# Reducing Optical Reflection Loss Through Textured PEDOT: PSS in Hybrid Sn-Pb Perovskite Solar Cells

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## Experimental Section

### Preparation of planar and textured PEDOT: PSS

***Planar PEDOT: PSS*:** The planar PEDOT: PSS layer is applied to the substrate using the spin-coating technique. The solution is spun at a rate of 4000 rpm for a duration of 30 seconds, followed by heat treatment at 150°C for 15 minutes to complete the process.

***Textured PEDOT: PSS*:** 80 nm polystyrene (PS) spheres are mixed into a PEDOT: PSS solution and a homogeniser is used to ensure uniform dispersion of PS spheres in the PEDOT: PSS solution. The prepared PS sphere solution is spin-coated at 4000 rpm for 20 seconds onto a pre-treated 15-ohm ITO. Before spin coating, the ITO is cleaned with deionized water, acetone, and isopropanol through 10-minute sonication and then air-dried using a nitrogen flow. Finally, the ITO undergoes UV Ozone treatment for 1 hour. Using a hot plate, the sample is heated at 150°C for 15 minutes to solidify the PEDOT: PSS and PS spheres onto the ITO substrate. The sample is placed in an anhydrous THF solution for etching for one hour to remove the PS spheres. Then, the sample is placed on a 150°C hot plate to evaporate any residual THF.

### Preparation of perovskite precursor solution:

The preparation of perovskite precursor solution can be divided into two parts. The first part is the preparation of a 1.3M $MAPbI_{2.85}Br_{0.15}$ precursor solution. MABr (7.28 mg), $PbBr_2$ (23.86 mg), MAI (196.33 mg), $PbI_2$ (569.35 mg), and GaSCN (30.72 mg) are dissolved in a DMF: DMSO = 9:1 mixed solvent. The second part is a 1.3M $Cs_{0.05}FA_{0.95}SnI_3$ precursor solution. CsI (16.88 mg), FAI (212.4 mg), SnI2 (484.28 mg), SnF2 (20.38 mg) are dissolved in a DMF: DMSO = 4:1 mixed solvent. Finally, the $Cs_{0.05}FA_{0.95}SnI_3$ and $MAPbI_{2.85}Br_{0.15}$ are mixed in equal proportions to obtain a mixed tin-lead perovskite precursor solution.

### Sn-Pb perovskite solar cell fabrication:

The pre-prepared substrate (ITO/PEDOT: PSS) is transferred to a glove box, where the assembly of the solar cell is carried out. First, a perovskite precursor solution is spin-coated onto the ITO/PEDOT:PSS film at 1000 rpm for 10 seconds and then at 5000 rpm for 50 seconds. After 20 seconds from the start of the spin-coating process, 750µl of toluene is added as an anti-solvent. The sample is then heated at 100°C for 10 minutes and at 65°C for another 10 minutes. Next, a solution containing 1 mg of $EDAI_2$ dissolved in 1 mL of isopropanol and 1 mL of toluene is spin-coated onto the perovskite layer at 4000 rpm for 20 seconds. This is followed by heating at 65°C for 10 minutes.
Finally, under high vacuum conditions (below 10^-6 Pa), 40 nm of C60, 5 nm of BCP, and 100 nm of Ag are deposited through thermal evaporation, completing the fabrication of the solar cell.

