Effect of V-incorporated NiO Hole Transport Layer on the Performance of Inverted Perovskite Solar Cells

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Introduction

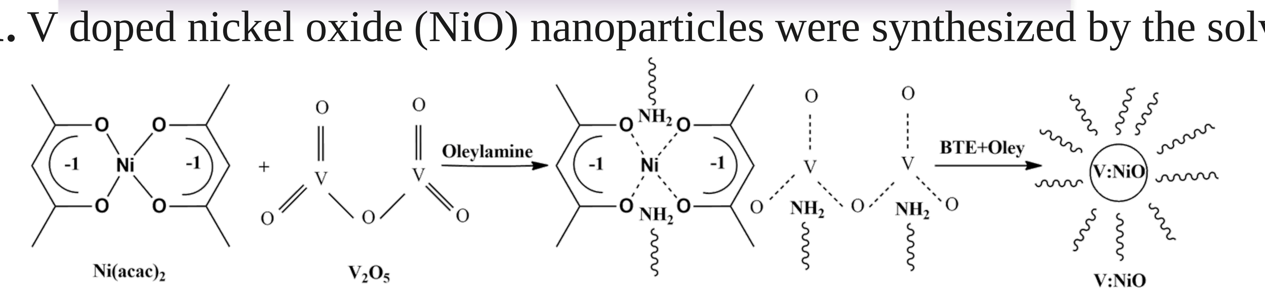
Organic-inorganic hybrid perovskite solar cells have resulted in tremendous interest in developing future generation solar cells due to high efficiency exceeding 25%. For inverted type perovskite solar cells, the hole transporting layer plays a crucial role in improving efficient and stable perovskite solar cells by modifying band alignment, electric conductivity, and interfacial recombination losses. Here, vanadium doped NiO is selected as a hole transporting layer to study the impact of V dopant on the optoelectronic properties of NiO and the photovoltaic performance. The V-doped NiO used as a hole-extraction layer can be prepared by the simple solvothermal decomposition method. The presence of V in the NiO layer has an influence on the conductivity of the NiO layer. In addition, the NiO with ~6±0.5 nm particle thickness prevents a lot of pinholes inside the film and relatively low processing temperature has the advantage of a wide choice of transparent conductive oxide substrate. As a result, inverted type planar perovskite solar cell incorporating of V:NiO hole-transport layer is improved over all power conversion efficiency and stability of both small area and large area of the devices.

Originality & Scientific Impact

- Inverted perovskite solar cells based on V:NiO nanoparticles as hole transport layer.
- Large area devices with a new method for device integration.
- Continuous light illumination stability.

Methods

1. V doped nickel oxide (NiO) nanoparticles were synthesized by the solvothermal decomposition method, as shown in the scheme.



2. For the integration of PSCs the surface of FTO substrate (7-8 Ω sq^{-1}) etched alternatively to separate anode and cathode of each cell, Briefly, in a 5.5X5.5 cm^2 FTO substrate partitioned vertically as 3 equal compartments by a simple wet etching procedure. Then, again performed alternative etching horizontally on the top and bottom sides of the FTO substrate. Then, the patterned FTO substrate was cleaned by sequentially sonicating in deionized water, ethanol and acetone for15 minutes each. Followed by the treatment of ultraviolet-ozone (10 min) was performed on the substrate just before the deposition of layers.

1. Material Analysis

XRD

- The incorporation of vanadium in the NiO lattice confirmed by the diffraction peak shifting towards lower angle.

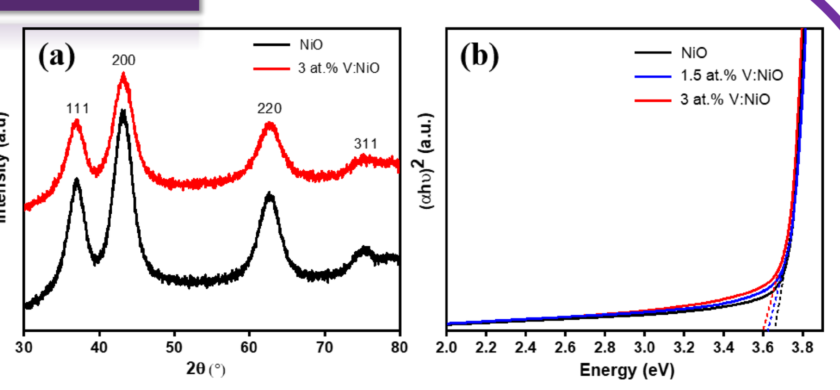


Fig.1 (a) XRD and (b) Tauc plot of NiO and 3at.% V:NiO

UV-Vis Tauc Plot

- NiO E_g - 3.65 eV
- V:NiO E_g - 3.59 eV

XPS

- Light doping of V confirmed on NiO lattice by XPS.
- The higher density of Ni3+ state in the V:NiO sample improved p-type conductivity

