Supplementary Information

**Fig. S1.** Optical transmittance of as-deposited Cu$_{2-x}$O/Cu/Cu$_{2-x}$O multilayer before grid patterning.

**Fig. S2.** Schematic of the TFH fabrication process using the RTR-sputtered Cu$_{2-x}$O/Cu/Cu$_{2-x}$O multilayer grid. Two terminal-side Ag contact electrodes were fabricated on the Cu$_{2-x}$O/Cu/Cu$_{2-x}$O multilayer grid films.

**Fig. S3.** Pictures of temperature measurement system for the TFHs, with (a) an IR image camera and
(b) a thermocouple.

Fig. S4. Absorbance spectra obtained at potentials from -0.2 V to 0.8 V for (a) the P3HT and (b) PEDOT:PSS films spin-coated on Cu$_{2-x}$O/Cu/Cu$_{2-x}$O multilayer grid electrodes.

Fig. S5. In situ transmittance spectra for P3HT/PEDOT:PSS film measured (a) at 520 nm and (b) 720 nm when different voltage pulses were applied for an interval of 60 s.