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**Breakthroughs in NiO<sub>x</sub>-HTMs towards stable, low-cost and efficient perovskite solar cells**

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**Abstract**

Although revolutionary progress in power conversion efficiencies (PCEs) of perovskite solar cells (PSCs) greater than 22 % has accompanied significant advances in materials engineering, processing, and device architectures, the selection of proper hole transporting materials (HTMs) is still critical for high efficiency, low-cost and long-term stability. The PSCs community is actively investigating a group of HTMs for high efficiency and long-term stability with commercial viability. In this context, inorganic nickel oxide (NiO<sub>x</sub>)-HTMs possess the advantages of energetically favorable energy band positions, high hole mobility, superior chemical stability, and low cost manufacturing. Herein, we address the initial breakthroughs and recent progress in NiO<sub>x</sub>-HTMs for PSCs. In addition to synthetic routes and deposition techniques used for NiO<sub>x</sub>-HTMs in two major device architectures (p-i-n and n-i-p structure), the stability and cost-breakdown of PSCs are evaluated in details. Finally, future directions for further improvements on issues such as high efficiency, stability and low-cost of PSCs based on NiO<sub>x</sub>-HTMs are also provided.

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