Modulation-Doped Multiple Quantum Wells of Aligned Single-Wall Carbon Nanotubes

Natsumi Komatsu[1], Weilu Gao[1], Fumiya Katsutani[1], Cheng Guo[2], and Junichiro Kono[1,3,4]

[1] *Department of Electrical and Computer Engineering, Rice University, Houston, Texas 77005, USA*
[2] *Department of Applied Physics, Stanford University, Stanford, California 94305, USA*
[3] *Department of Physics and Astronomy, Rice University, Houston, Texas 77005, USA*
[4] *Department of Materials Science and NanoEngineering, Rice University, Houston, Texas 77005, USA*

Doping, alloying, and combining traditional semiconductors are at the core of today's technologies, and there is considerable interest in constructing 3D architectures of low-dimensional materials with tailored electrical and optical properties [1]. In this study, we have fabricated a structure consisting of multiple thin layers of aligned single-wall carbon nanotubes (SWCNTs) with dopants inserted between the layers [2]. The individual layers were ~20 nm in thickness and 2 inches in diameter, containing SWCNTs that spontaneously aligned during vacuum filtration [3]. Figure 1a shows a scanning electron microscopy image of highly aligned and packed SWCNTs in a 2-inch-diameter film, demonstrating that the vacuum filtration method is indeed scalable. Multiple films were combined vertically by stacking, while inserting dopants between layers at the same time (Fig. 1b). The extinction ratio (ER) value, defined as $-\log(T_{\parallel}/T_{\perp})$ where $T_{\parallel}$ ($T_{\perp}$) is the transmittance for the parallel (perpendicular) polarization, increases linearly with increasing number of layers (Fig. 1c), suggesting that alignment and dense packing are well preserved during the stacking process. Figure 1d shows that this unique 3D architecture of doped SWCNTs works as an excellent terahertz (THz) polarizer with an ultrabroadband working frequency range (from ~0.2 to ~200 THz), a high ER (20 dB from ~0.2 to ~1 THz), and a low insertion loss (<2.5 dB from ~0.2 to ~200 THz), exceeding the performance of previously reported THz polarizers based on aligned SWCNTs [4].

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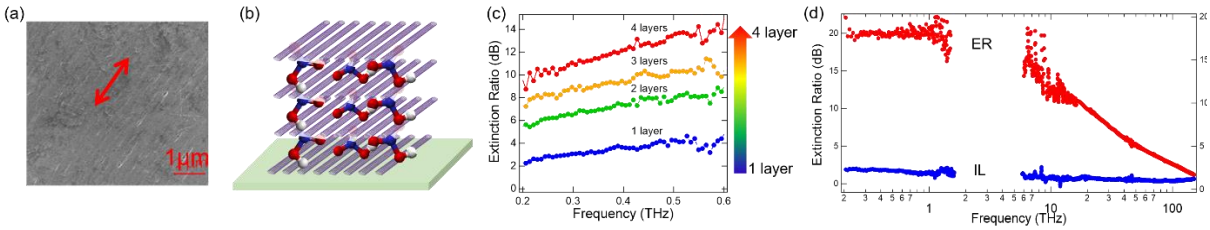

Fig. 1 (a) A scanning electron microscopy image of a highly aligned and packed SWCNT film. (b) A schematic of a fabricated structure of aligned and modulation-doped SWCNTs. (c) Effects of stacking on the THz response of aligned SWCNT films. ER value as a function of frequency in THz. (d) ER and insertion loss (IL) of stacked, modulation-doped aligned SWCNT films in the range of 0.2–200 THz. The frequency axis is on a logarithmic scale.