Electronic Supplementary Material (ESI) for Energy & Environmental Science.

Supporting Materials

Fabrications of OLED on plastic-paper

1. The 200 *200 mm^2 plastic-paper substrate with a thickness of 120 um was attached to the same size glass carrier (conventional alkali-free glass, 0.7mm thick) as a mechanical supporting during the device fabrication process. 2. 100 nm ITO films were deposited on plastic-paper substrates by radio frequency magnetron sputtering with a power density of 6.2 W/cm^2. The measured sheet resistance of ITO films was approximately 40Ω/□. 3. ITO film were patterned by conventional photolithography process. 4. The configuration of the Green OLEDs is shown in Fig. 5(a), where ITO is an anode, F4-TCNQ is tetrauoro-tetracyanoqino dimethane, doped into N,N,N0,N0-tetrakis(4-methoxyphenyl)-benzidine (MeO-TPD) as hole injection layer , NPB is N,N0-di(naphthalene-1-yl)-N,N0-diphenyl-benzidine as a hole transport layer, TCTA is 4,40,400-tri(9-carbazoyl) triphenylamine as an exciton/ electron blocking layer, $Ir(ppy)_3$ is Tris(2-phenylpyridine)iridium(III) as a green emitter , Bepp2 is bis[2-(2-hydroxyphenyl)-pyridine] beryllium as a host of green emitter and electronic transport layer , LiF is an electron injection layer and Al is a cathode. All layers were thermally deposited without breaking the vacuum at a base pressure of $2x10^{-7}$ Torr. The deposition rates of both host and guest were controlled by their correspondingly independent quartz crystal oscillators. 5. Devices were encapsulated immediately after preparation under a nitrogen atmosphere using SiNx (300 nm) thin films which were fabricated at 80 C by PECVD.

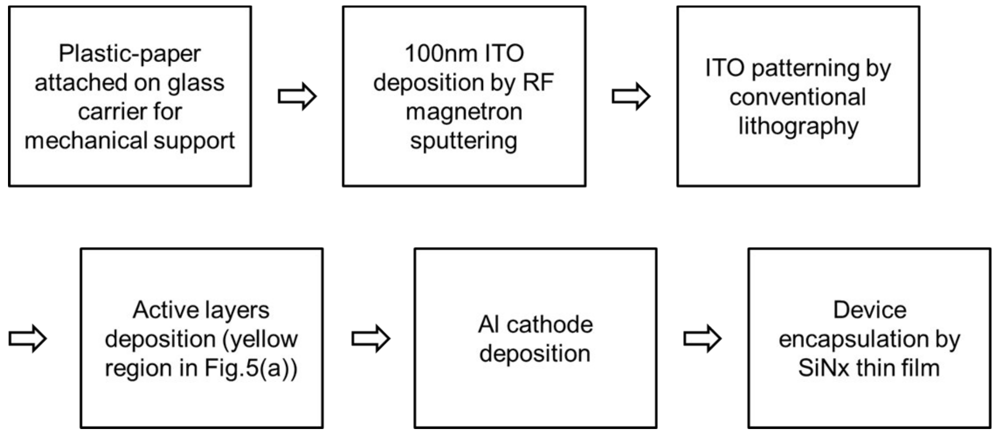

Figure S1: Flow chart of OLED fabrication processes.

OLED lighting characterization

The electroluminescence (EL) spectra of the devices were obtained by a Konica Minolta CS2000 spectra system. The emission area of the devices was 3 * 3 mm^2 as defined by the overlapping area of the anode and cathode. The luminance–current density (J)–voltage (V) characteristics were recorded simultaneously, using a computer controlled source meter (Keithley 2400) and multimeter (Keithley 2000) with a calibrated silicon photodiode.

