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Frontiers, opportunities, and challenges in perovskite solar cells: A critical review

Mohammed Istafaul Haque Ansari[a], Ahsanulhaq Qurashi[b,*,1], Mohammad Khaja Nazeeruddin[c,**,1]

[a] Department of Mechanical Engineering, Indian Institute of Technology, Kanpur 208016, India
[b] Center of Excellence in Nanotechnology (CENT) and Chemistry Department, King Fahd University of Petroleum & Minerals, Dhahran, 31261, Saudi Arabia
[c] Laboratory of Photonics and Interfaces, Department of Chemistry and Chemical Engineering, École Polytechnique Fédérale de Lausanne, Station 6, CH-1015 Lausanne, Switzerland

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ABSTRACT

The breakthrough discovery of organic-inorganic hybrid perovskite materials for converting solar energy into electrical energy has revolutionized the third generation photovoltaic devices. Within less than half a decade of rigorous research and development in perovskite solar cells, the efficiency is boosted upto 22%. Aforesaid high PCE is accredited to high optical absorption properties, balanced charge transport properties, and longer diffusion lengths of carriers. Two dominant perovskite solar cell architecture has evolved; n-i-p, and p-i-n with mesoporous or planar heterojunction. In planar heterojunction configuration, perovskite light harvester is layered between hole/electron transport layers and the electrodes. The electron and hole transporting films increase charge collection efficiency and reduce recombination at interfaces. In the following review, we present a critical survey of the recent progress in perovskite absorber and charge transport materials that account for the exceptionally higher PCE of perovskite devices. Furthermore, numerous fabrication techniques and device architectures are summarized.

Contents

* Corresponding author at: Center of Excellence in Nanotechnology (CENT) and Department of Chemistry, King Fahd University of Petroleum & Minerals, Dhahran, 31261, Saudi Arabia.
** Corresponding author at: Laboratory of Photonics and Interfaces, Department of Chemistry and Chemical Engineering, École Polytechnique Fédérale de Lausanne, Station 6, CH-1015 Lausanne, Switzerland.
E-mail addresses: ahsanulhaq06@gmail.com (A. Qurashi), mdkhaja.nazeeruddin@epfl.ch (M.K. Nazeeruddin).
[1] Laboratory of Photonics and Interfaces, Department of Chemistry and Chemical Engineering, École Polytechnique Fédérale de Lausanne, Station 6, CH-1015 Lausanne, Switzerland.

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Mohammed Istafaul Haque Ansari completed his master from Jawaharlal Nehru Centre for Advanced Scientific Research (2009–2012). He completed his PhD from Jawaharlal Nehru Centre for Advanced Scientific Research Banglore India. Dr. Ansari is more interested into energy materials.

Dr. Ahsanulhaq Qurashi received his PhD in 2008 from Chonbuk national University, South Korea, and completed post doctoratal fellowship from Toyama University, Japan (2008–2010). Presently he is Associate Professor in CENT\Chemistry KFUPM. His research is focused on development of advanced functional nanomaterials for energy harvesting, catalysis, chemical and biosensor Applications. He is editor of book "Metal Chalcogenide Nanostructures for Renewable Energy Applications", Subject Assistant Editor to International Journal of Hydrogen Energy, regional editor of Current Nanoscience and editorial board member of Nature Scientific Report, MRB and Sensor Letters. He has published more than 75 papers in high quality international journals and presented over 50 papers in various international conferences

Dr. Mohammad Khaja Nazeeruddin received M.Sc. and Ph. D. in inorganic chemistry from Osmania University, Hyderabad, India. He joined as a Lecturer in Deccan College of Engineering and Technology, Osmania University in 1986, and subsequently, moved to Central Salt and Marine Chemicals Research Institute, Bhavnagar, as a Research Associate. He was awarded the Government of India's fellowship in 1987 for study abroad. In 2014, EPFL awarded him the title of Professor. His current research at EPFL focuses on Dye Sensitized Solar Cells, Perovskite Solar Cells, CO2 reduction, Hydrogen production, and Light-emitting diodes. He has published more than 509 peer-reviewed papers, ten book chapters, and he is inventor/co-inventor of over 50 patents. The high impact of his work has been recognized by invitations to speak at over 130 international conferences, and has been nominated to the OLLA International Scientific Advisory Board. He appeared in the ISI listing of most cited chemists, and has more than 49′000 citations with an h-index of 105. He is teaching "Functional Materials" course at EPFL, and Korea University; directing, and managing several industrial, national, and European Union projects. He was awarded EPFL Excellence prize in 1998 and 2006, Brazilian FAPESP Fellowship in 1999, Japanese Government Science & Technology Agency Fellowship, in 1998, Government of India National Fellowship in 1987–1988. Recently he has been appointed as World Class University (WCU) professor by the Korea University, Jochiwon, Korea (http://dses.korea.ac.kr/eng/sub01_06_2.htm), Adjunct Professor by the King Abdulaziz University, Jeddah, Saudi Arabia and Eminent Professor in Brunei.

