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Supporting Information

Critical role of dopant in NiO_x hole transport layer for mitigating redox reactivity at NiO_x /absorber interface in mixed cation perovskite solar cells

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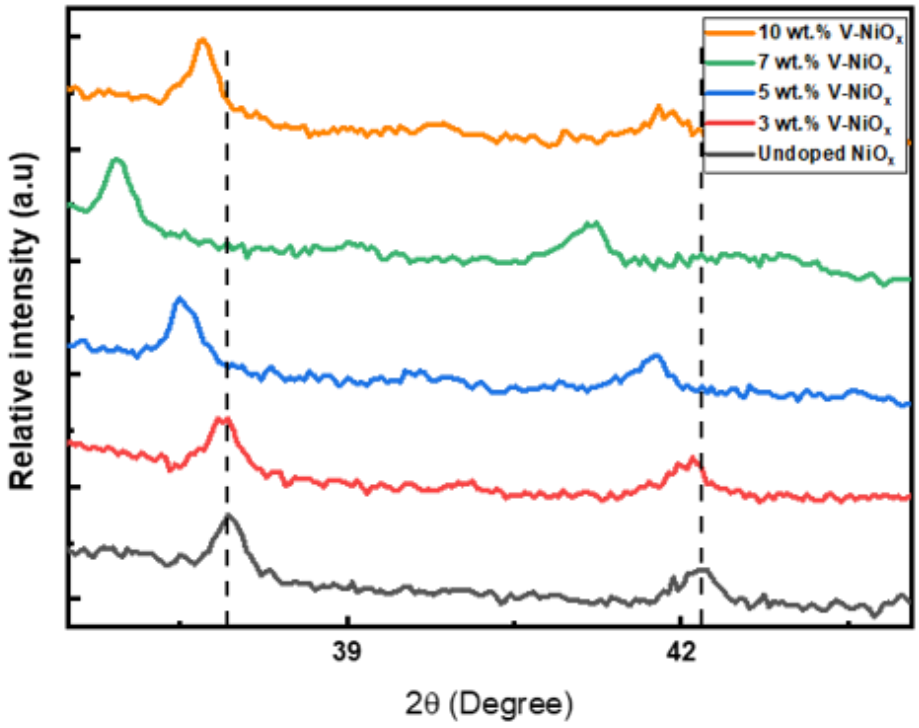

Fig. S1. Enlarged XRD plot of undoped and doped NiO_x thin films showing shift to lower 2θ value with increased dopant concentration

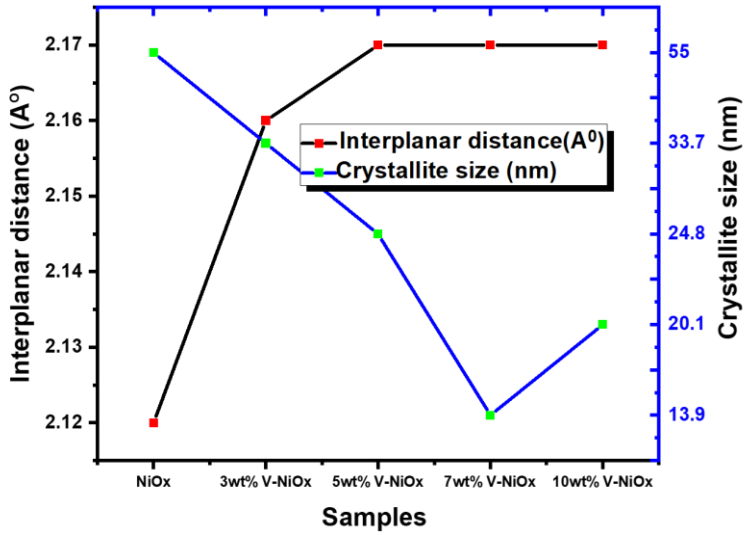

Fig. S2. Comparison plot of interplanar spacing and crystallite size in undoped and different wt. % V doped NiO_x