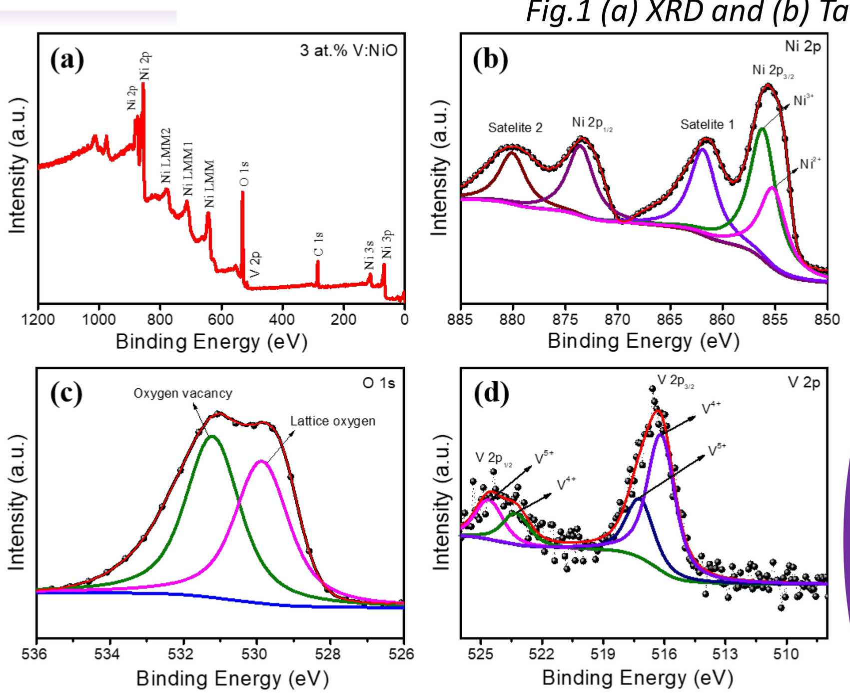


Fig.2 (a-d) XPS spectra of 3at.% V:NiO

TEM

- The average diameter of NPs ~6±0.5 nm
- dspacing - 0.21 nm

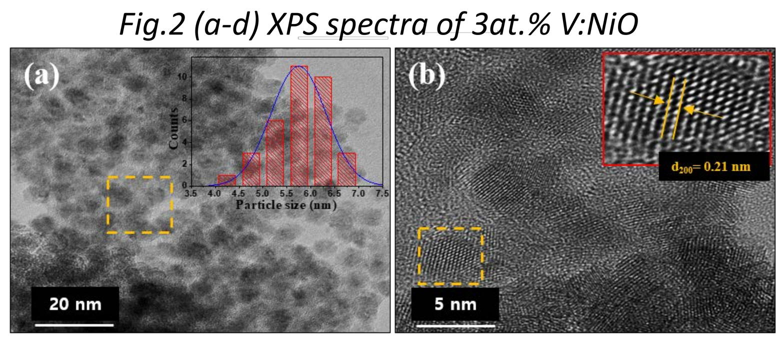
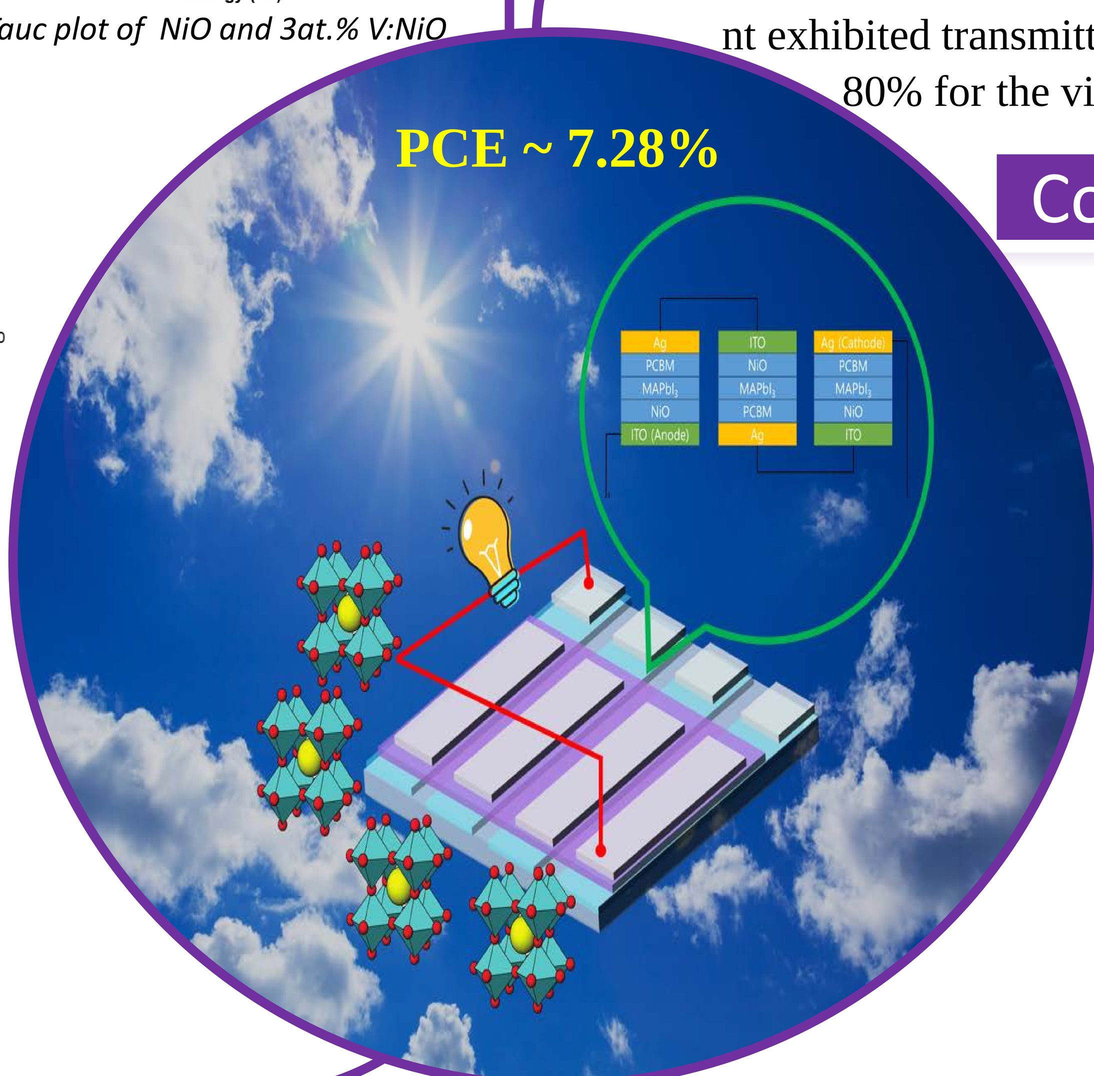


Fig.3 (a) TEM (b) HR-TEM images of 3at.% V:NiO



2. Film Analysis

UV-Transmittance

- V:NiO film with 3 at.% V doping content exhibited transmittance higher than 80% for the visible range.

