Exciton and Trion Electroluminescence from Aligned Carbon Nanotube Films

Ali Mojibpour[1], Motonori Nakamura[2], Saunab Ghosh[1], Natsumi Komatsu[1], Kazuhiro Yanagi[3], Yohei Yomogida[3], and Junichiro Kono[1,*]

[1]Department of Electrical and Computer Engineering, Rice University, Houston, Texas 77005, USA, [2]Department of Systems, Control and Information Engineering, National Institute of Technology, Asahikawa College, Asahikawa, Hokkaido, 071-8142, Japan, [3]Department of Physics, Tokyo Metropolitan University, Tokyo 192-0372, Japan
E-mail: kono@rice.edu

Charged excitons, or trions, have attracted much interest due to their nonzero charge and spin, which can be utilized to control optical properties by external electric and magnetic fields. While the trion binding energy is on the order of a few to tens of meV in two-dimensional systems based on III-V semiconductors and transition metal dichalcogenides, in semiconducting single-wall carbon nanotubes (SWCNTs) the trion binding energies are significantly increased due to enhanced Coulomb interactions, characteristic of one-dimenaional systems, to ~200 meV [1]. Therefore, they are easily observable even at room temperature. However, their formation and emission properties, especially in device settings, have not been well understood. Furthermore, their polarization properties have not been explored well, compared to neutral excitons.

Here, we study electrical creation of excitons and trions in light-emitting devices based on films of highly aligned, densely packed, and single-chirality (6,5) SWCNTs. These films were prepared using the controlled vacuum filtration method [2,3], with minimum surfactant presence and without any polymer wrapping to provide high electrical conductivity and enhanced hole transport. Gold contacts with a 7-μm channel length were patterned by photolithography followed by a lift-off process using acetone. The SWCNT film was then transferred onto the contacts and patterned into a 50-μm channel width, as shown in Fig. 1(a).

The device was biased by a Keithley 2636B, and electroluminescence (EL) from the device was collected by a long working-distance objective lens (f = 200 nm) with a numerical aperture of 0.42. The collected EL emission was then fed into an Acton SpectraPro-300i spectrometer equipped with a liquid-nitrogen-cooled 2D InGaAs camera.

Through impact excitation, electron-hole pairs were created, which then recombined to exhibit exciton and trion emission from the SWCNT channel; see Fig. 1(b). A typical EL spectrum for the device showed two distinct peaks, as shown in Fig. 1(c). By comparing EL and the photoluminescence (PL) spectra for doped and undoped SWCNT films, we were able to ascribe the observed peaks to emission from neutral excitons and trions, respectively. Through position-resolved spectrum analysis, we observed that the EL spectrum varies across the channel. Since the rate of the conversion of neutral excitons to trions depends on the number of charges surrounding the excitons, the spatial dependence of the EL spectrum can be attributed to nonuniform charge transport inside the channel.

Furthermore, we observed that SWCNTs aligned in the direction of the current flow produce stronger light emission than those aligned in the perpendicular direction. This increase can be in terms of increased conductance in the direction of alignment. In addition, the EL was polarized along the SWCNT axis independent of the current direction; Fig. 1(d) shows the EL for the case of SWCNTs aligned parallel to the current.

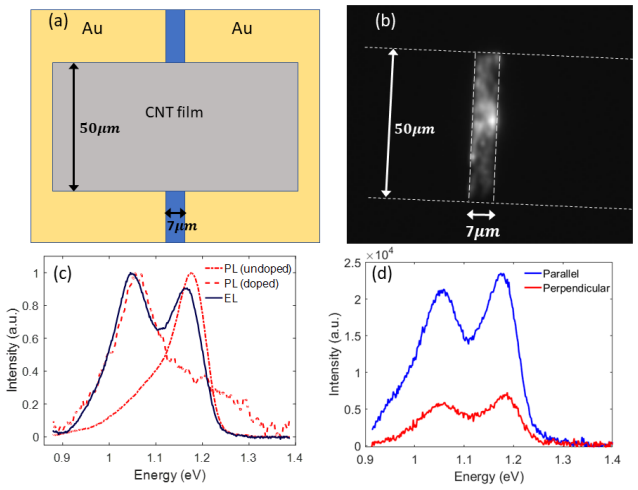

Figure 1. (a) Schematic illustration of the aligned (6,5) SWCNT based light-emitting device. (b) Near-infrared camera image of the EL emission from the device. (c) PL spectra for doped and undoped (6,5) SWCNTs superimposed on the EL spectra collected from the device. (d) EL emission is polarized parallel to the SWCNT alignment.

In conclusion, highly aligned (6,5) single-wall carbon nanotube thin films were employed to fabricate light emitting devices with polarized emission. The effect of alignment of SWCNT in the direction of the current was then compared with alignment perpendicular to the current.

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