**Electronic Supplementary Information**

# Active carbon-nanotube polarizer-embedded electrode and liquid-crystal alignment

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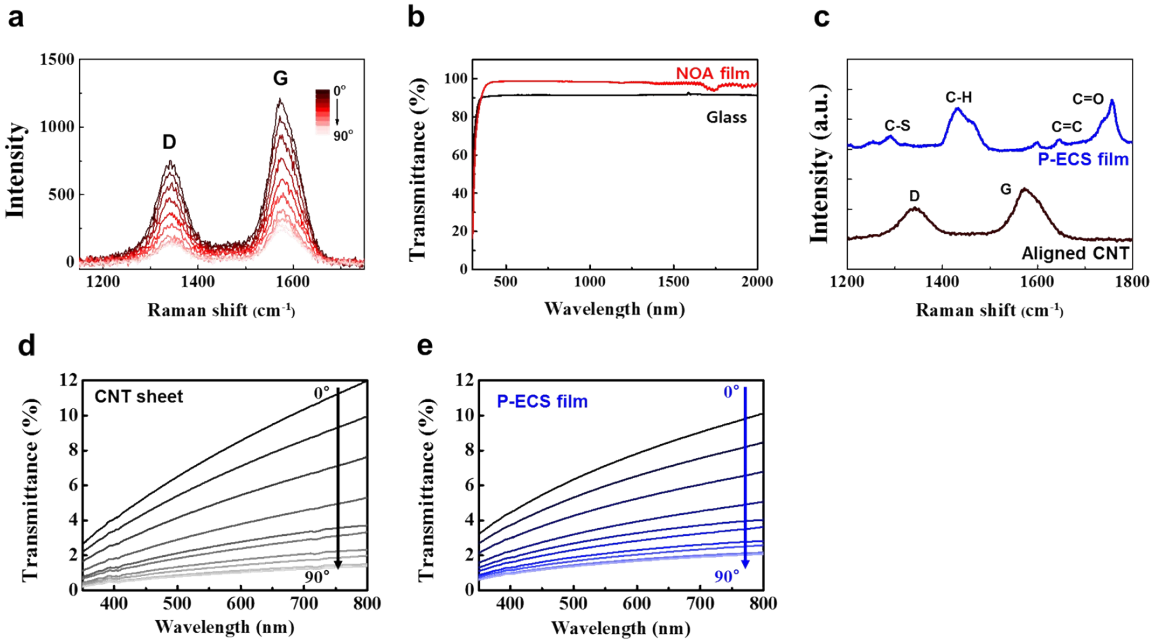


**Figure S1.** Degree of alignment of CNTs (n = 10): (a) Polarization-angle dependent Raman spectra of as-drawn CNT sheet with a step of 10° from 0 to 90°, (b) transmittance of NOA film and glass in the UV-Vis-NIR (300–2000 nm) range, (c) Raman spectra of aligned CNT layers (black line) and polymer-embedded CNT sheet film (blue line), and (d-e) polarization-angle dependent transmittance of aligned CNT sheet (black lines) and polymer-embedded CNT sheet film (blue lines) with a step of 10° from 0 to 90°.