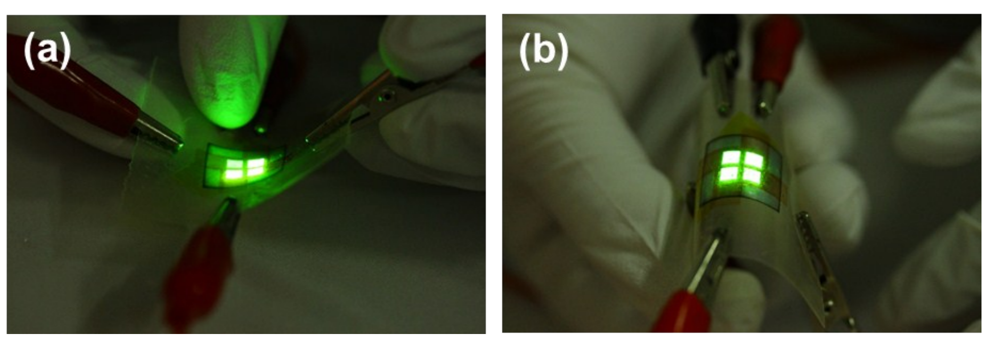

Figure S2: Pictures of bending of OLED on plastic-paper with 2x2 lighting matrix. (a) Concave up bending and (b) concave down bending.

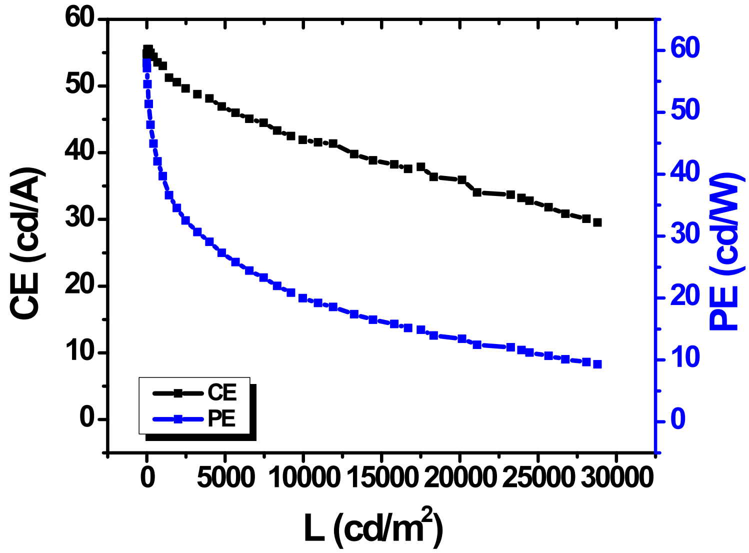

Figure S3: Current efficiency and power efficiency of OLED on plastic-paper.

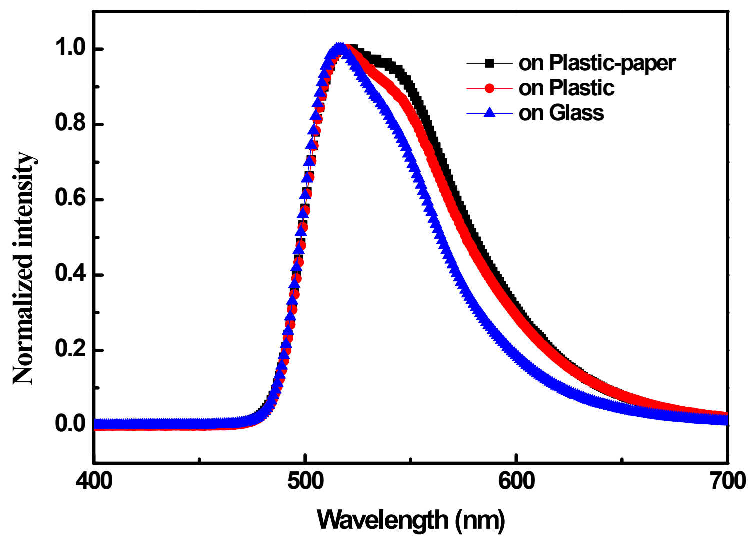

Figure S4: Lighting spectra of green OLED on plastic-paper, plastic (polyethylene naphthalate (PEN)) and glass substrate.