**Other characteristics:**

A Solar Simulator from Enlitech Technology, model IVS-KA6000, was used to measure the current-voltage (J-V) characteristics of perovskite solar cells under 100mW/cm² AM 1.5G solar irradiance. Before testing, the xenon lamp was warmed up for 30 minutes to stabilize the light source. Measurements were taken using a Keithley 2400 digital source meter, with light intensity calibrated using a certified silicon reference cell. To comprehensively assess the solar cell's performance, both forward and reverse scans were conducted: reverse from open-circuit voltage ($V_{OC}$) to short-circuit current ($J_{SC}$) (1.2V→-0.2V), and forward from $J_{SC}$ to $V_{OC}$ (-0.2V→1.2V), at a scan rate of 20mV/s. UV-Vis measurements are conducted by Shimadzu UV-1800. Scans were conducted across a wavelength range of 300-1000nm. The ZEISS ULTRA PLUS SEM (Scanning Electron Microscope) is employed to capture images of nanostructures and the surface morphology of the top view, cross-sectional, and tilted SEM images. The working distance is 7mm, with an EHT of 4.00kV. Measurements using AFM (Atomic Force Microscopy) were carried out with a Bruker Dimension ICON equipped with Scan Asyst. For EQE measurements, a monochromator coupled with a calibrated silicon photodiode detector was utilized. The wavelength range for scanning was set from 350 nm to 1000 nm. The Sn-Pb perovskite solar cells were carefully mounted on a sample holder and positioned such that the active area of the device was appropriately aligned with the incident light beam from the monochromator.

