

Graphene-based Back Electrodes for Cost-effective, Efficient and Large-area Gold-free Perovskite Solar Cells

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Perovskite solar cells (PSCs) are the fastest-advancing technology among the third generation photovoltaics and promise to achieve even higher power conversion efficiency (PCE) than silicon solar cells while significantly decreasing their manufacturing costs. To now, the most performant PSCs reported in literature are based on a mesoscopic architecture [1], which have reached a certified PCE up to 22.7%. Furthermore, small lab-scale cells have been scaled up to large-area devices (>1 cm²) and modules (>10 cm²) by means of deposition methods compatible with industrial manufacturing. However, gold films are typically used as the back electrode of the mesoscopic PSCs, arising severe concerns for their future commercialization. In fact, on one hand, both gold cost and deposition through energy-consuming vacuum evaporation drastically affect the overall cost of the mesoscopic PSCs. On the other hand, gold ion migration toward either the hole-transporting layer (HTL) or the perovskite causes severe instability effects under operating conditions, decreasing the PSC lifetime [2]. Therefore, the Levelized Cost of Energy of current gold-based mesoscopic PSCs is still not yet competitive with commercial photovoltaic technologies.

In this work, we show a simple approach to replace the gold of PSC back electrode with nanocarbon films without altering the underlying structure of the traditional mesoscopic PSCs. First, we formulated a new graphene-based paste in alcohols (e.g., 2-propanol) that can be deposited in form of electrode film by printing techniques (e.g., spin coating and doctor blading) at low temperature (<100 °C), including room temperature. The graphene-based pastes optimally retain their electrical properties over a wide range of temperature (-45/+150 °C) and under tensile strain of almost 10%. In particular, they recover the electrical conductivity over cyclic tensile stresses between 0% and 3%, which are beyond the values measured for the thermal-induced tensile stresses. Subsequently, we optimized the printing parameters for the paste deposition onto the HTL of gold-based mesoscopic PSCs. An automatized doctor blading apparatus has been developed to provide a repeatable and scalable manufacturing process of the proposed graphene-based PSCs. The PCE of our graphene-based PSCs (> 13%) are less around 15% lower than the devices using gold as the back electrode. Moreover, our cells exhibit a fill factor (FF) over 70%, which resembles the one of the gold-based references. Our low-temperature graphene-based pastes are currently implemented in advanced mesoscopic PSCs [3,4] and perovskite solar modules (PSMs) [5] including graphene-doped TiO₂ ETL and 2D transition metal dichalcogenides interlayer [6] in order to overcome the "gold" PCE and reach the state-of-the-art performance through viable large-scale manufacturing processes.

References

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Figures

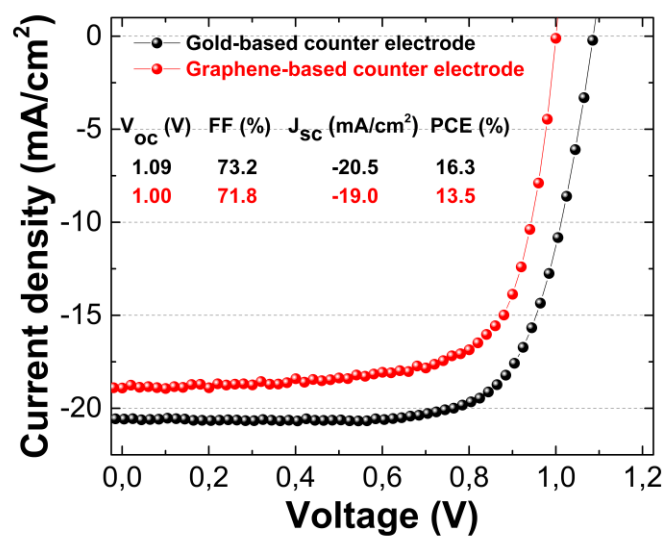


Figure 1: J-V curves and photovoltaic parameters of graphene-based PSCs and gold-based reference.