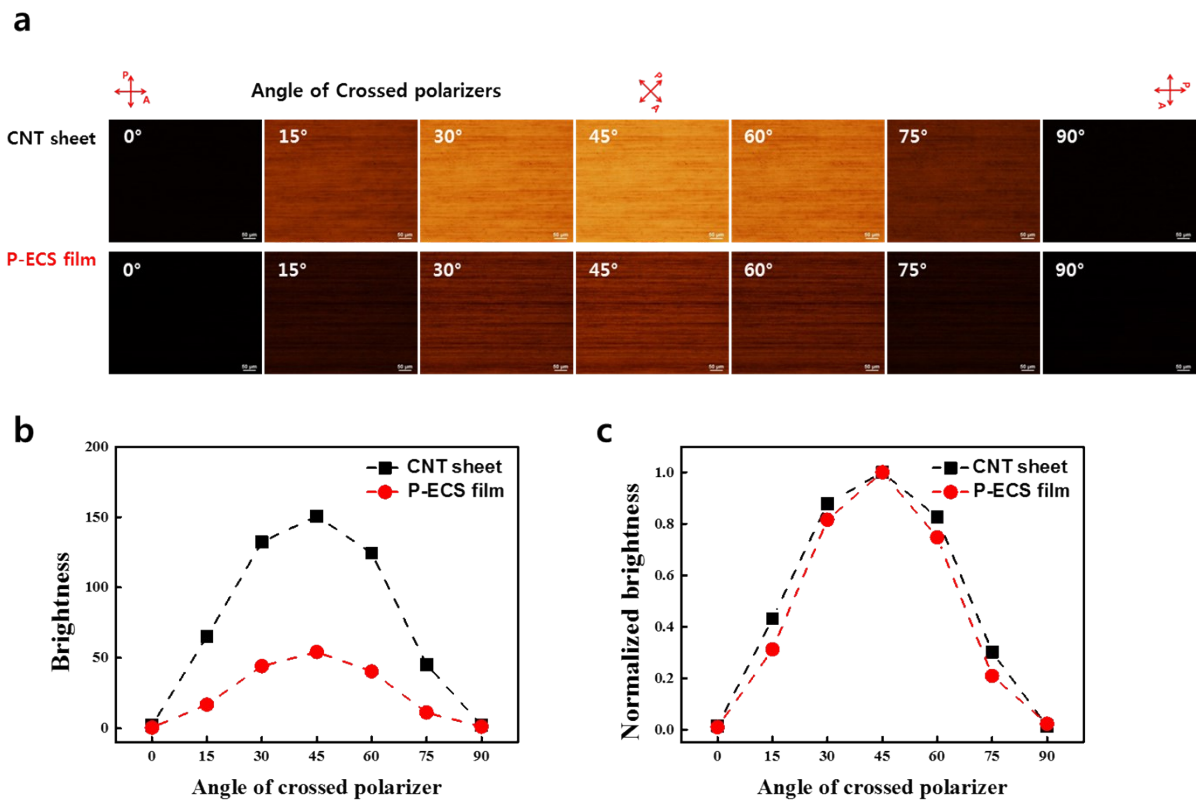


**Figure S2.** (a) Polarized optical microcopy image of CNT sheet and polymer-embedded CNT sheet (P-ECS) film under the crossed polarizer (polarizer-analyzer) with a step of 15° from 0 to 90°. The number of CNT layers is 10. (b) Relative brightness and (c) normalized brightness of CNT sheet and P-ECS film. The relative brightness is calculated by an image analysis software.

We evaluated the alignment of CNTs by the polarized optical microscopy (POM). CNT sheet shows a higher relative brightness ratio (68.9), defined by $B_{max}/B_{min}$, than P-ECS film (43.2) under the tilt angle of the crossed polarizer-analyzer from 0 to 90°. The similar tendencies between before and after coating are observed in the normalized brightness, remaining the high degree of alignment after polymer coating.