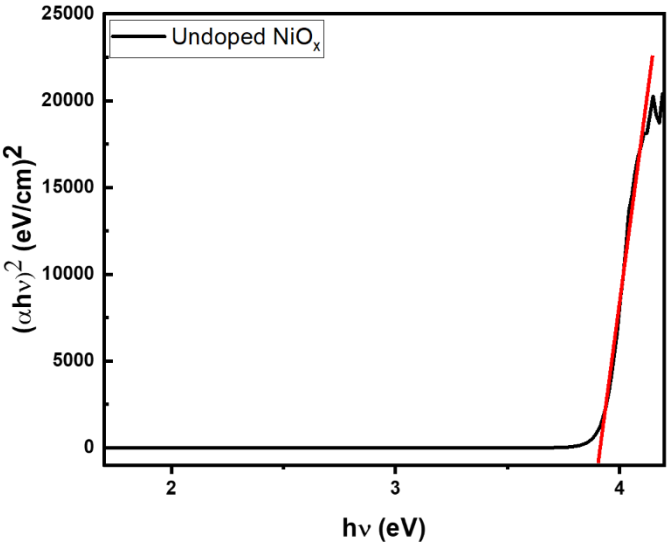

Fig. S3. Tauc plot of undoped NiO_x thin film.

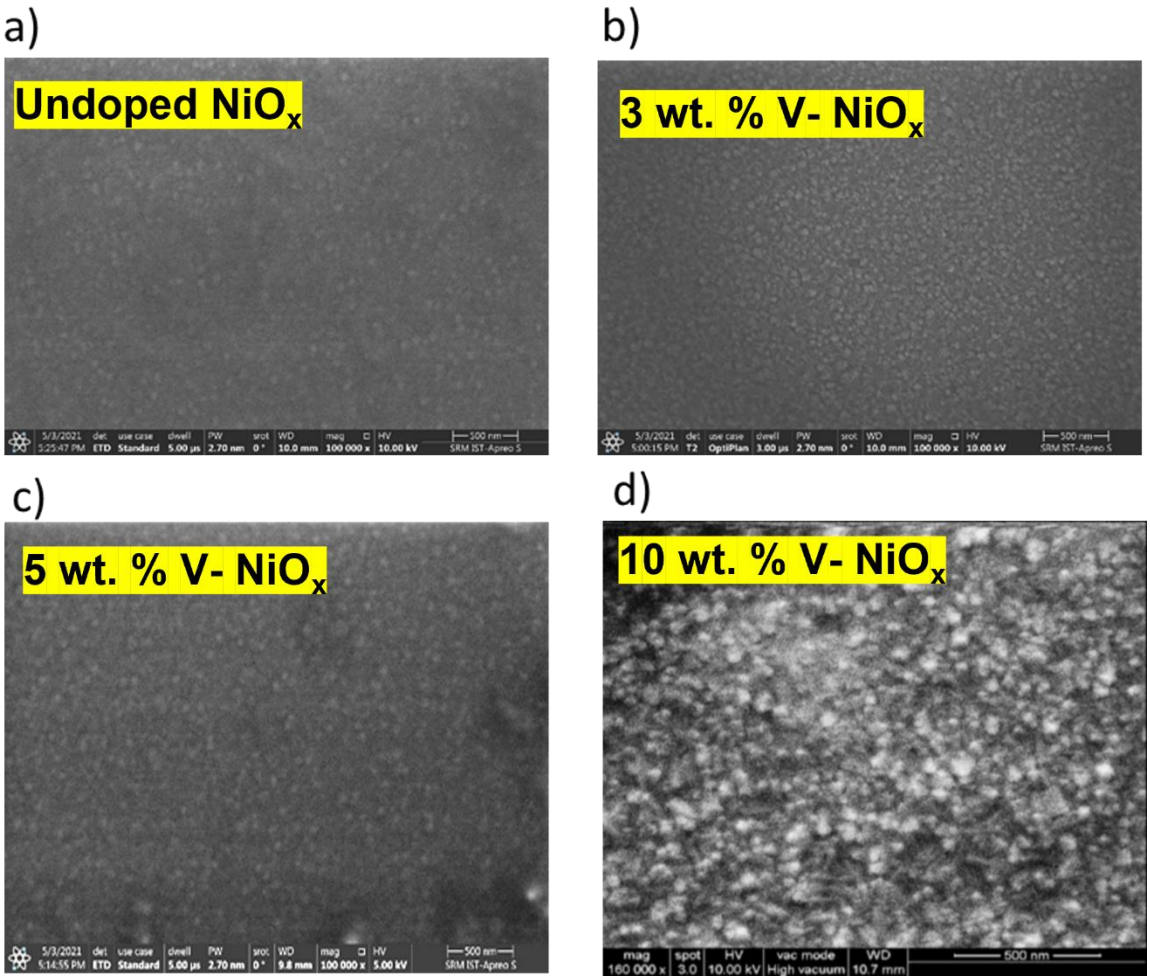

Fig. S4. SEM images of a) undoped NiO_x b) 3 wt.% V:NiO_x c) 5wt.% V:NiO_x d) 10 wt.% V:NiO_x thin film.