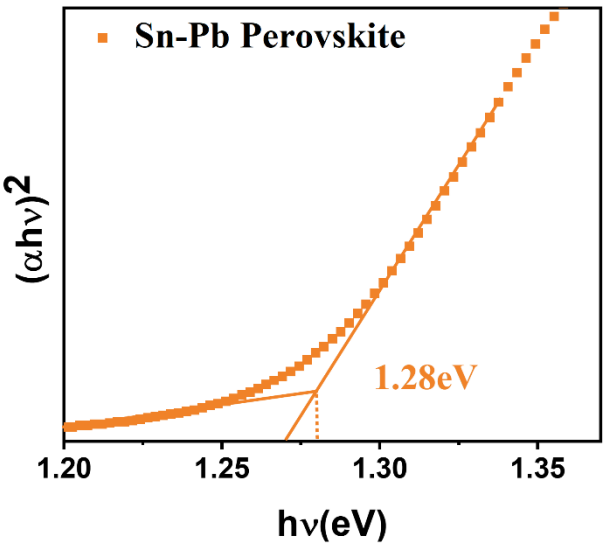


**Figure S1**. Tauc plot of Sn-Pb perovskite films.

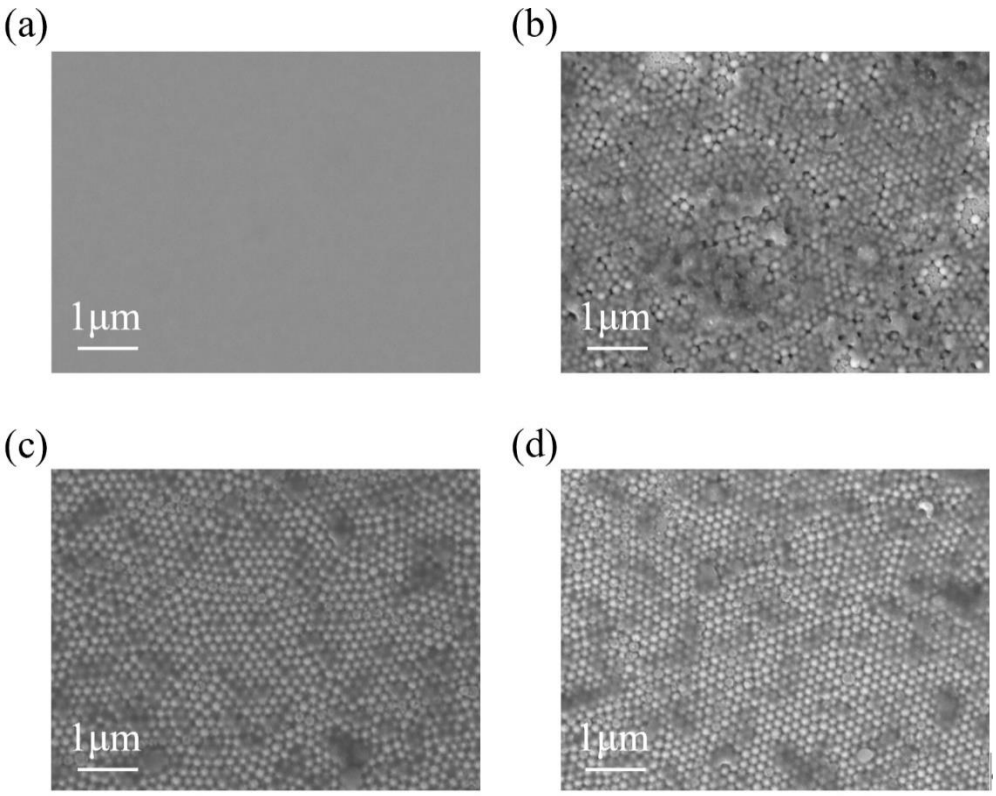


**Figure S2.** Top view SEM image of (a) planar PEDOT:PSS and textured PEDOT: PSS processed at concentrations of (b)15mg/mL, (c)10mg/mL, and (d)6mg/mL of PS spheres before the THF immersion.

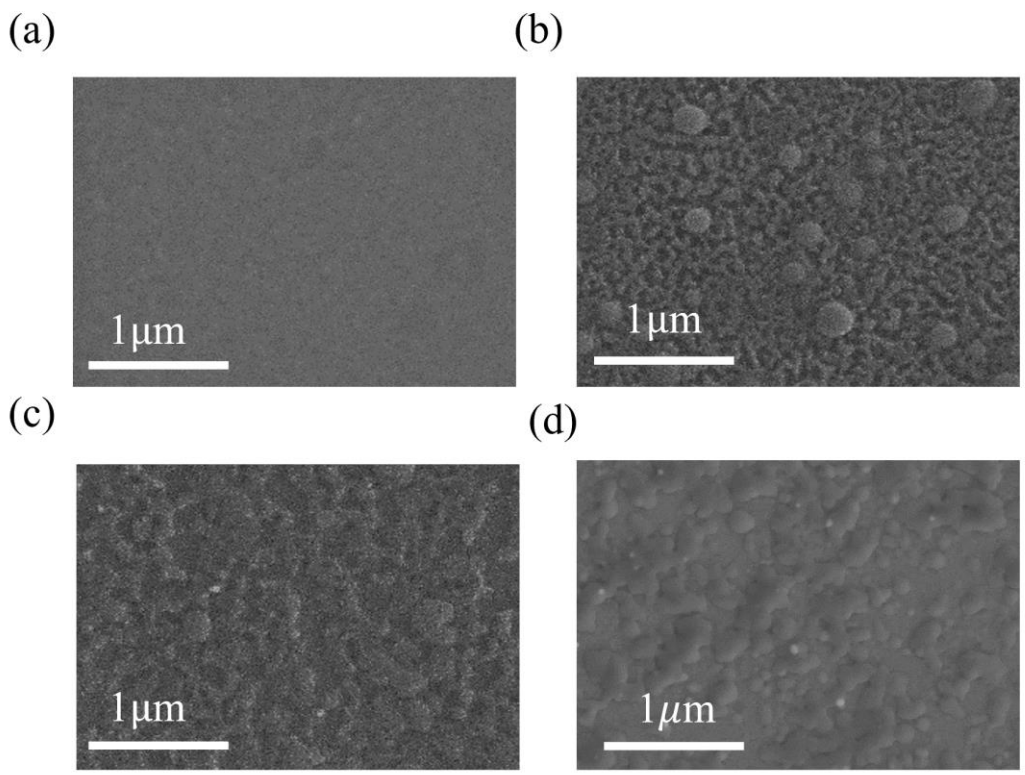


**Figure S3.** Top view SEM image of (a) planar PEDOT:PSS and textured PEDOT: PSS processed at concentrations of (b)15mg/mL, (c)10mg/mL, and (d)6mg/mL of PS spheres.

