Two-dimensional (2D) interface engineering for enhancing performances and scalability of perovskite based photovoltaics

Sara Pescetelli[1],
Antonio Agresti[1] Leyla Najafi[2], Sebastiano Bellani[2], Francesco Bonaccorso[2] and Aldo Di Carlo[1]

1 Department of Electronics Engineering, University of Rome "Tor Vergata", via del Politecnico 1 00133 Rome – ITALY
2 Graphene Labs, Istituto Italiano di Tecnologia, via Morego 30, 16163 Genova, Italy
3

pescetel@uniroma2.it

Recently, organic-inorganic halide perovskite solar cells (PSCs) are in the spotlight of photovoltaic (PV) research to rival the leading technologies silicon solar cells and inorganic thin-film solar cells since power conversion efficiency (PCE) exceeding 23%[1]can be obtained by affordable (low-cost and low-temperature) solution processing with a scaling-up prospective. In this context, the interface engineering of PSCs plays a pivotal role in achieving high PCE. In fact, graphene and related two-dimensional materials (GRMs) are promising candidates to tune "on demand" the interface properties of PSCs. In particular, the perovskite photoactive layer needs to work synergistically with the other functional components of the cell, such as charge transporting/active buffer layers (ABL) and electrodes.
In this work, we proposed an engineered mesoscopic n-i-p structure with zero-dimensional MoS_2 quantum dots (MoS_2 QDs), derived by liquid phase exfoliated MoS_2 flakes, anchored to the functional site of reduced graphene oxide (RGO) flakes as ABL between perovskite and Hole Transport Layer.[2] This ABL insertion provides both hole-extraction through an electron injection mechanism and electron-blocking properties.
Our "graphene interface engineering" (GIE) strategy based on MoS_2 QD/graphene hybrids enables PSCs to achieve a PCE up to 20.12% (average PCE of 18.8%).
The possibility to combine quantum and chemical effects into GIE, coupled with the recent success of graphene and GRMs as interfacial layer,[3] represents also a promising strategy for the development of next-generation perovskite solar modules (PSMs).[4]
In fact, the proposed strategy has been scaled from lab-scale devices to large-area PSMs. Moreover, 2D materials can be directly produced from cost-effective and environmentally friendly solution-processed methods from their bulk counterparts, allowing inks with on-demand (opto)electronic properties to be formulated. Solution-processed 2D materials can be deposited by using printing/coating techniques suitable to cover a large area. In this regard, the proposed MoS_2 QD/RGO composite cannot be produced in large amount and this constrains its application to large-area module. In this perspective, a chemically functionalized molybdenum disulphide ($fMoS_2$) is produced by high-throughput liquid expholiation technique and employed as an efficient ABL at the perovskite/HTL interlayer for improving the hole injection/collection at the counter-electrode (CE).
Notably, our 2D material-engineered PSMs have shown a PCE of 13.4% over an active area of 108 cm^2.
Finally, the proposed PSMs have also displayed an increased lifetime under prolonged thermal stress, unambiguously confirming the crucial role of the 2D material-based layers in preventing perovskite/CTL interface degradation.

References

[1]https://www.nrel.gov/pv/assets/images/efficiency-chart.png.
[2] Najafi, L.; et al. ACS Nano (2018), 12, 10736–10754.
[3] Biccari, F.; et al. Adv. Energy Mater. 2017, 1701349, 1–8.
[4] Agresti, A.; et al. ACS Energy Lett. (2017), 2 , 279–287.