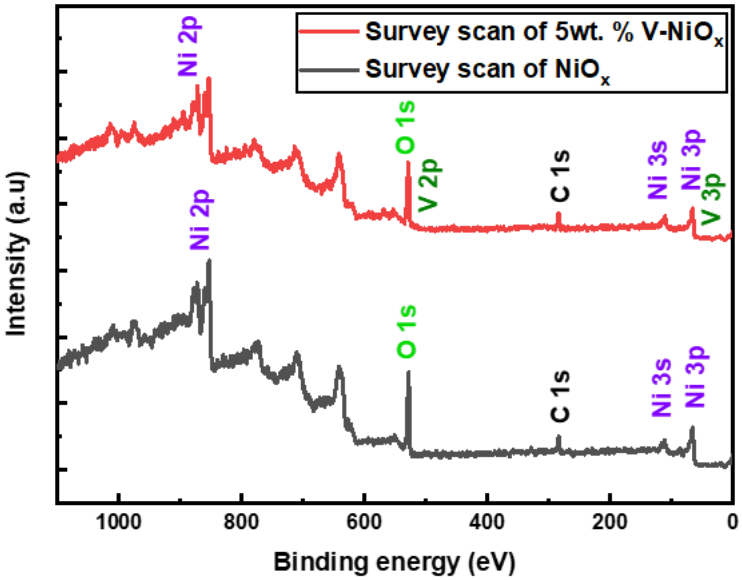

Fig. S5. XPS survey scan for undoped NiO_x and 5 wt. % V doped NiO_x

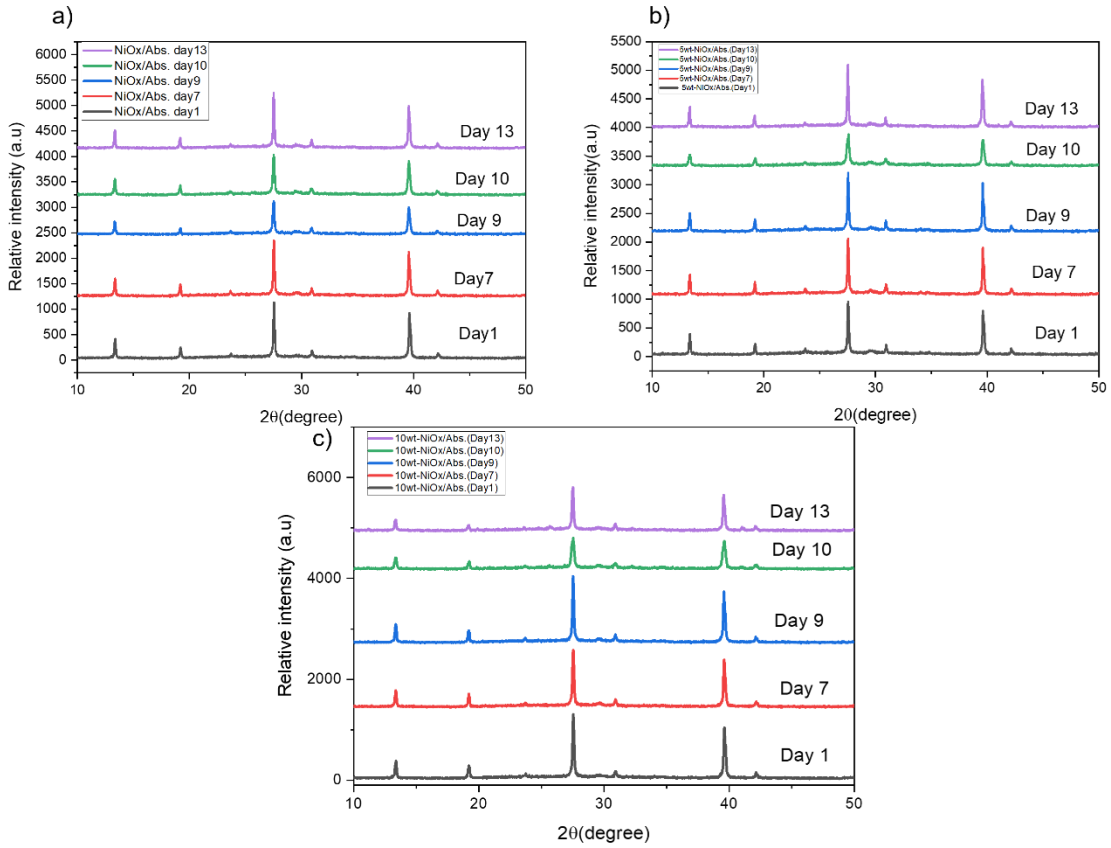

Fig. S6. Degradation analysis of $CsFAPbI_3$ thin films samples stored in dark, N_2 atmosphere for 13 days. a) $CsFAPbI_3$ absorber on undoped NiO_x b) $CsFAPbI_3$ absorber on 5 wt. % V:NiO_x c) $CsFAPbI_3$ on 10 wt. % V:NiO_x