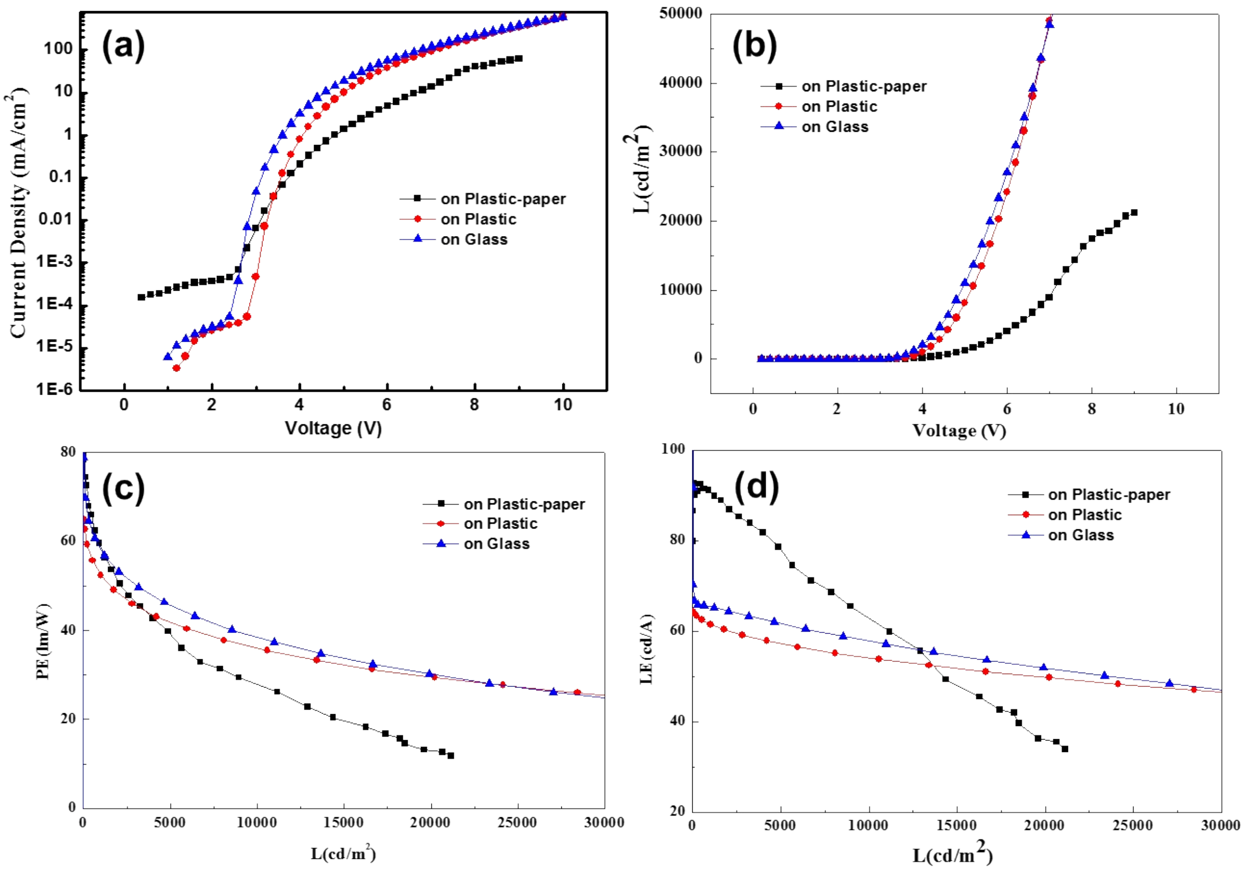

Figure S5: Comparison of OLED lighting parameters for substrates of plastic-paper, plastic (PEN) and glass. (a) Current density as a function of driving voltage; (b) luminescence versus voltage; (c) power efficiency versus luminescence and (d) luminescence current efficiency.

Surface reflection measurement

The light reflection of transparent substrate can determine how much light goes into solar cell and therefore affects the power conversion efficiency. We have measured the reflectance of the plastic-paper, plastic and glass on the top of the solar cells, to make clear whether similar amount of light was into the solar cell for a convincing comparison. The results are summarized in Figure S6. The light reflections are similar in the range from 550 to 800 nm. Therefore, we conclude the difference in solar cell efficiency is mainly due to the optical haze of the substrates.

