics of NMOS (6,5) SWCNT TFTs with channel width of 50 μm before and after 10 V bias stress for 1 hour.

Figure S8. The transfer characteristics of NMOS (6,5) SWCNT TFTs with channel width of 50 μm , $V_{DS}=10$ V.

Table S1. Average threshold voltages of SiN_x top-gated (6,5) SWCNT TFTs with different channel widths.

Channel (width:length)	5:5	25:5	50:5	75:5	100:5
Average V _{th}	0.95	0.70	0.76	0.61	0.59
# of valid data	109	127	333	82	144

References:

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2. Streit, J. K.; Bachilo, S. M.; Ghosh, S.; Lin, C.-W.; Weisman, R. B. Directly Measured Optical Absorption Cross Sections for Structure-Selected Single-Walled Carbon Nanotubes. *Nano Lett.* **2014**, *14*, 1530-1536.