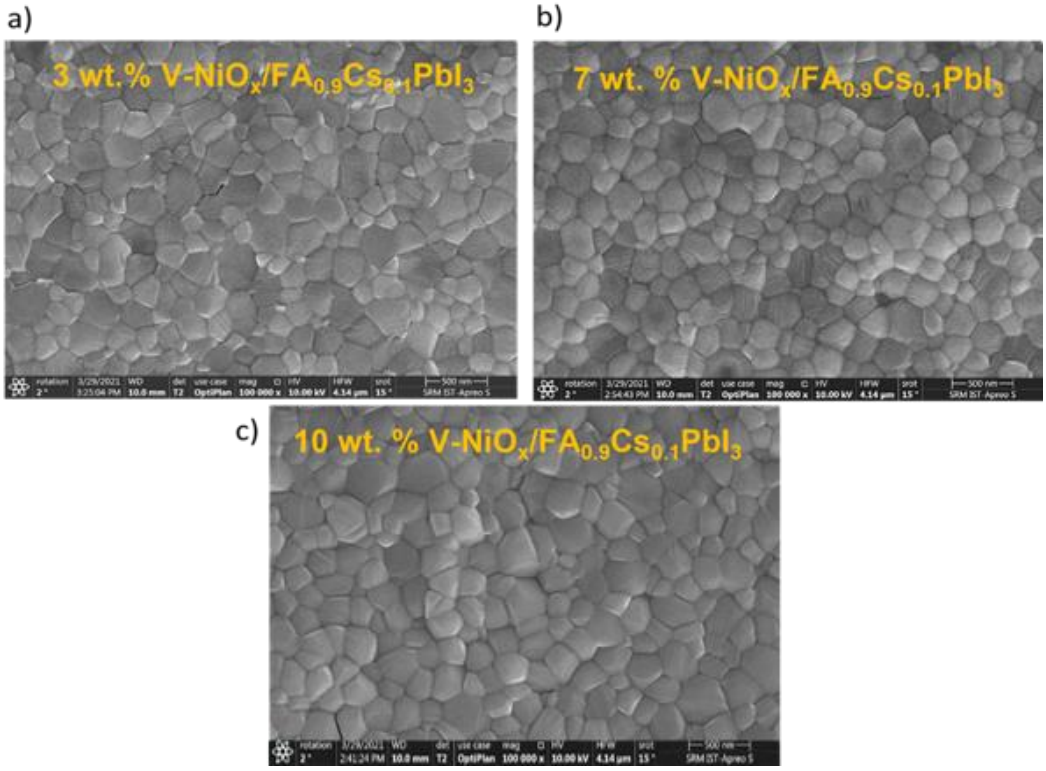

Fig. S7. SEM image of absorber coated on a) 3 wt. % V:NiO_x b) 7 wt. % V:NiO_x and c) 10 wt. % V:NiO_x with inset showing corresponding grain size distribution.