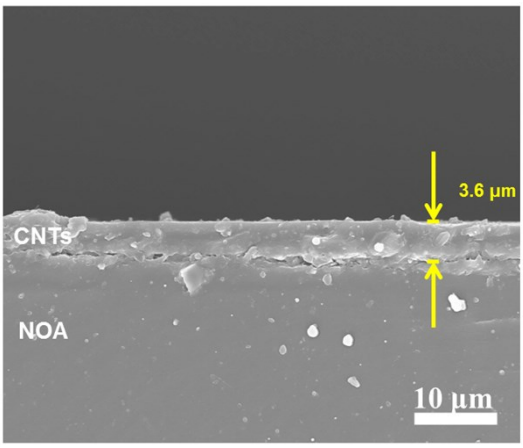


**Figure S3.** SEM image of the cross-section of polymer embedded CNT sheet film.

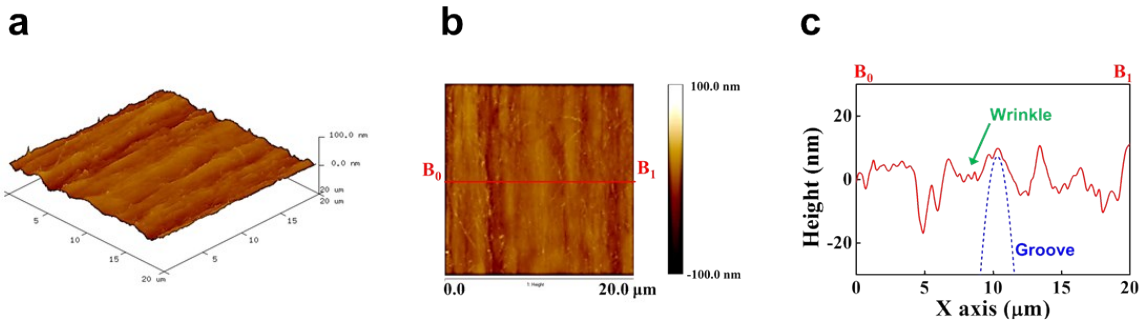


**Figure S4.** AFM imaging of the surface of P-ECS film (n = 5): (a) 3D image, (b) 2D height morphology, and (c) line profile corresponding to the red line in (b).

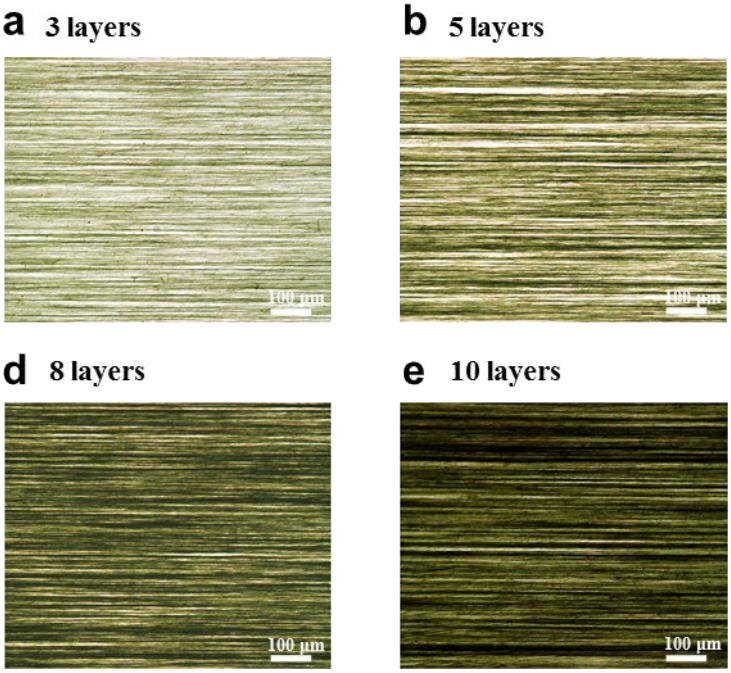


**Figure S5.** Optical microscopy images of P-ECS films with different number of CNT layers.

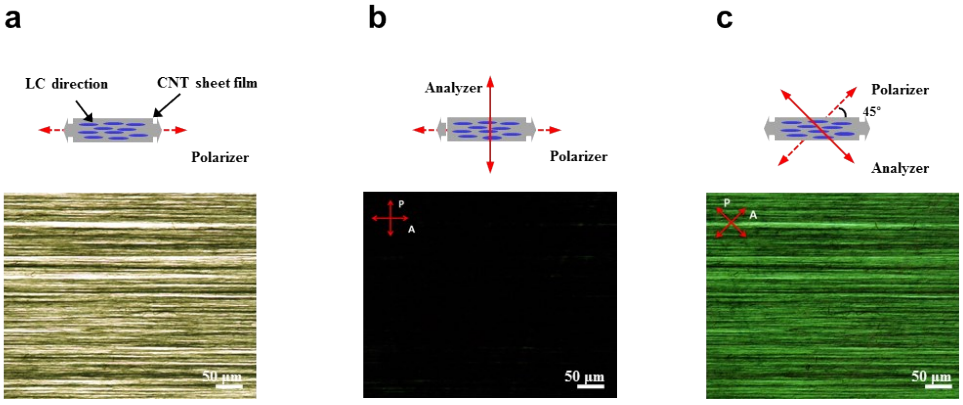


**Figure S6.** Polarized optical microscopy measurement to evaluate LC alignment: LC-coated P-ECS film (n = 5) with (a) one polarizer (parallel direction, bright state), (b) crossed polarizer-analyzer (dark state), and (c) 45° tilted polarizer-analyzer (medium bright state).

