Electronic Supplementary Material (ESI) for Nanoscale.

Supporting Information

Solid state carbon nanotube device for controllable trion electroluminescent emission

Shuang Liang,[†] Ze Ma,[†] Nan Wei,[†] Huaping Liu,[ζ,‖] Sheng Wang,[†,*] Lian-Mao Peng[†,‡,*]

[†]Key Laboratory for the Physics and Chemistry of Nanodevices, Peking University, Department of Electronics, Peking University, Beijing 100871, China, [‡]Academy for Advanced Interdisciplinary Studies, Peking University, Beijing 100871, China.

[ζ]Beijing National Laboratory for Condensed Matter Physics, Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China.

[‖] Collaborative Innovation Center of Quantum Matter, Beijing 100190, China.

[*]Address correspondence to shengwang@pku.edu.cn, lmpeng@pku.edu.cn

Part 1: The EL mechanism and characteristics of the CNT films in this research.

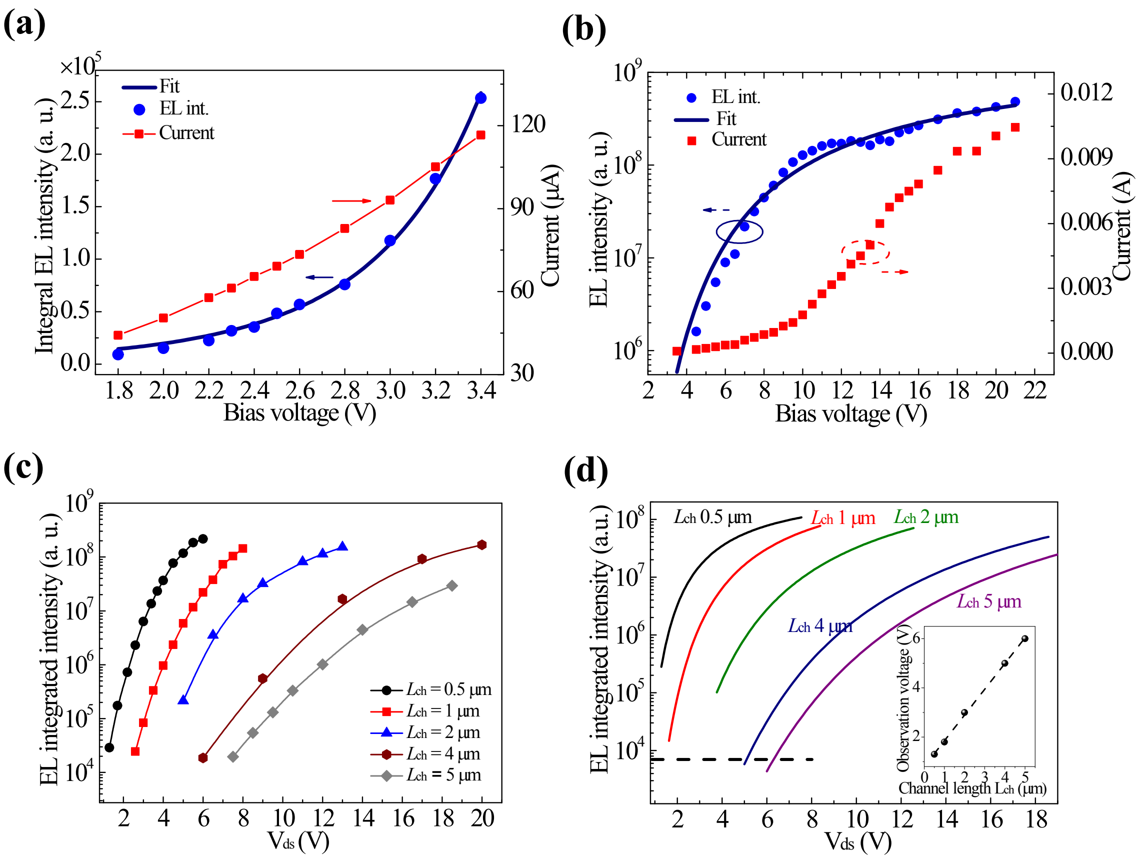

Figure S1. (a) The emission intensity dependence on a small voltage scale of 1.8-3.4 V. (b) The dependence within a large voltage scale of 3.5-22 V. (c) The dependence of EL intensity on the channel length (L_{ch}) and the bias. (d) The simulation results of EL intensity on the L_{ch} and the bias, and the observation voltage (inset) can have a consistency with the experimental observation.