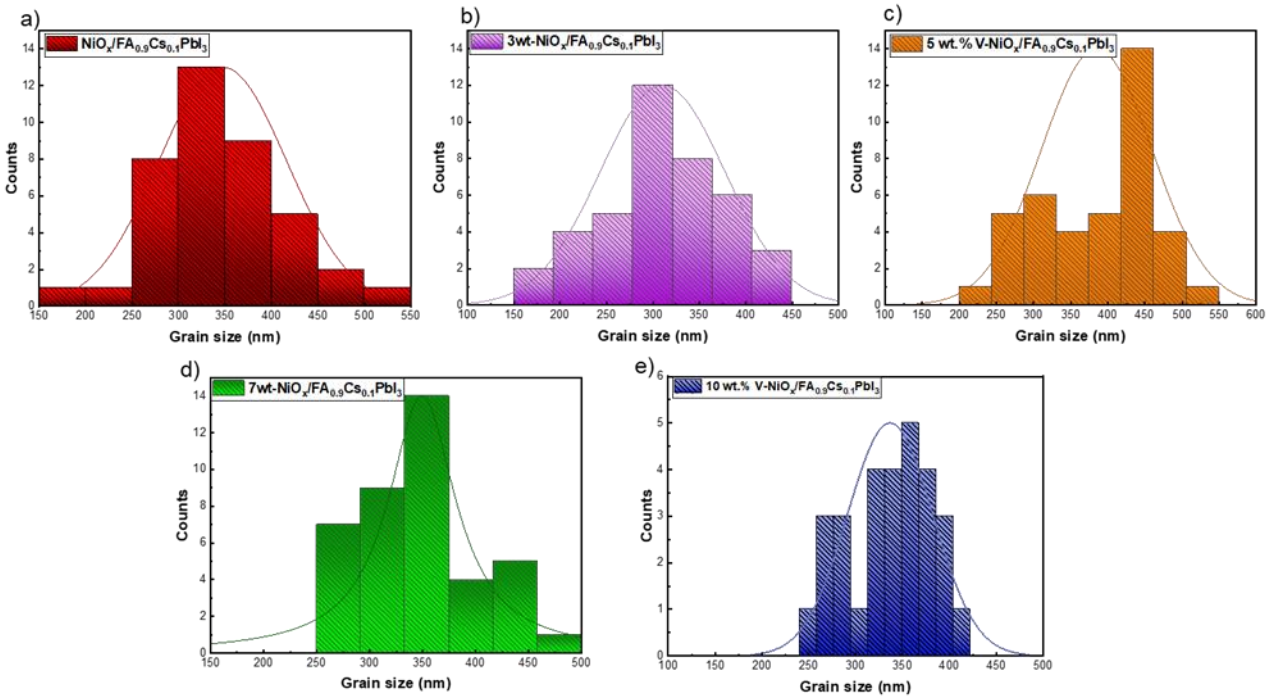

Fig. S8. Grain size histograms of absorber coated on top of a) undoped NiO_x b) 3 wt.% V:NiO_x c) 5 wt.% V:NiO_x d) 7 wt.% V:NiO_x and e) 10 wt.% V:NiO_x.

