Supporting information for

Improving the Conductivity of sol-gel Derived NiO_x with Mixed Oxide Composite to Realize over 80% Fill Factor in Inverted Planer Perovskite Solar Cells

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Table S1 Summary of photovoltaic parameters of the PVSCs based on different hole transport layers including PEDOT:PSS, NiO_x.

Devices	J_{sc}(mA cm^{-2})	V_{oc} (V)	FF %	PCE %	R_s (Ω cm^{-2})	R_{sh} (kΩ cm^{-2})
PEDOT:PSS	20.66	0.90	71	13.2	2.54	0.727
NiO_x	20.8	1.03	73	15.6	5.25	0.706

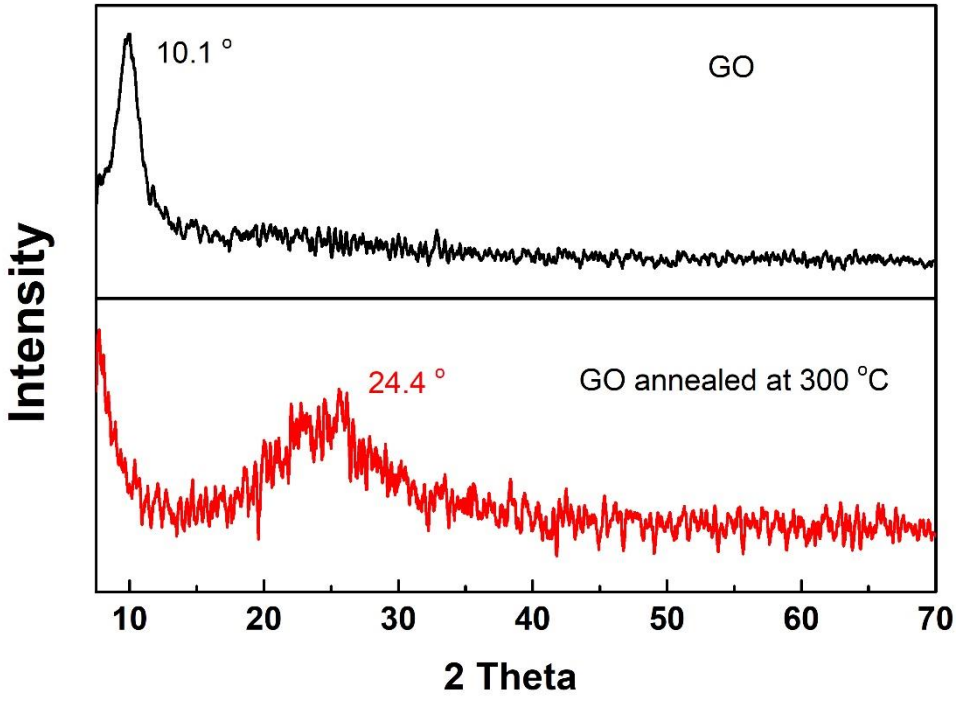

Figure S1. XRD patterns of GO and GO annealed at 300 ºC.

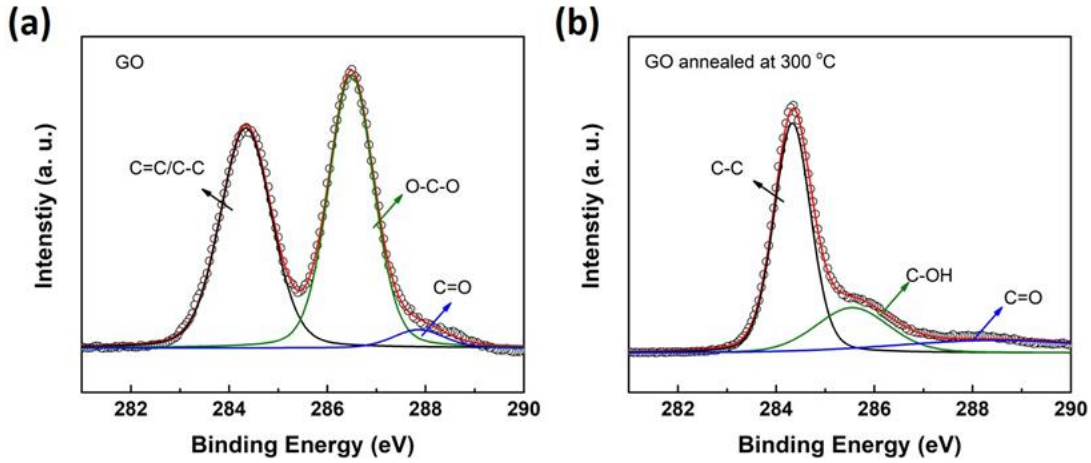

Figure S2. XPS spectra of (a) GO and (b) GO annealed at 300 ºC.