We show the dependence of integrated emission intensity on the bias and the current, and the fit curves according to impact excitation equation reveal that the emission intensity is proportional to impact excitation rate,[1,2] shown in Figure S1a-b. By L_{ch} scaling method (Figure S1c), the obvious variation in EL intensity can be obtained. These experimental observations can be explained by impact excitation mechanism, which is exponentially sensitive to source-drain bias V_{ds}, and for the first time, we infer that the voltage-shared behavior by more excitation regions in longer channel is the primary cause for this observation shown in Figure S1c-d. Assuming emission sites equiprobably distribute along channel regions, thus the scaling of L_{ch} will lead to two important variations: the increase in the number of excitation sites ($\propto$ luminescence coefficient A_L before the equation), and reduced excitation voltage around excitation sites ($\propto V_{eff}$), which are closely associated with impact excitation equation. We thus carried out simulations, adopting parameters of $A_L = 4\times10^8$, $b = 5.1\times10^{-2}$ (eV), and $\alpha = 4.0\times10^{-3}$ nm^{-1}, obtained from devices with $L_{ch} = 0.5$ μm. Then, for other devices, the A_L or the V_{ds} will be scaled as the ratio, that is to say, the parameters of nA_L and (1/n)V_{ds} should be adopted for devices with the L_{ch} = 0.5n μm (for instance, 4A_L and 0.25V_{ds} should be used for L_{ch} = 2 μm). And simulation results (Figure S1d) well reappear experimental tendency. The threshold voltage V_{Th} can also be estimated from simulations (inset), through the black dashed line (integrated intensity is set at 7000 for observed EL emissions, excludeing the background noise interference), in accordance with experimental results.

Part 2: The evolution of the PL spectra of CNT films in air.

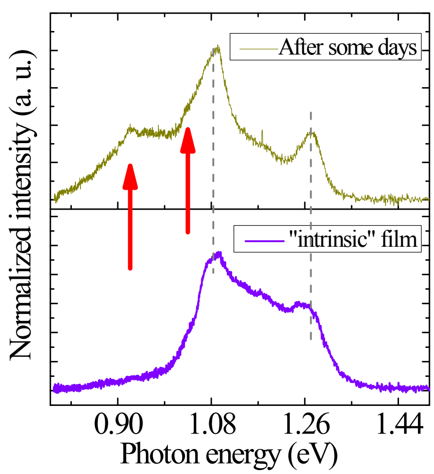

Figure S2. PL spectral evolution of the CNTs films, excited by 633-nm laser.

The CNT films can also show some trions emissions by optical excitation, when the films were placed in atmospheres for some days. This behavior can be attributed to the oxygen adsorption and doping. It should be pointed out that for all films (including the “intrinsic” films, where trions emissions cannot emerge under optical excitation), the devices can still show dominant trion emissions under electrically-induced impact excitation, as explained in the main text.

Part 3: The shifts of the G-mode Raman peaks with increased bias (temperature)

Figure S3 shows the dependence of the temperature on the bias, which was estimated by peak-shifts of the G-mode in Raman scattering, excited by 633-nm laser.[3] As shown in Figure S3a, with increasing the bias, the downshift of the peak position can occur. For better corresponding to the actual temperature, the temperature at the bias of ~11 V can be calibrated by melting state of the copolymer layer, which has experimental stability of ~600 K. Figure S3b shows the approximate linear relation between the bias and the position of G-mode. Assuming the linear relation can be kept within the voltage scope,[4] then the estimated temperature is ~800 K at ~18 V. At this high bias, the device was near to be breakdown.

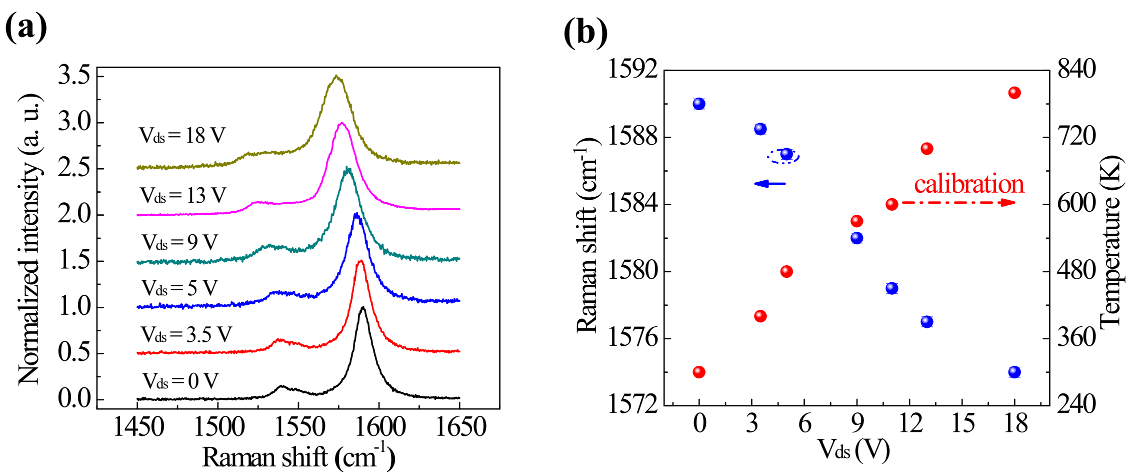

Figure S3. (a) Raman scattering spectra versus the bias. (b) Peak position of G-mode versus the bias and the temperature. The temperature was calibrated by the copolymer with the experimental stability of ~600 K.

Notes and references

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