1. Introduction

Pollution free renewable energy is gaining importance at an accelerated pace for the comfortable survival of human civilization. A foremost source of renewable energy is the solar energy which is inexhaustible and abundantly received by earth's surface. The upper atmosphere of earth encounters 174,000 terawatts (TW) of solar energy flux [1]. The yearly potentiality of solar radiation flux was 1575–49837 exajoules (EJ) as revealed by the United Nations Development Programme in its Global Energy Estimation in 2000, which is much higher than the entire energy utilization around the globe, which was 559.8 EJ in 2012 [2,3]. The amount of solar energy flux received by various parts of the earth depends on the latitude of the geographical area, as depicted in Fig. 1. The countries which are below latitude 45 °N and above latitude 45 °S are subjected to an annual average solar irradiation exceeding 1600 kWh/m^2, with peak irradiation received by some of the geographical areas of USA, Africa, Middle East and north-western Australia.

The solar energy can be harvested and transformed directly into electrical energy by photovoltaic cell, which is a type of photoelectric appliance whose electrical properties such as current, voltage or resistance, change once subjected to radiation of sun. It is customary to name the solar cells after the semiconducting material they are made up of. Some solar cells are constructed to capture solar radiation that is received by earth's surface, whereas some are optimally designed for space applications. They are built on single film of light-harvesting substance (single junction) or based on manifold physical structures (multijunctions) to avail merit of several absorbing and photoinduced charge dissociation processes.

As a result of substantial price reduction in recent years, solar power has now established itself as a cost effective and reliable source of energy. The production cost of solar cells has declined by 75% within less than a decade, due to which SCs has emerged as a cost competitive solar energy harnessing devices. The total photovoltaic cumulative installed capacity by top ten countries in 2014 and 2019 is shown as a pie chart in Fig. 2.

Solar cells are categorized as first, second and third generation cells according to their development stages, as depicted in Fig. 3. The first generation solar cells (SCs) are built on silicon crystal, a predominant semiconductor for the photovoltaic technology. Crystalline silicon (c-Si) is the crystalline semblance of silicon and exists in two forms either single crystal or multiple crystal consisting of small crystals. The second generation SCs consisting thin film are made of CdTe, CIGS and amorphous silicon, whose layer thickness ranges from a few nanometers to tens of microns, which is enough thin than traditional first generation SCs made of crystalline silicon and employing flakes up to 200 μm. The thin film technology is cheaper but have less Power Conversion Efficiency (PCE) than the conventional c-Si technology. Other thin-film technologies which are ongoing research and development phase are the third generation solar cells that comprise organic, dye-sensitized, polymer, copper tin zinc sulphide (CZTS), nanocrystals, micromorphs, quantum dots and perovskite solar devices. Fig. 4 shows the developmental trend of different types of solar cell technologies during the past four decades, where it can be clearly observed that the improvement of performance for perovskite solar cells was rapid.

A promising new class of thin-film SC which has drawn considerable interest and attention of the researchers is the perovskite SC, due to it's remarkable rapid growth of PCE in the photovoltaic industry [5–7]. The perovskite solar cell consists of a perovskite compound, generally an organic-inorganic lead or tin halide substance, that harnesses the solar energy as well as acts as a charge carrier conductor. Perovskites are a class of substances having typical chemical formula ABX_3, thus A, B are cations and X is an anion of unlike charges and dimensions (A is monocation, bigger compared to B dication). Fig. 5 depicts the crystal structure of methylammonium lead halides perovskite, $CH_3NH_3PbX_3$ (X = I, Br or Cl), where $CH_3NH_3^+$ cation is enclosed by octahedra of PbX_6. The X ions are mobile and can wander throughout the crystal, possessing 0.6 eV activation energy; the migration being induced by vacancy [8]. The energy depends on the position of halides axial to axial or equatorial to axial, and equatorial to equatorial. Organic-inorganic hybrid