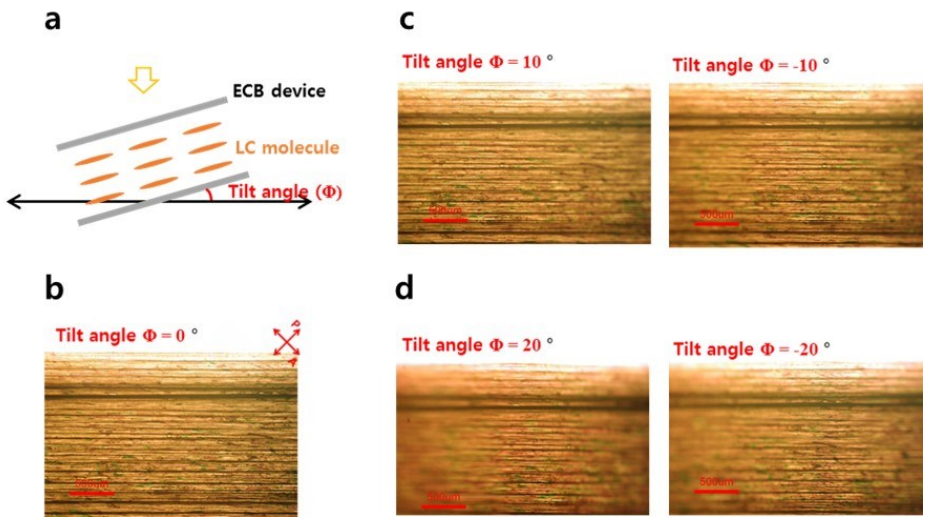


**Figure S7.** Polarized optical microscopy (POM) measurement of cell device under tilt angle (Φ) with 45° tilted polarizer-analyzer: (a) Schematic of the cell device consisting of two parallel aligned P-ECS film. The LC molecules are injected into the gap (5 μm). POM image at (b) Φ = 0°, (c) Φ = ±10°, and (d) Φ = ±20°.