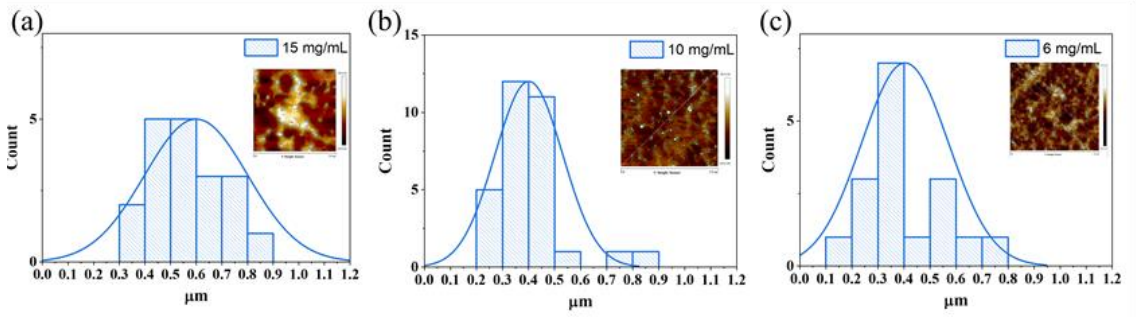


**Figure S4.** Size distribution of cavities in PEDOT:PSS films processed using varying concentrations of PS spheres: (a) 15 mg/mL, (b) 10 mg/mL, and (c) 6 mg/mL.

