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Editorial

Perovskites: Versatile Weaponry in the Arsenal of Energy Storage and Conversion

Athanasios Zarkadoulas [1,2] and Vassilis N. Stathopoulos [1,2,*]

[1] Laboratory of Chemistry and Materials Technology, Department of Agricultural Development, Agrofood and Management of Natural Resources, National and Kapodistrian University of Athens, Psachna Campus, 34400 Evia, Greece
[2] Centre of Excellence "Energy, Renewable Resources and Transportations", National and Kapodistrian University of Athens, Panepistimiopolis, 15771 Zografou, Greece
* Correspondence: vasta@uoa.gr

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1. Background

A plethora of multi-functional materials with properties that can be adjusted and tuned to meet the needs of energy storage and conversion has emerged over the last years. In this context, perovskites are a "jack of all trades", since they exhibit many advantages, including stability, durability, efficiency in energy applications, manufacturability, tailored properties, and facile synthesis.

The perovskite structures mentioned in this editorial refer to either perovskite oxides with stoichiometry ABO_3 (where A indicates alkaline or alkaline earth metal ion, and B indicates lanthanoid metal ion) or halide perovskites ABX_6 (where A indicates organic cation, B indicates metal ion, and X indicates halide ion). The typical crystal lattices for ABO_3 and ABX_6 structures are shown in Figure 1. Substitution at specific sites of perovskites can lead to distortions or vacancies, giving rise to structured materials with different properties from the parent perovskite. Doping with other elements (ions) is also possible.

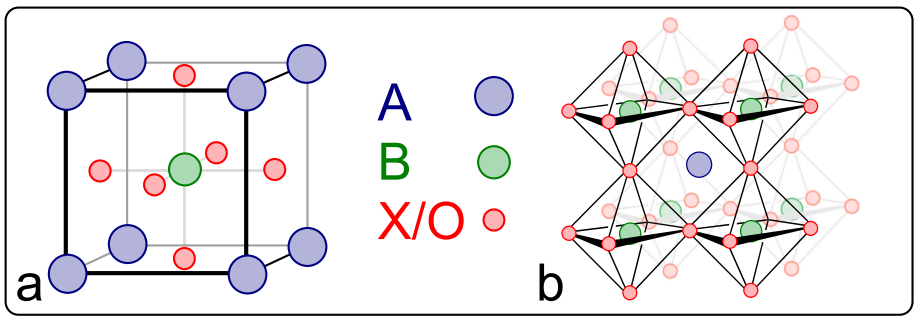

Figure 1. (**a**) Crystal structure (unit cell) of a cubic perovskite; (**b**) crystal structure showing corner-sharing octahedra.

2. Energy Storage and Conversion

2.1. Perovskite Solar Cells (PSCs)

After early studies that verified the activity of halide perovskites in solar energy conversion in photovoltaic cells the field has advanced significantly. Meroni et al. [1] reviewed on triple-mesoscopic carbon perovskite solar cells (mCPSCs), focusing on the advancements in both materials and processes in each layer, giving insight for forthcoming studies and applications. Earlier, Kim et al. [2] in a review article underlined the significance

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of the electron transport layer (ETL) in the charge transfer process of perovskite solar cells, covering both progress and development methods.

Catone et al. [3] reported on the usefulness of fast transient absorbance spectroscopy in order to evaluate the dependence of hot-carrier dynamics during the initial stages of excitation on structural features (morphology and dimensions) of mixed-cation hybrid lead halide perovskite crystals.

As a means of boosting the power conversion efficiency (PCE), Chen et al. [4] investigated the embedding of hybrid perovskite quantum dots (AuNP:QD-$CSPbBr_3$) in MA-localized surface plasmon coupling in $MAPBI_3$ (MA: methyl-ammonium, $CH_3NH_3^+$) PSCs, giving rise to an ~28% increase in PCE.

Increased conversion efficiency in potassium- and formamidinium-doped $MAPbI_3$ PSCs was also achieved by Oku et al. [5] by inserting decaphenylcyclopentasilane layers at the perovskite/hole transport interface and annealing at ~200 °C. This process led to decreased PbI_2 build-up and prolonged stability.

Lead halide perovskites $(FAPbI_3)_{0.95}(MAPbBr_3)_{0.05}$ have been employed by Chung et al. [6] in a solar-driven cell for the tandem electrochemical CO_2 reduction to CO and H_2 (Au electrode) and water oxidation to O_2 (Co-Pi electrode). An efficiency of 8% was achieved for the overall solar-energy-to-fuel process.

Driven by the need to replace toxic Pb in the light-absorbing layer with a less toxic metal such as Sn, which exhibits comparable properties with Pb in PSCs, Shah et al. [7] summarize the progress and state-of-the-art development in tin halide perovskite solar cells. Advancements in the field of lead-free PSCs point towards the great potential tin exhibits as a viable substitute for lead in the commercialization and manufacturability of PSCs.

Cheng et al. [8] prepared mixed lead–tin $MA_{0.5}FA_{0.5}Pb_{0.8}Sn_{0.2}I_3$ perovskite thin films by altering solution compositions, overcoming the synthetic challenges posed by tin stability and different reaction rates.

A theoretical approach to evaluate conversion capacity of $MASnI_3$ PSCs was performed by Gan et al. [9] using solar cell capacitance simulator (SCAPS). Both electron and hole transport layers were investigated. Structural aspects such as thickness and defects were also scrutinized, indicating $Cd_{0.5}Zn_{0.5}S$ (electron transport) and $MASnBr_3$ (hole transport) as the most suitable materials for each layer.

2.2. Perovskite Oxides

As sustainable, more versatile replacements for expensive Pt in microbial fuel cells for the oxygen reduction reaction (ORR), Nandikes et al. [10] reviewed the use of perovskite oxide-based nanocomposites, giving a perspective on the structure–activity relationship and outlook for future work in this field.

Perovskite oxides are major protagonists in syngas production. Ahmad et al. [11] reported on syngas production via CH_4 reforming with CO_2, with $SrNiO_3$ and $CeNiO_3$ perovskites. The cerium analog displayed higher conversion activity, attributed in pore volume and specific surface areas. Both catalysts were deactivated by carbon deposition.

In a related topic, Mikkola et al. [12] reported on another use of perovskite oxides in solid oxide electrolyzer cells. To overcome material wear in solid oxide fuel and electrolyzer cells, $LaFeO_3$ along with Co and Mn spinels were used as coatings on stainless steel connectors. The $LaFeO_3$ perovskite exhibited failure in pure O_2 atmosphere at 800 °C, in the form of delamination.

Finally, the porosity and crystallinity of perovskites enable them to store hydrogen, a very useful feature in energy storage. Lahlou Nabil et al. [13] investigated experimentally and theoretically the dihydrogen storage capability of $LaCrO_3$, finding storage capacity of ~4% *w*/*w*, via a thermodynamically stable $LaCrO_3H_6$ hydride.

3. Outlook

Using the above examples for the versatility of perovskites in various applications regarding energy conversion, storage and stability, it is evident that they constitute an attractive family of materials with a very wide area of applicability. Current and future trends include the development of sustainable, green, non-toxic materials for applications in solar energy conversion (PSCs), energy storage (H_2 storage), synthesis of feedstock chemicals (solid oxide fuel and electrolyzer cells), or even anti-corrosion coatings.

Conflicts of Interest: The authors declare no conflict of interest.

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