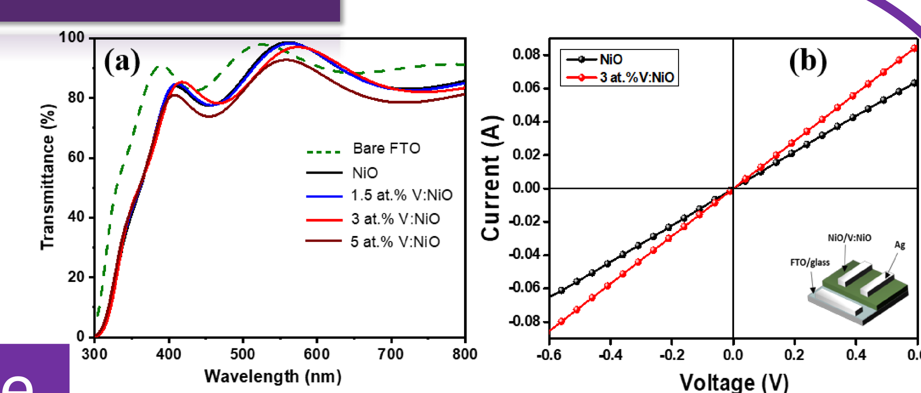


Fig.4 (a) Transmission spectra (b) I-V curve of undoped and doped NiO

Contact Angle

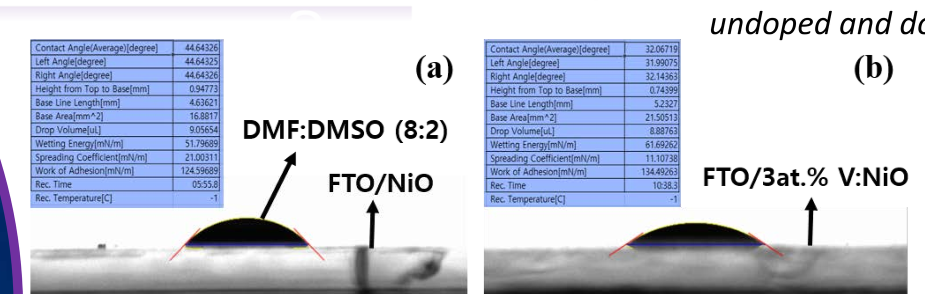


Fig.5 Contact angle measurement of (a) FTO/NiO and (b) FTO/3at.% V:NiO

- Light doping of V improved the hydrophilic nature of the film.

AFM

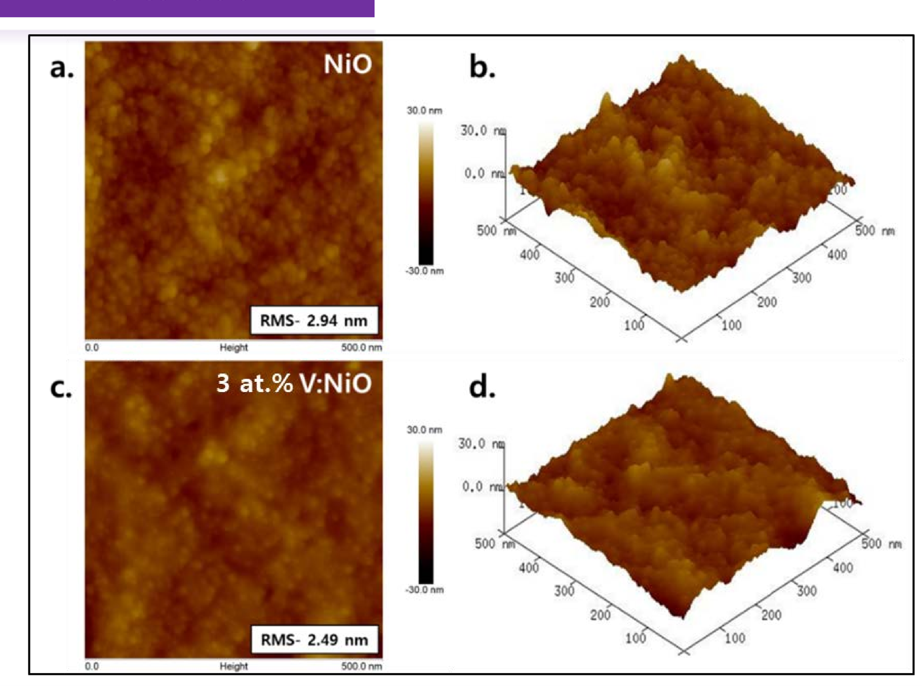


Fig.6 AFM images of (a) FTO/NiO (b) FTO/3at.% V:NiO films

- RMS NiO – 2.94 nm.
- RMS V:NiO- 2.49 nm.