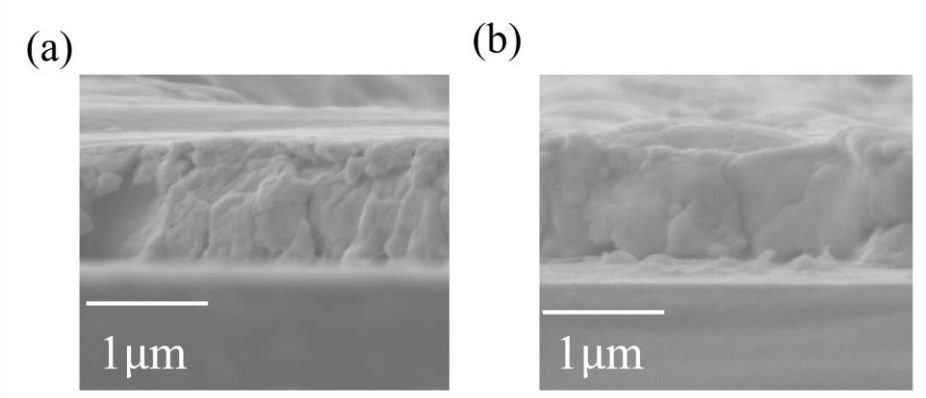


**Figure S5.** Cross-sectional SEM image of perovskite deposited on (a) planar PEDOT: PSS and (b) textured PEDOT: PSS

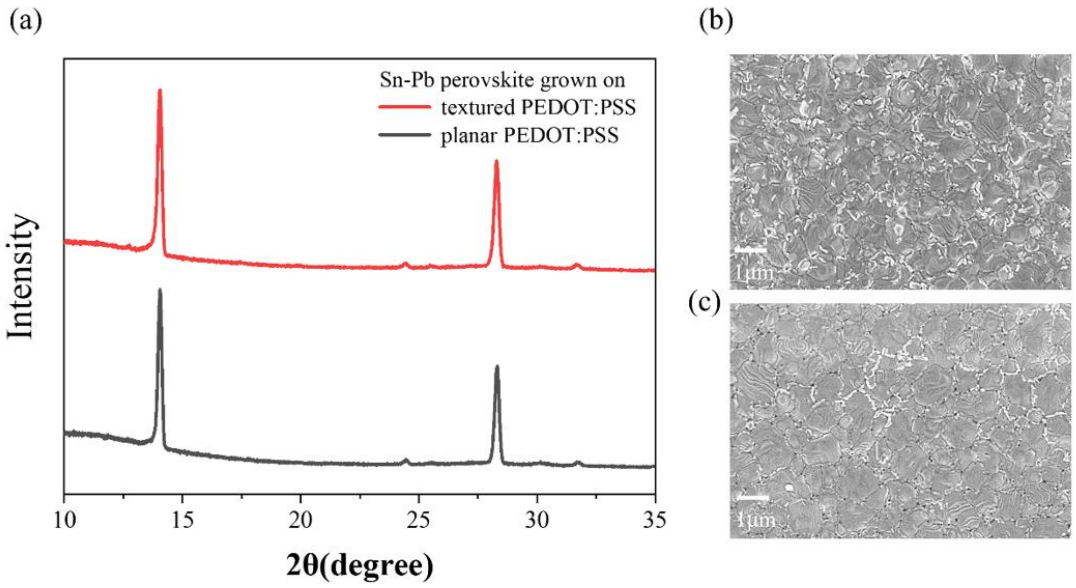


**Figure S6**. (a) XRD pattern of Sn-Pb perovskite grown on planar and textured PEDOT: PSS. Top-view SEM image of the Sn-Pb perovskite deposited on (a) planar and (b) textured PEDOT: PSS.

