1. Sample Preparation and TCR Characterization

We first prepare suspended silicon microstructures using a silicon-on-insulator (SOI) process using a one-mask process to define the silicon microstructures and wet chemical etching to release the free-standing silicon microstructures. The silicon microstructure is highly doped p-type (p^+) single-crystalline silicon, with a resistively of $1\times10^{-2}\Omega$-cm (impurity concentration of 1×10^{19}cm^{-3}). The typical width and length of the silicon microstructures are 5µm and 150µm, respectively, and the thickness is 15µm. A 5-nm-thick Ni-Fe (80%–20% by weight) mixture is evaporated to serve as the catalyst without using a mask. The synthesis is conducted in a room temperature vacuum chamber of 3×10^4 Pa with acetylene (C_2H_2)-Ar mixture gas (55 sccm–60 sccm) after the growth structure had been heated to high temperature. The temperature coefficient of resistance (TCR) of the same MWCNT used in all experiments is measured with input current < 0.5 µA in a temperature controlled chamber and is approximated as a linear response in this region.

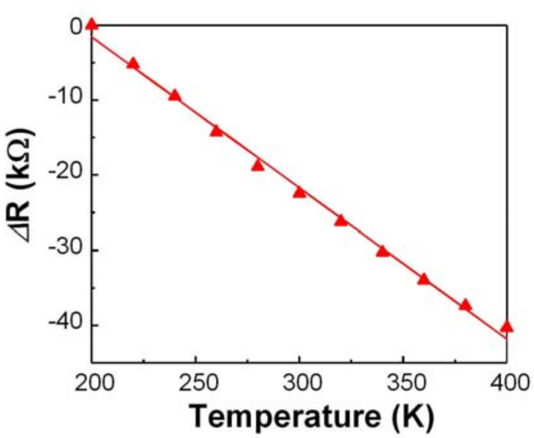

Figure 5. Measurements used to determine the temperature coefficient of resistance. The MWCNT change in resistance versus temperature plot is used to approximate the TCR.

2. Electrothermal Model

A one-dimensional electrothermal model can be derived based on the principle of energy conservation by considering a small length, dx, on the MWCNT:

$$k_{CNT} A \frac{\partial T_{CNT}}{\partial x}\Big|_{x+dx} - k_{CNT} A \frac{\partial T_{CNT}}{\partial x}\Big|_{x} - K_g (T_{CNT} - T_0)\pi D_{CNT} dx + J^2 \rho_0 [1 + TCR(T_{CNT} - T_0)] A dx = 0$$

Where K_g represents the heat transfer coefficient via gas, D_{CNT} is the MWCNT diameter, J is the current density, and ρ_o is the resistivity at the temperature of T_0. A differential equation can be organized by defining $k_g \equiv \frac{K_g \pi D_{CNT}}{Ap}$ as:

$$k_{CNT} \frac{\partial^2 T}{\partial x^2} - k_g (T_{CNT} - T_0) p + J^2 \rho_0 [1 + TCR(T_{CNT} - T_0)] = 0$$

This equation is solved by boundary conditions to give the temperature profile. The resistance of the MWCNT is then calculated based on the temperature profile and TCR. By curve fitting, we extract the value of k_{CNT} and the thermal conductivity of the gases and observe excellent consistency between the model and the experimental data.