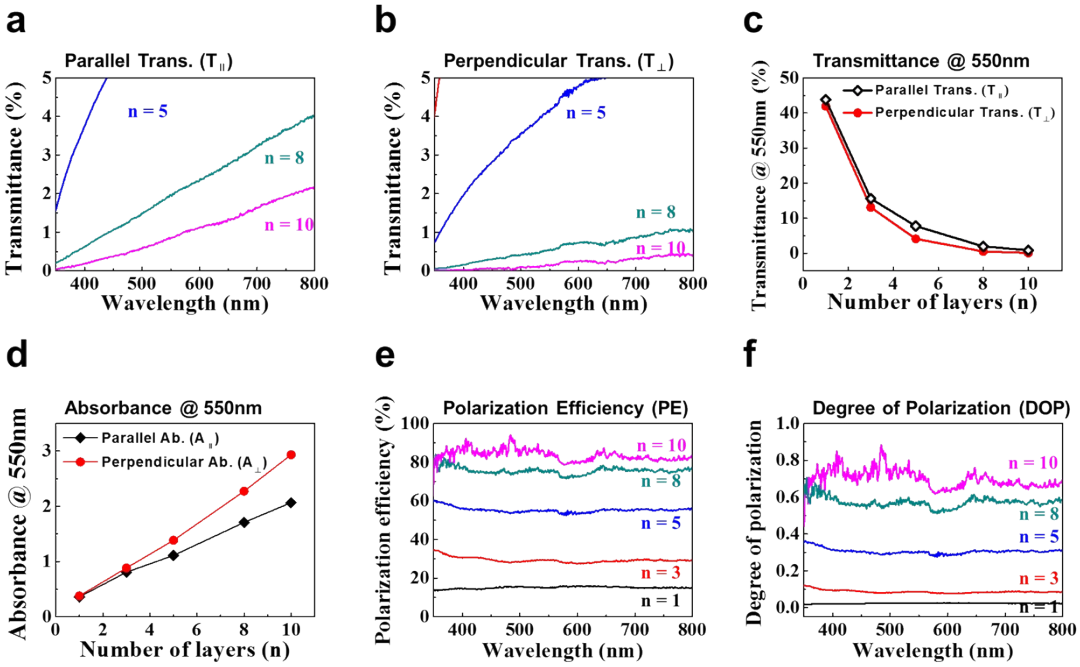


**Figure S8.** Optical anisotropy performance of two overlapped P-ECS films with various numbers of CNT layers: (a) parallel transmittance, (b) perpendicular transmittance, (c) transmittance at λ = 550 nm as a function of CNT layers, (d) absorbance at λ = 550 nm as a function of CNT layers. (e) Polarization efficiency and (f) degree of polarization. n is the number of CNT layers.

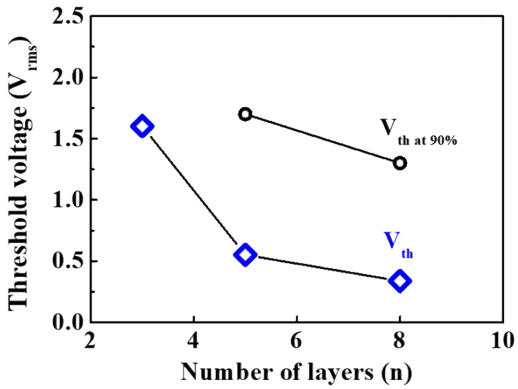


**Figure S9.** Threshold voltage ($V_{th}$, blue open rhombus symbols) and $V_{th}$ at 90% of normalized intensity (black open circle symbols).

**Simulation of standard cell**

The voltage-dependent transmittance of a standard cell was simulated by TechWiz LCD2D tool (SANAYI system Co.ltd). The ITO and polyimide were used as an electrode and homogeneous alignment layer, respectively with the ZLI 4792 liquid crystal. We summarized the parameters for simulation in Table S1. The V-T data is plotted in Fig. S9.

**Table. S1** Parameters of standard cell for simulation

| Item | Materials | Parameters |
|---|---|---|
| Electrode | ITO | Resistivity: 0 |
| Surface orientation | Polyimide | Top Pretilt : 1, Azimuthal : 90 [deg]<br>Bottom Pretilt : 1, Azimuthal : 0 [deg] |
| Liquid crystal | ZLI 4792 | $n_e$ : 1.5763, $n_o$ : 1.4794<br>$\varepsilon_{\parallel}$ : 8.3, $\varepsilon_{\perp}$ : 3.1 |
| Cell gap | | 5 μm |
| Voltage condition | | Range of applied voltage : 0~5 V<br>Applied step voltage : 0.1 V |

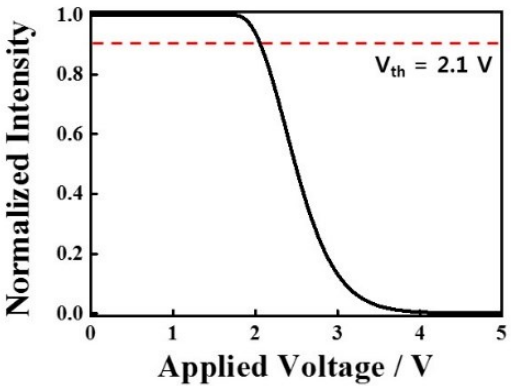


**Figure S10.** Simulation results of voltage-dependent transmittance of standard cell (ITO/Polyamide).

**Measurement of polar anchoring energy**

The polar anchoring energy (W) was calculated by LCD physical properties measurement system (RDMS-200 & LCR meter, Agilent 4248A). The specimen consists of parallel aligned two P-ECS film with LC injection, referred to the electrically controlled birefringence (ECB) device. We summarized the parameters for calculation in Table S2.