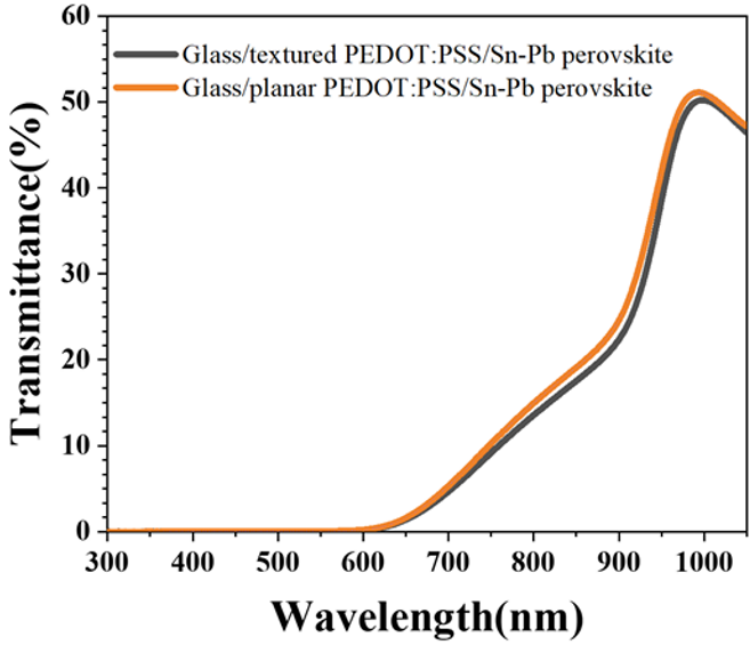


**Figure S7.** Transmittance spectrum of Sn-Pb perovskite film grown on the planar and textured PEDOT:PSS.

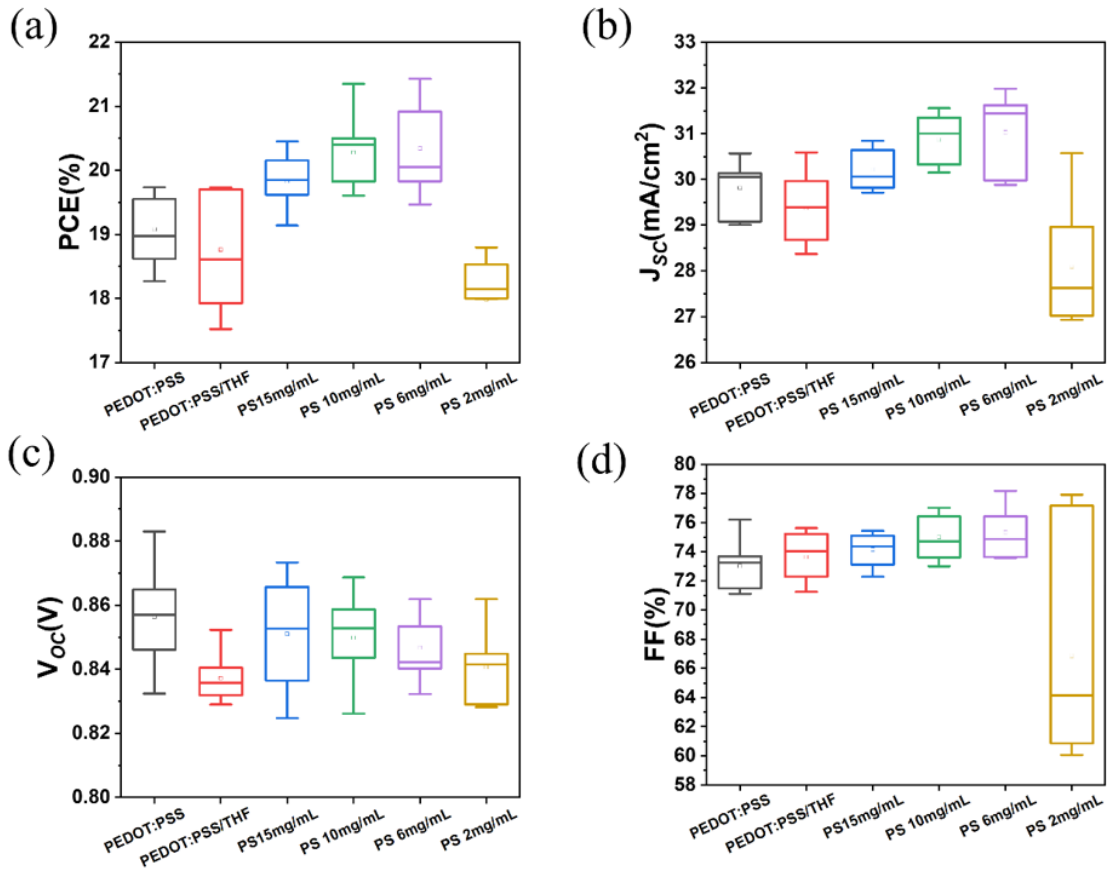


**Figure S8.** Statistical parameters of J-V characteristics in Sn-Pb perovskite solar cells (PSCs) fabricated with both planar and textured PEDOT: PSS, processed at varying PS concentrations. The parameters include (a) power conversion efficiency, (b) current density, (c) open-circuit voltage, and (d) fill factor.