3. Device Performance

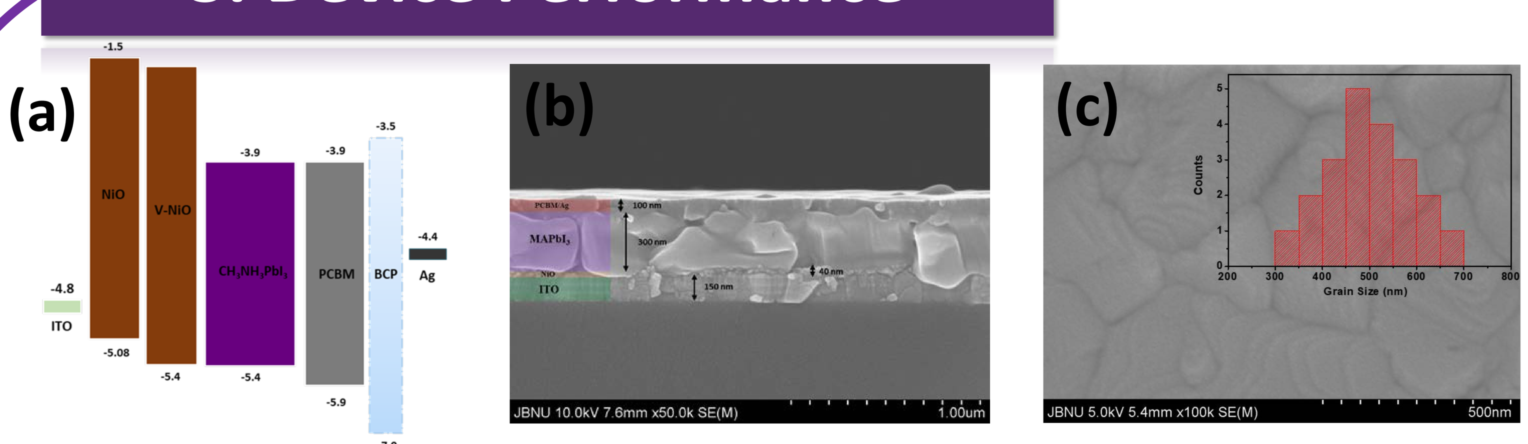


Fig.7 (a) Schematic illustration of band diagram, (b) FE-SEM cross sectional image of the full cell and (c) FE-SEM top view of $MAPbI_3$

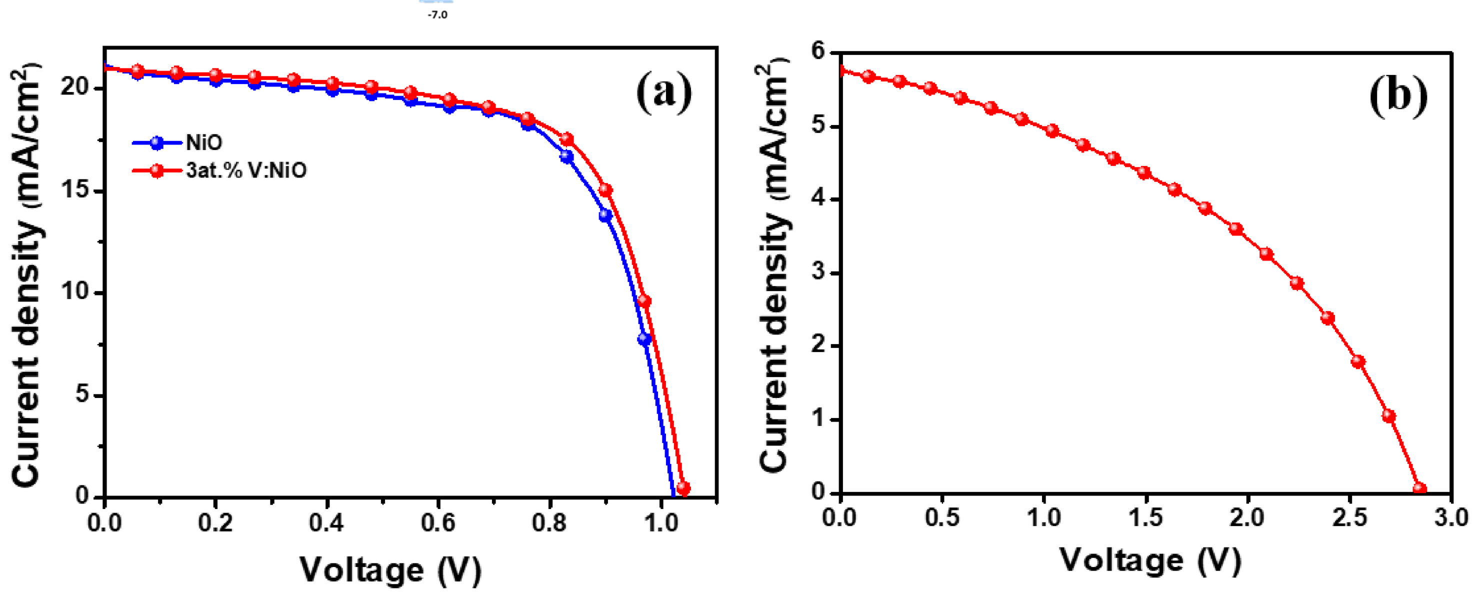


Fig.8 J-V characteristics of (a) small area devices and (b) integrated device.