The electrochemical impedance spectroscopy (EIS) was conducted under dark with a bias close to V_{oc} to further investigate the charge transport in the devices. **Figure S1** shows the Nyquist plots collected over the frequency range of 1Hz to 1MHz. It is well known that the high frequency semicircle gives detailed electrical process about charge transport at the interfaces between charge extraction layer and perovskite layer. By fitting the plots with the equivalent circuit shown in the inset of **Figure S1**, the NiO_x:rGO based device exhibits a reduced charge transport resistance (83.2 Ω) compared to the pure NiO_x counterpart (269 Ω) suggesting that introducing the rGO sheets into the NiO_x matrix is an effect approach to improve its charge extraction efficiency.

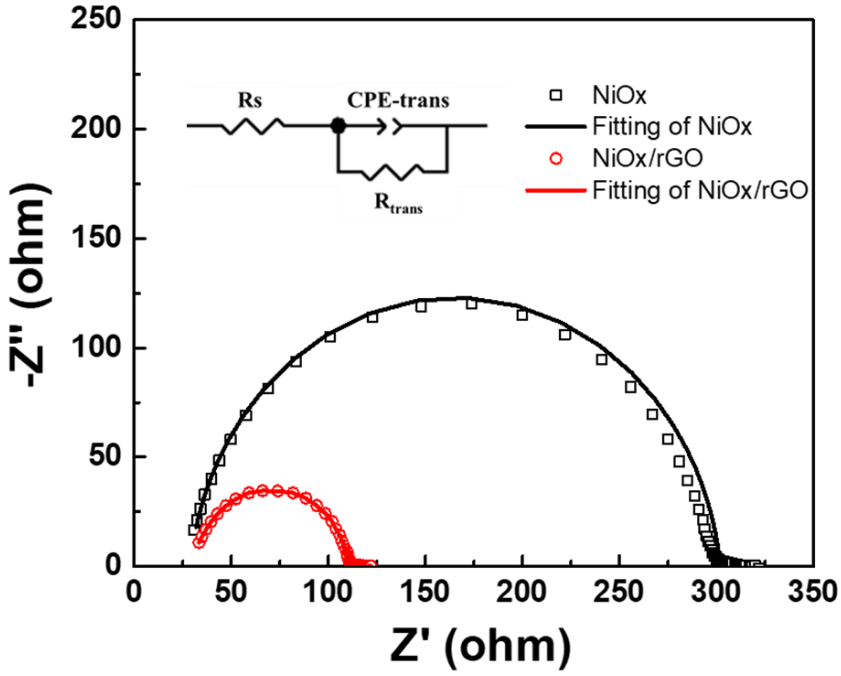

Figure S3. Typical Nyquist plots of NiO_x and NiO_x/rGO based devices under dark with a bias closed to the V_{oc}.

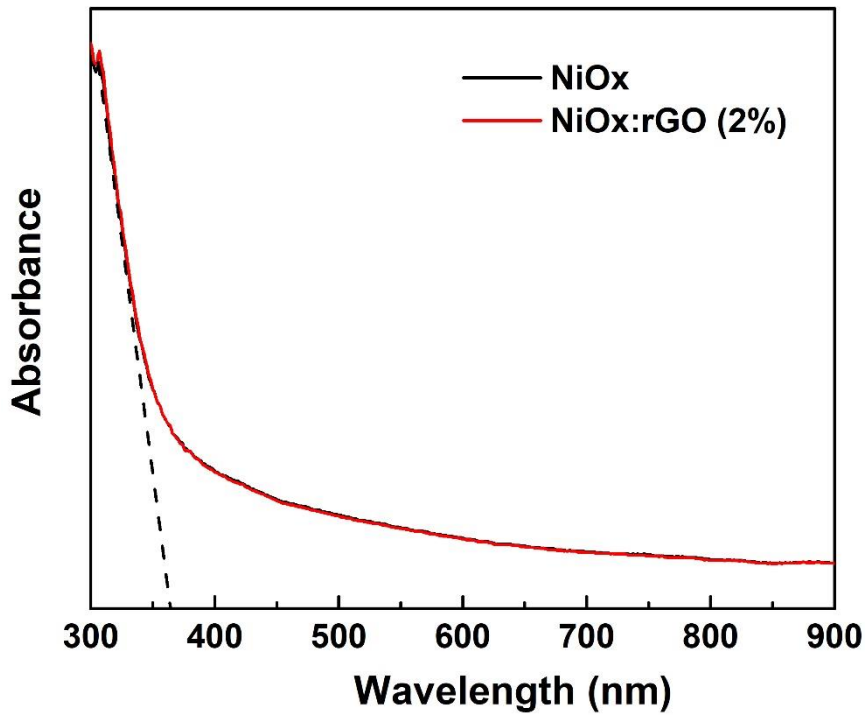

Figure S4. UV-vis absorption spectra of NiOx and NiOx:rGO (2%) films.

