PROSPECTIVE ARTICLE

Solar Energy Sources Based on Perovskites – Future Research Prospects and Industrial Opportunities

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Perovskite materials have become one of the hottest topics in solar energy conversion in recent years. They reached similar efficiency to the polycrystalline silicon solar cells, and also found applications in a variety of fields out of energy harvesting, such as lighting. The main advantage of this class of materials is the ease of processing, in line with the large-scale solution fabrication techniques. Although the technology still faces some challenges related to long-term stability the prospects for commercialization at the beginning of 2021 are much more realistic in comparison with the forecasts released at the end of the previous 2019 year. In this perspective articles analysis of the research and market perspectives of the perovskite solar cells is made.

Introduction

With the increasing energy consumption worldwide, conventional fossils cannot fulfil the energy demands, so the application of harvesting devices providing clean, renewable energy has become a top priority of the research groups. Among the existing energy harvesting technologies such as piezoelectric, thermoelectric, radiofrequency, etc. photoelectric conversion realized with the solar cells design is the best established and the most reliable alternative energy source. Variety of technologies has been implemented to ensure effective conversion of the absorbed light into electricity, but the most recent efforts have been focused on the perovskite solar cells. They have exhibited significant progress in their parameters since the first report in 2012, when ~ 10% of efficiency has been reported for lead iodide perovskite solar cell [**1**]. The Perovskite materials structure is rather complex as a hybrid of organic-inorganic metal halide compound where more often methylammonium is located in the vertex of the face-centered cubic lattice, metal cations (most often lead Pb^{2+}) occupy the core of the cubic structure and halogen anions of Cl^-, Br^-, or I^- occupy the apex of the lattice. Multiple metal-halogen octahedra are joined together to form 3D structure. Because of the combination of organic and inorganic counterpart the advantages of both classes of materials are mixed in the new compound and provide the high efficiency due to the inorganic content and low-cost film deposition by solution processing due to the organic content [**2**]. For four years the conversion efficiency has been doubled and according to a report of the National Renewable Energy Laboratory (NREL) and reached ~22 % and afterward, in 2018 has reached 23% [**3**]. Up to date, this value is still near to the achieved in 2018 (25.5% reported by Ulsan National Institute of Science and Technology (UNIST) [**4**]), but still the potential for further development and commercialization is large. **Fig. 1** shows the development of the solar energy technology through the years, particularly the current official values for the efficiency of perovskite solar cells. It is summarized by the Ossila company, which is a major supplier of perovskite inks for this sector [**5**].

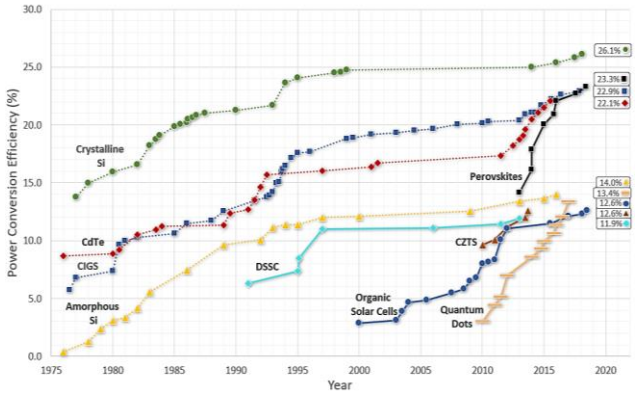


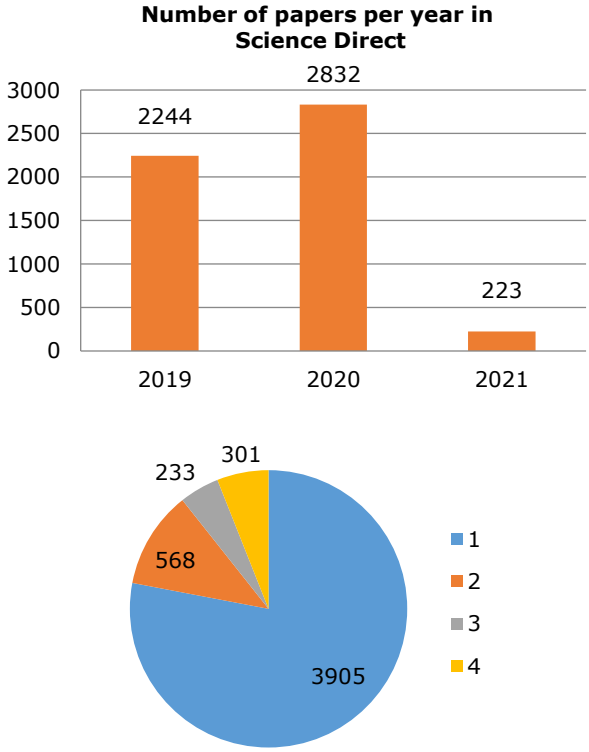
Fig. 1. Development of the solar energy technology through the years, based on the power conversion efficiency comparison, including the current official data for the efficiency of perovskite solar cells **[5].**