**Table. S2** Parameters for the measurement of polar anchoring energy.

| Item | Unit | Value |
|---|---|---|
| Dielectric constant | | $\varepsilon_{\parallel}$ : 8.3, $\varepsilon_{\perp}$ : 3.1 |
| Cell gap | μm | 5 |
| Elastic constant | pJ/m | 13.2 |
| Final voltage | V | 8 |
| Step voltage | V | 0.5 |
| Test frequency | kHz | 10 |
| Fitting point | | 8 |
| Start fitting voltage | V | 4.5 |
| End fitting voltage | V | 8 |
| **Polar anchoring energy** | **$J/m^2$** | **$6.43 \times 10^{-5}$** |

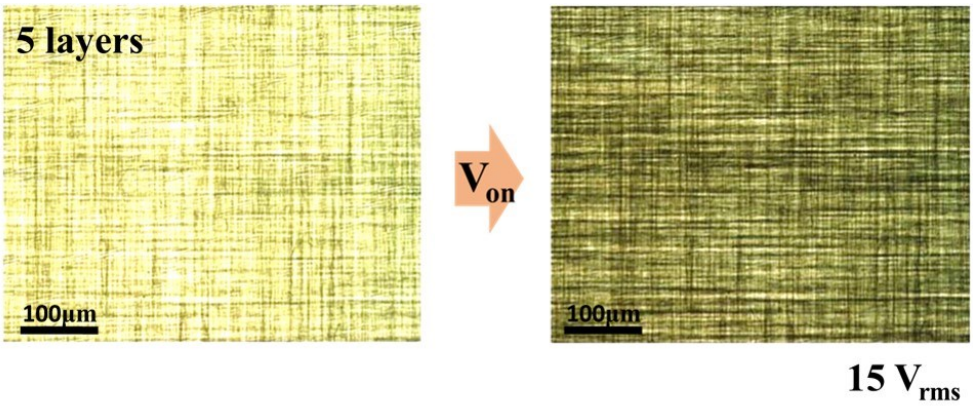


**Figure S11.** Optical microscopy images of the LC cell device (n = 5) in voltage-off and -on states (15 $V_{rms}$).

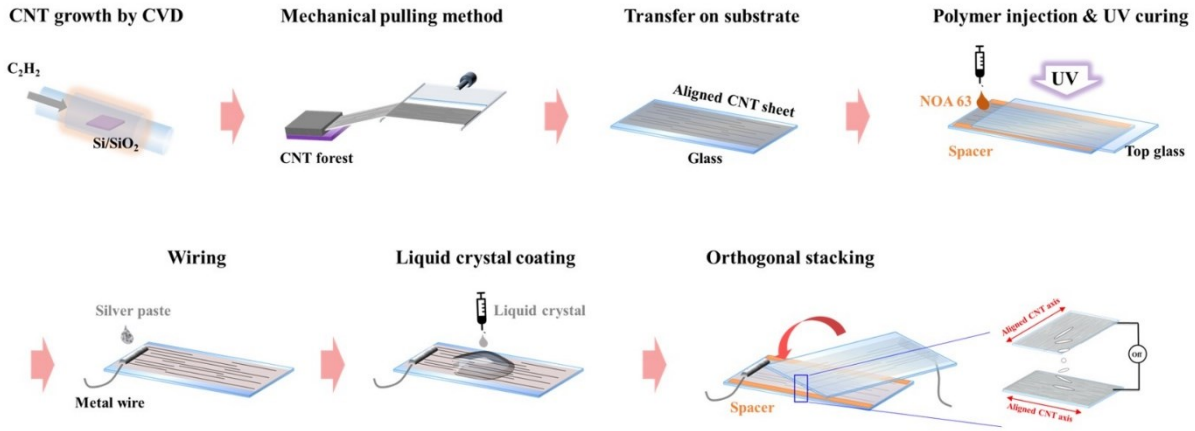


**Figure S12.** Schematics showing the steps in the fabrication of a LC cell device (one drop filling method).