Devices	V_{oc} (V)	J_{sc} (mA/cm²)	FF	PCE (%)
NiO	1.03	21.11	0.62	13.48
3 at.% V:NiO	1.04	21.09	0.63	13.82
Integrated cell	2.85	5.81	0.44	7.28

Table.1 Photovoltaic parameters

4. Stability

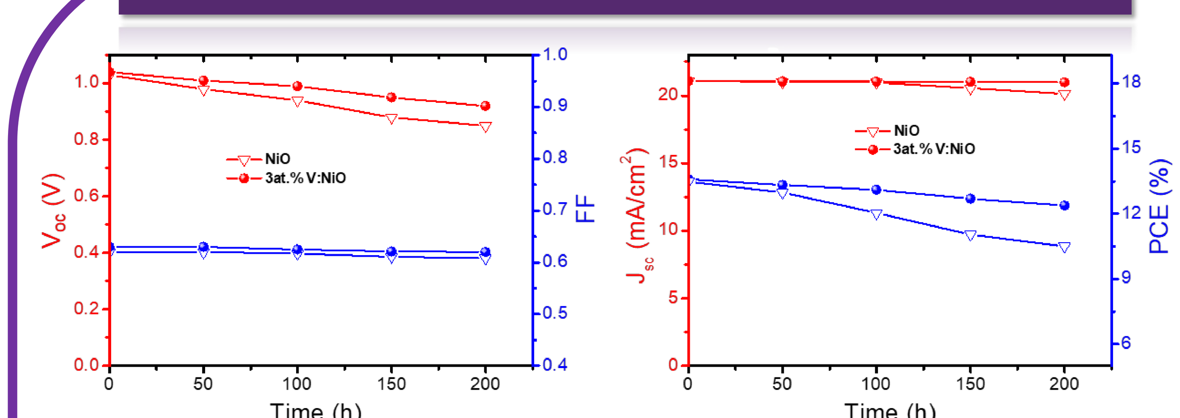


Fig.9 Stability data of small area device.

- Air stability (*RH-40%) of the small area PSC device showed better stability over 8 days without encapsulation.
- V doped NiO device observed stability higher than undoped device.

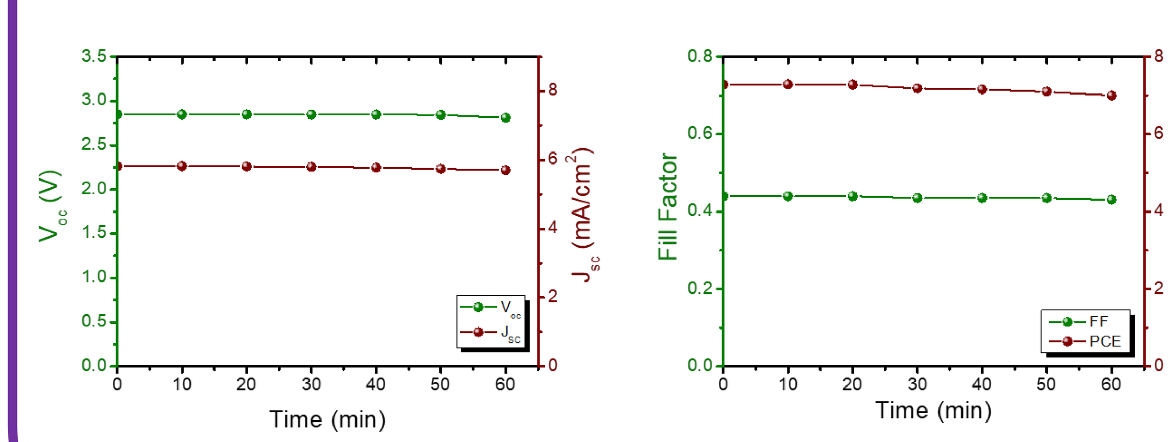


Fig.10 Stability data of integrated perovskite solar cells with continuous solar illumination over one hour.

- The integrated device show 98% of initial PCE retained over continuous solar illumination for one hour under room condition (RH-40 %)

*RH ~ Relative Humidity

Conclusions

- We have successfully fabricated air-stable integrated solar cell based on V doped NiO.
- We found that the V doped NiO film improved both electric conductivity and surface adhesion as compared to the undoped NiO film.
- Light vanadium content in the NiO lattice enhanced PCE and stability for both small area and large area devices

References

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