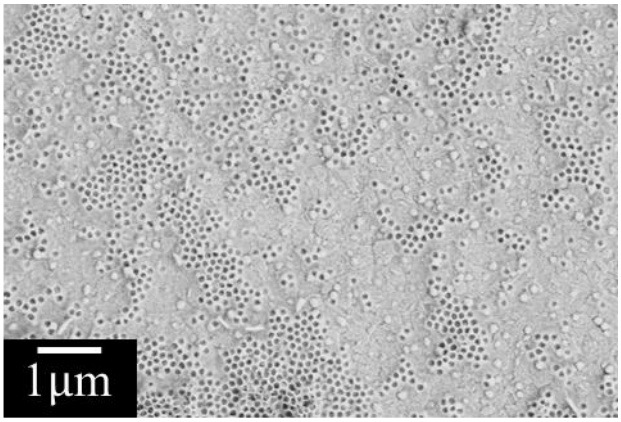


**Figure S9.** Top-view SEM image of textured PEDOT: PSS processed at concentrations of 2mg/mL of PS spheres.

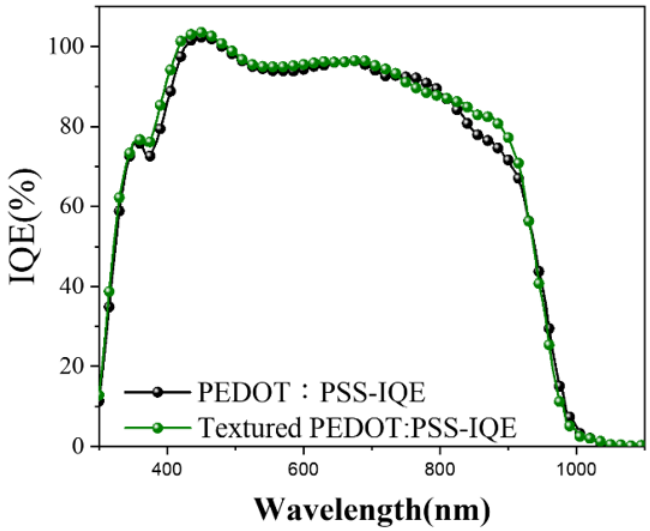


**Figure S10.** Internal quantum efficiency (IQE) of the Sn-Pb PSCs employed planar and textured PEDOT: PSS as the hole transport layer.

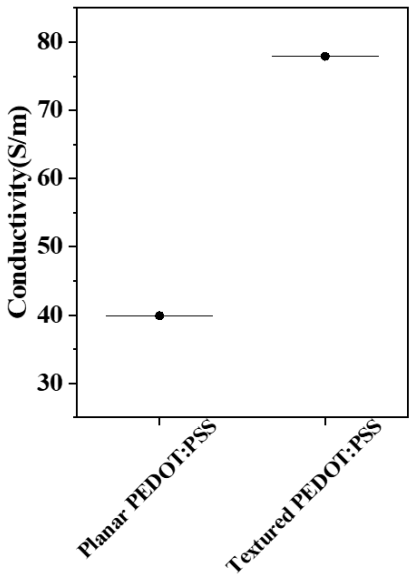


**Figure S11. Conductivity of the planar and textured PEDOT:PSS measured by transfer length method (TLM).**

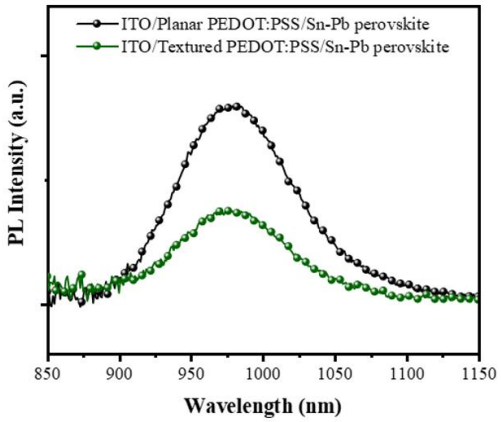


**Figure S12.** Photoluminescence spectrum of Sn-Pb perovskite deposited on ITO/planar PEDOT:PSS substrate and ITO/textured PEDOT:PSS substrate

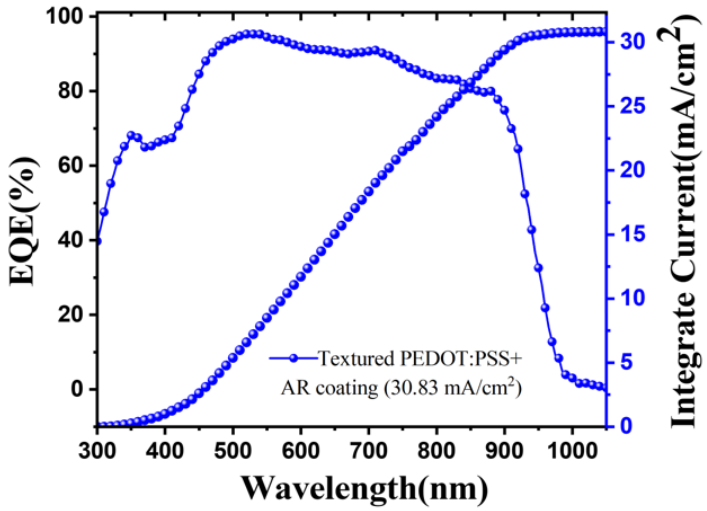


**Figure S13.** An external quantum efficiency (EQE) of the Sn-Pb PSC employed textured PEDOT: PSS with antireflection (AR) coating.