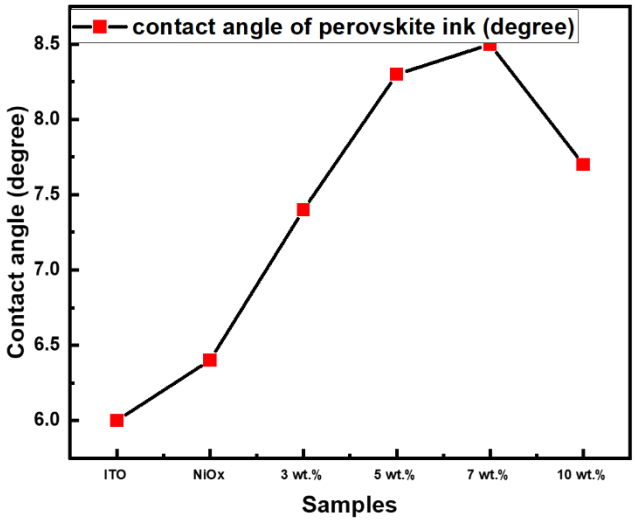

Fig. S9. Contact angle measurement on undoped and different wt. % V doped NiO_x thin films with DMF:DMSO solvent.

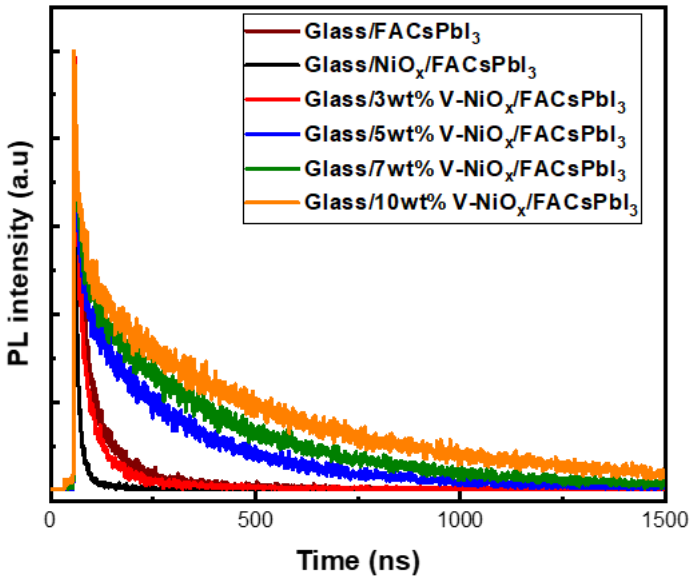

Fig. S10. Time resolved PL spectra of absorber on top of undoped and different wt. % V-doped NiO_x HTL.

