# Optimization of $NiO_x$ by sputtering for scalable semi-transparent perovskite solar cells

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Perovskite solar cells have appeared as a promising technology for highly efficient devices and tandem applications. However, one of the main challenges is to develop a fully scalable stack to enables their commercialization while maintaining high efficiency and stability. Among the possible deposition techniques, magnetron sputtering appears as the most suitable techniques for industrial purposes.

$NiO_x$ is one of the most promising inorganic hole transport layers (HTL) and is widely used for perovskite solar cells. It exhibits high optical transparency, a large band gap, good stability, and relatively low cost. The main challenge lies in controlling the double edge sword of $Ni^{3+}$: while it ensures the holes transport properties of $NiO_x$ in the bulk, an excess at the film surface may induce recombination sites and lead to a degradation of the perovskite.[1]

This work aims at optimizing the optoelectronic properties of $NiO_x$ by tuning the deposition conditions. Specific attention will be inclined toward the effect of oxygen ratio introduced during the deposition which is the key parameter to control the $Ni^{3+}$ concentration.[2] More precisely, we will see how the oxygen ratio significantly affects the $V_{oc}$ and fill factor (Figure 1a). The effects of thermal post-treatment on the optical properties and surface state will also be investigated (Figure 1b). Finally, strategies to efficiently passivate the sp-$NiO_x$ surface and mitigate the charge defects effects will be proposed. Thus, using optimized sp-$NiO_x$, we could increase the fill factor up to 80% compared to 70% with $NiO_x$ deposited by ALD and reach an efficiency of 16.6% in a fully scalable p-i-n stack (0.09 $cm^2$) with perovskite deposited by slot-die in open-air conditions (Figure 1c).

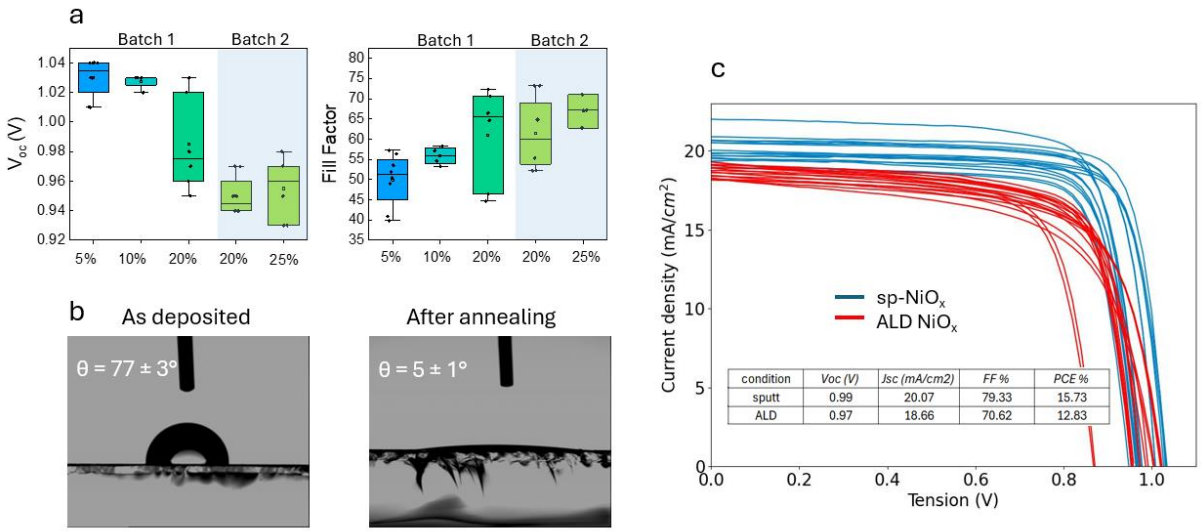


*Figure 1: a) Effect of the $O_2$ ratio on the $V_{oc}$ and FF, over two different batches deposited under the same conditions. b) Contact angle of NiOx thin films as deposited and after annealing. c) Comparison of JV curves of semi-transparent PIN perovskite solar cells with sp-$NiO_x$ and ALD-$NiO_x$.*

1. Peng, Z. *et al. ACS Appl. Energy Mater.* **6**, 1396–1403 (2023).

2. Lee, L. K. *et al. ACS Mater. Lett.* 1698–1706 (2025).