To further evaluate the charge recombination process of NiO_x and NiO_x:rGO based devices, light dependence V_{oc} was carried out (**Figure S2**). Normally, the slope of V_{oc} versus the natural logarithm of light intensity reveals the dominant recombination mechanism in the device. The slope of kT/q indicates bimolecular recombination while the slope larger than kT/q suggests that trap-assisted recombination occurs. The NiO_x:rGO based device have smaller slope of 1.32 kT/q compared to the pure NiO_x based device (1.97 kT/q), indicating that the trap-assisted recombination is effectively supressed in NiO_x:rGO based device. These results agree well with the TPC and TPV results.

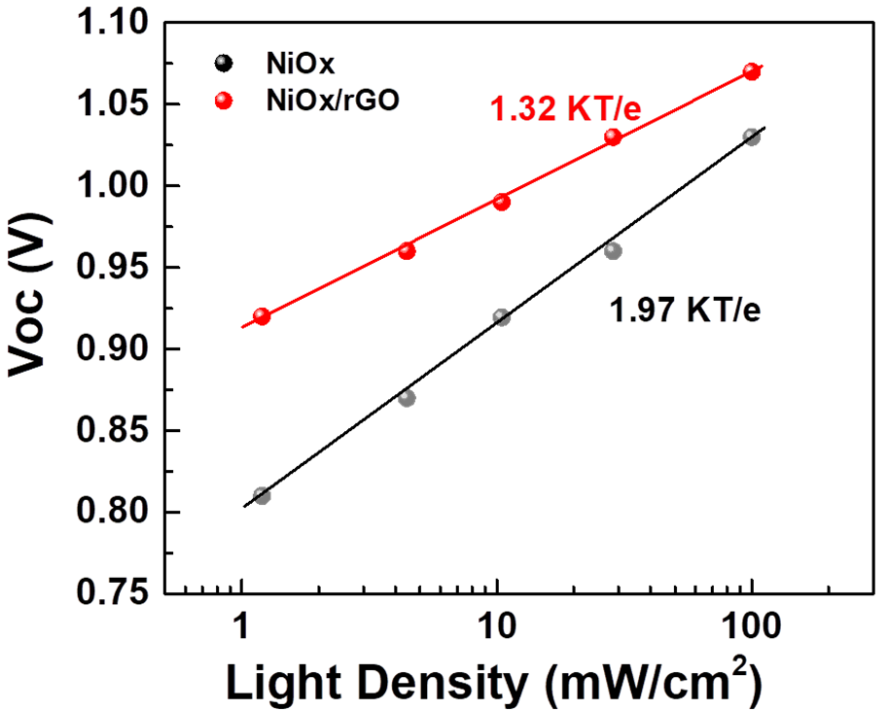

Figure S5. Light dependence V_{oc} of NiO_x and NiO_x:rGO based devices.

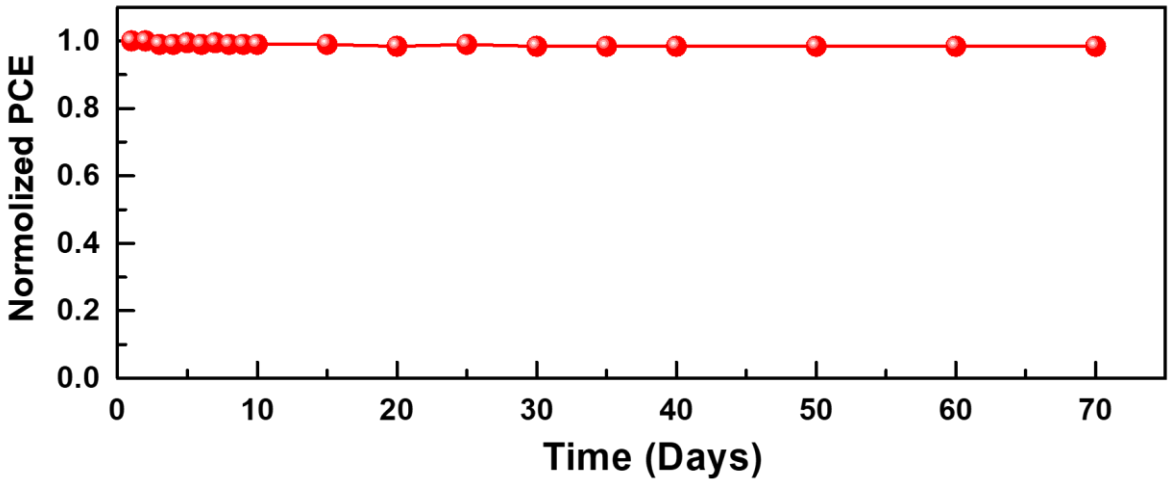

Figure S6 Shelf-lifetime of the NiO_x:rGO based PVSC.