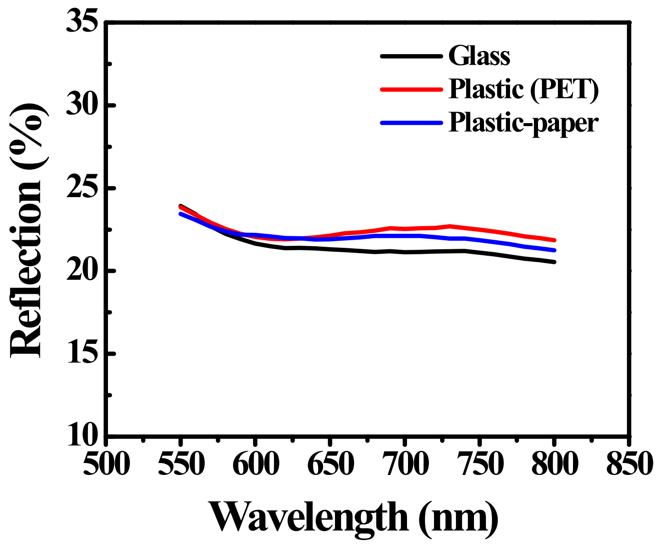

Figure S6: The light reflection measurement of glass, PET and plastic-paper laminated on bare GaAs solar cells.

"We also measure the optical reflectance of different substrates (Fig. S7). The surface light reflection for all these substrate ranges from 8%-12%."

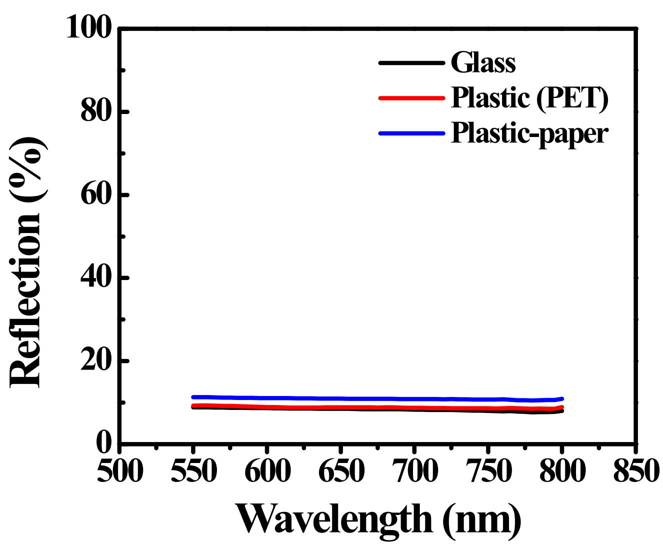

Figure S7: The light reflection measurement of glass, PET and plastic-paper substrates.

Comparison with metal nanowire in plastics

Researchers have been using metal nanowires (such as Ag nanowires) to increase the optical haze in plastic substrates.[1–8] Among all these studies, the optical haze is shown to be limited, much smaller than the values reported in this work.

The following are the major differences, which is also summarized in Table S1:

(1) The most fundamental difference between haze substrate enabled by metal nanowires and our plastic-paper hybrid substrate is the electrical conductivity. Ours is an **insulating** substrate, which can be generally used as a substrate for building optoelectronics; metal-nanowire-based haze substrate is electrically **conductive**.

(2) As a haze substrate (advantageous for light coupling), our transparent hybrid substrate also has a much higher optical haze value.

(3) The optical haze is broadband in our substrate, which is not for plastic with Ag NWs.

(4) The cost for our plastic-paper hybrid is apparently lower than plastic with Ag NWs.

Table S1: Comparison of plastic-paper and Ag nanowire (NW) embedded in plastic substrate.

	Plastic-paper	Ag NW in plastic [1-8]
Electrical properties	**Insulating**	**Conductive**
Transmittance	85% - 90%	60%-90%
Haze	90%-97%, broadband	40%-70%, not broadband
Cost	Low (use plastic and paper)	Potentially high due to use of Ag NWs

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