The graph includes the values certified at the end of 2019, as the annual report for 2020 is in preparation. Although the intrinsing instability of these materials and the toxicity of Pbl are still issues, the fast progress in their efficiency increasing at low cost makes them potential leaders among the new solar technologies.

Research perspectives

The number of publications on an annual basis in the world popular scientific databases is continuously increasing, which is an evidence for the active contribution of the research groups in this direction.

During the period 2019-2020 one of the most popular worldwide European situated database for scientific literature Science Direct has collected 5070 papers devoted to this topic (containing the key words combination "perovskite solar cell"), 3905 of which are research papers, 568 are reviews, 233 are short communications and 301 are book chapters [**6**]. Some of the most prominent journals under Elsevier publishing already planned to publish research related to this topic in 2021. The articles pending for release in 2021 are 223 (**Fig. 2**). The leading journals in the field, which devote most of their space to this topic, are Nano Energy, Solar Energy, and Journal of Alloys and Compounds. At the same time range IEEE Xplore, which is the largest USA database for scientific literature indicated about 359 papers when the same searching criteria are applied, giving information about dominant conference reports (277) over the journal papers (77).



1-research papers; 2-review papers; 3-short communications; 4-book chapters.

Fig. 2. Current and near future papers distribution on the topic per year and type, according to the Science Direct database.

The conferences have a general title related to the optoelectronic devices, nanotechnologies, renewable energies, electron devices. As it is expected considering the unsolved yet problems in the field, the main focus of the published research is put on the enhancement of the stability of perovskite solar cells, heat mitigation, synthesis and doping strategy for the absorbing, hole and electron transporting layers, defects and degradation mechanisms.

Other advanced technologies aiming perovskite solar cells performance enhancement are lead-free perovskites and tandem perovskite-silicon cells. Related research centres for study of such approaches that worth be mentioned, because they establish the modern trends and state-of-the-art research in the field are:

Korver Corp.

This is an American company situated in California and having branch in China. Its mission is development of high-efficient perovskite-silicon tandem solar cells in up-scaled format, having sufficient lifetime according to the current standards to be commercially fabricated.

Lawrence Berkeley National Laboratory (Berkeley Lab)

Berkeley Lab is a multidisciplinary national laboratory again located in California near the University of California. The team conducts perovskite-based research not only in the field of solar cells, but generally for the optoelectronics and other applications.

Helmholtz Zentrum Berlin (HZB)

The Helmholtz Zentrum Berlin für Materialien und Energie (HZB) is a research center that studies the processes in the materials that are related to possible lossless energy conversion.

Merck, Sigma Aldrich, Ossila

These are companies providing commercial raw materials for engineering the perovskite solar cell with the necessary purity grade and certificates of analysis and safety protocols for the end users. The have well developed distribution network around the globe.

Nowadays, the tandem technology seems to be the most promising for market release of device including perovskites in its composition due to the well-established efficiency and stability of the silicon-based devices and due to the market share held by the silicon in general. Currently, the efficiencies of these types of cells go beyond 26%, which is practically competitive with the p-n junction polycrystalline silicon cell. For this reason, the forecasts predict that the perovskite-silicon solar cells are expected to appear in large-scale production in 2021 [**7**].