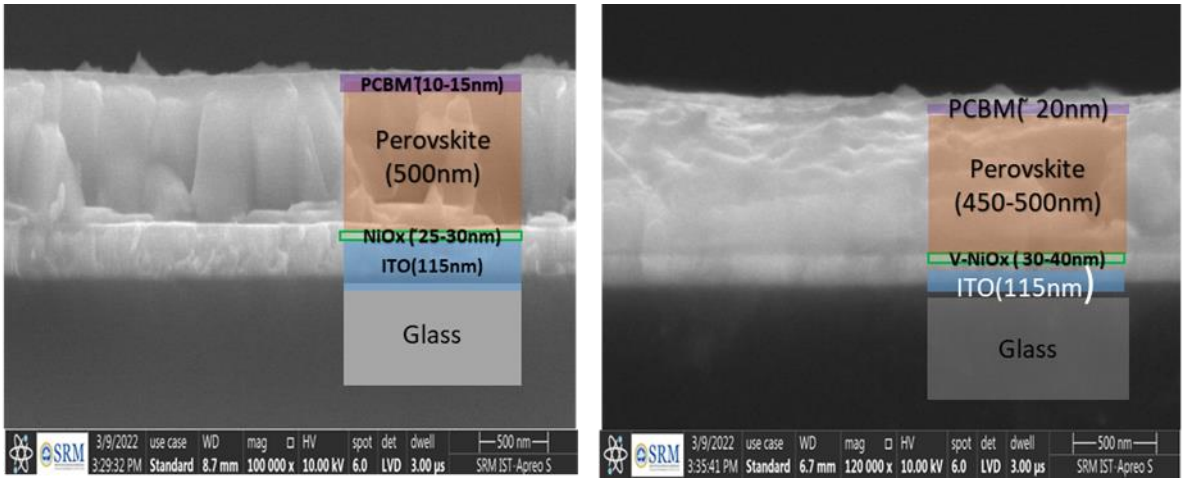

Fig. S11. a) Cross-section SEM images of $FA_{0.9}Cs_{0.1}PbI_3$ absorber on undoped NiO_x HTL b) 5 wt. % V:NiO_x HTL.

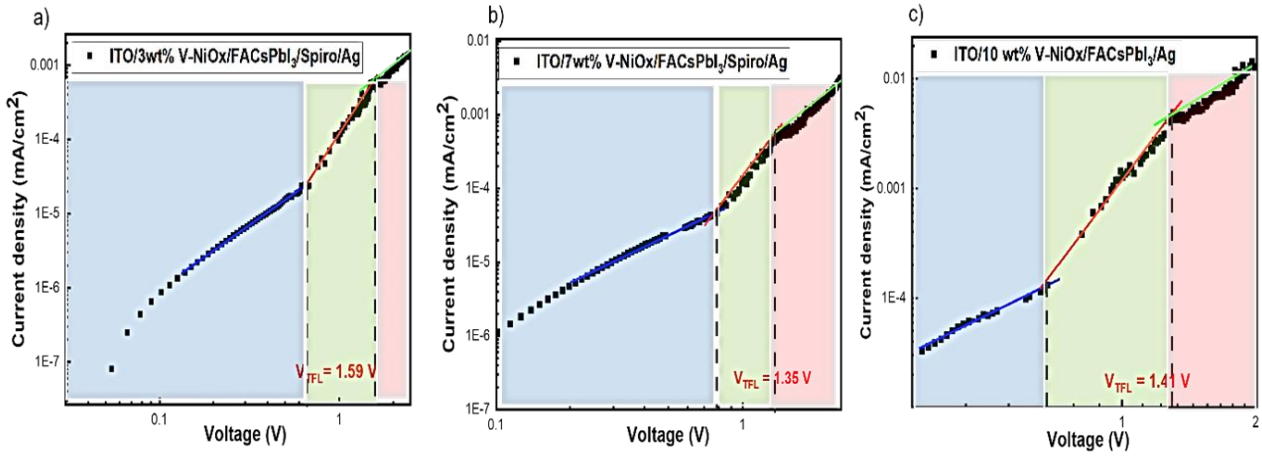

Fig. S12. SCLC plots of a) 3 wt. % V:NiO_x b) 7 wt. % V:NiO_x and c) 10 wt. % V:NiO_x hole only devices.