Market perspectives

The basic segments of the perovskite solar cells market, according to the prognoses, are geographically distributed in 6 regions over 5 continents North America, Europe, Asia Pacific, Latin America, and Middle East and Africa. Boosting of this technology that will probably result in redistribution of the market segments is expected in countries such as India (where currently this research is national priority for projects funding), Japan, and China [**8**]. North America and Europe are put among the attractive regions for perovskite solar cell due to the intensive implementation of solar technology in these regions in general. The development of the market in regions such as

Latin America, Middle East and Africa is expected to expand with a much slower rate due to the high development costs and poor infrastructural capabilities. The companies such as Saule Technologies, Fraunhofer ISE, Oxford Photovoltaics, Xiamen Weihua Solar Co., Ltd, Dyesol, and FrontMaterials are some of the potential key players that are pointed as leaders in the perovskite solar cell market. The perovskite market is planned to grow with 32 % at the beginning of 2021 as compared to the previous 2019 year, reaching USD 2.35 Billion by 2026 [**9**].

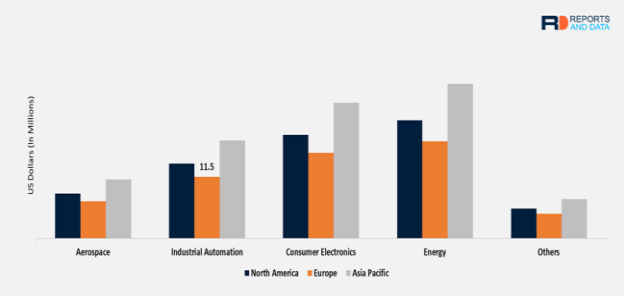


Fig. 3 Application of the perovskite solar cells in the different sectors together with a geographical distribution cross-section analysis [**9**].

The growth of the market is in terms of new structures of the cells, new manufacturing methods, new product types requiring specific parameters of the power supply and new industries that are dependent on the solar energy. Regarding the structures, the planar technology is expected to experience increased rate of implementation during the foreseen period of 6 years. The reason is the using of thin films for its realization and the already well elaborated procedures for low temperature thin film based energy sources production in large scale format, which will affect as a decrease of the manufacturing costs and the ending price of unit electrical power per unit area. Regarding the industry, out of the energy sector, the consumer electronics holds a favourable position on the market of the alternatively powered devices and it is expected a growth of approximately 32 % during the above-mentioned period (**Fig. 3**). As well, the Internet of Things (IoT) market is very promising, due to the expected vast development in the next years. For this kind of application, inkjet printing is an appropriate deposition process allowing high-volume, large-area production [**10**]. Although the focus is primary on the portable devices, it shouldn't be underestimated applications like Smart glasses and BIPVs (Building-integrated photovoltaics).

Conclusion

Considering the latest reports of the research groups, centres and industrial representatives the commercialization of the perovskite solar cells doesn't seem so far in future. There are solid indications that devices including perovskites (tandem cells) will make an unprecedented breakthrough in the market, opening the door to significant profits and investments in the development of infrastructure for the production of this type of devices. Nevertheless, the specialists in chemical synthesis still have to work for stabilizing the bonds in the material to achieve desired long-term stability for standing alone perovskite-only solar cell.

Acknowledgements

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Conflicts of interest

There are no conflicts to declare.

Keywords

Perovskite solar cells, Tandem perovskite-silicon cells, Solar energy sources

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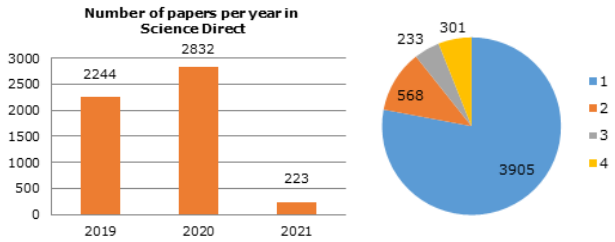
Authors biography

Mariya Aleksandrova received her MSc degree in electronics and the Ph.D. degree in the technology of electronic manufacturing from the TU-Sofia, in 2007 and 2010, respectively. Since 2015, she is an Associate Professor with the Department of Microlec¬tronics, TU-Sofia. She is an author or co-author of 6 books and more than 80 papers in international journals and conference proceedings. Her current research interests include microelectronic technologies, MEMS, piezoelectric energy harvesting, flexible electronics.

Graphical abstract



1-research papers; 2-review papers; 3-short communications; 4-book chapters.

Current and near future papers distribution on the perovskite solar cells per year and type, and photo of perovskite solar cell laboratory sample produced at the Department of Microelectronics, TU-Sofia.