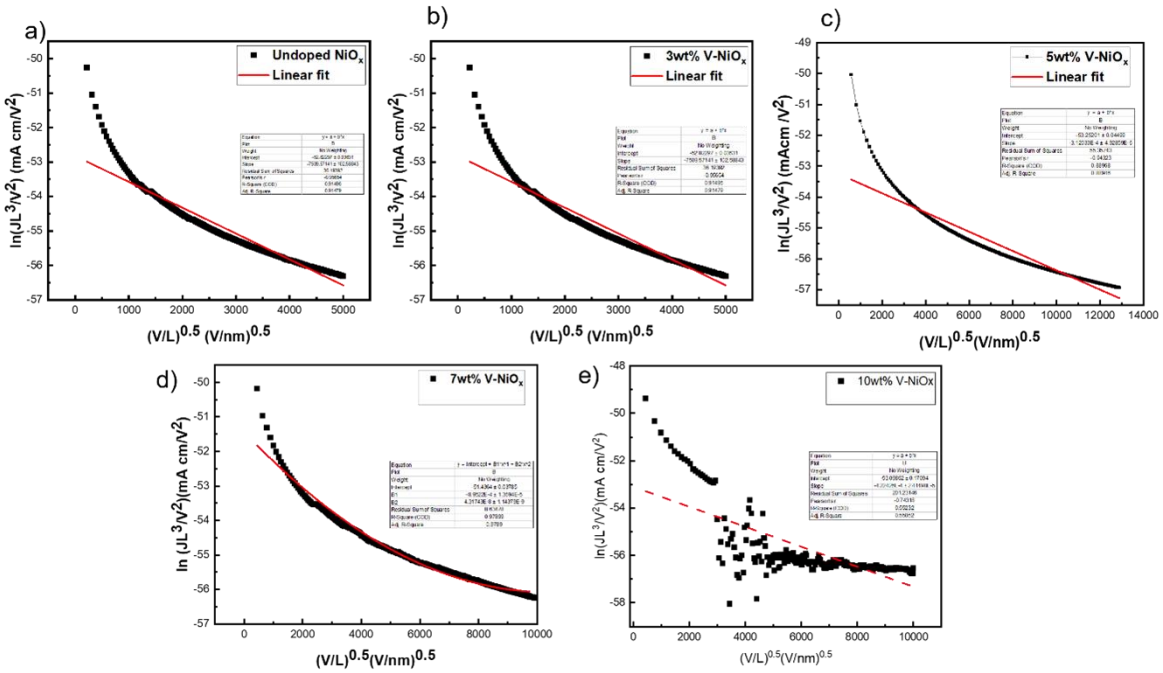

Fig. S13. Mobility plots of a) undoped NiO_x b) 3 wt.% V:NiO_x c) 5 wt.% V:NiO_x d) 7 wt.% V:NiO_x and e) 10 wt.% V:NiO_x.

Thin film sample	Interplanar spacing (Å)	Crystallite size (nm)
1) Undoped NiO_x	2.12	55.4
2) 3 wt.% V:NiO_x	2.16	33.7
3) 5 wt.% V:NiO_x	2.17	24.8
4) 7 wt.% V:NiO_x	2.17	13.9
5) 10 wt.% V:NiO_x	2.17	20.1

Table S1. XRD plot parameters of interplanar spacing and crystallite size for doped and undoped NiO_x thin films

Thin film sample	Crystallite size (nm)
1) Undoped NiO_x/$FACsPbI_3$	5.18
2) 3 wt.% V:NiO_x/$FACsPbI_3$	12.96
3) 5 wt.% V:NiO_x/$FACsPbI_3$	13.18
4) 7 wt.% V:NiO_x/$FACsPbI_3$	14.14
5) 10 wt.% V:NiO_x/$FACsPbI_3$	19.44

Table S2. Crystallite size of $FA_{0.9}Cs_{0.1}PbI_3$ absorber on doped and undoped NiO_x HTL.

Thin film sample	Urbach energy E_u (meV)
1) Undoped NiO_x/$FACsPbI_3$	31.30
2) 3 wt.% V:NiO_x/$FACsPbI_3$	35.92
3) 5 wt.% V:NiO_x/$FACsPbI_3$	35.77
4) 7 wt.% V:NiO_x/$FACsPbI_3$	35.20
5) 10 wt.% V:NiO_x/$FACsPbI_3$	36.34

Table S3. Urbach energy values for $FA_{0.9}Cs_{0.1}PbI_3$ absorber on doped and undoped NiO_x HTL

Thin film sample	Surface energy (mJ/m^2)
1) Undoped NiO_x	31.30
2) 3 wt.% V:NiO_x	35.92
3) 5 wt.% V:NiO_x	35.77
4) 7 wt.% V:NiO_x	35.20
5) 10 wt.% V:NiO_x	36.34

Table S4. Surface energy values of doped and undoped NiOx HTL.

Sample	Wt. % of dopant added to precursor solution	Wt. % of dopant found in thin film sample
3 wt. % V:NiO_x	3	0.53
5 wt. % V:NiO_x	5	2.60
7 wt. % V:NiO_x	7	4.79
10 wt. % V:NiO_x	10	3.07

Table S5. Values of dopant concentration added to precursor solution and that experimentally found in thin film samples.