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Review article

Recent progress in stabilizing hybrid perovskites for solar cell applications

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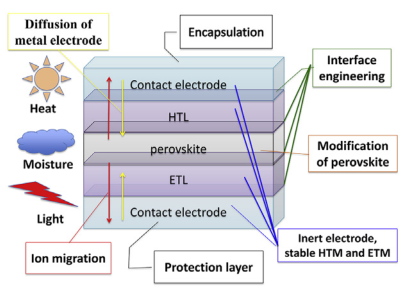
HIGHLIGHTS

- Progress in stabilizing hybrid perovskite solar cells (PSCs) is reviewed.
- Key issues related to the stability of perovskite components are evaluated.
- Optimizing multiple factors associated with component structures is essential.
- Strategies for improving the stability of PSCs are discussed and summarized.

GRAPHICAL ABSTRACT



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ABSTRACT

Hybrid inorganic-organic perovskites have quickly evolved as a promising group of materials for solar cells and optoelectronic applications mainly owing to the inexpensive materials, relatively simple and versatile fabrication and high power conversion efficiency (PCE). The certified energy conversion efficiency for perovskite solar cell (PSC) has reached above 20%, which is compatible to the current best for commercial applications. However, long-term stabilities of the materials and devices remain to be the biggest challenging issue for realistic implementation of the PSCs. This article discusses the key issues related to the stability of perovskite absorbing layer including crystal structural stability, chemical stability under moisture, oxygen, illumination and interface reaction, effects of electron-transporting materials (ETM), hole-transporting materials (HTM), contact electrodes, ion migration and preparation conditions. Towards the end, prospective strategies for improving the stability of PSCs are also briefly discussed and summarized. We focus on recent understanding of the stability of materials and devices and our perspectives about the strategies for the stability improvement.

1. Introduction

The research of hybrid inorganic-organic perovskites in photovoltaic and optoelectronic applications has been expanding exponentially [1]. The "gold triangle" of solar cells for commercial application is power conversion efficiency (PCE), cost, and stability.

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List of abbreviations

2-AET 2-aminothanethiol
2D two-dimensional
4-ABPACl butylphosphonic acid 4-ammonium chloride
4-tBP 4-*tert*-butylpridine
5-AVA 5-aminovalenric acid
ALD atomic layer deposited
AM-TiO_x amine-mediated titanium suboxide
BA n-butylammonium
BCP bathocuproine
BDT benzo[1,2-b:4,5:b']dithiophene
BT 2,1,3-benzothiadiazole
CA cyclopropylamine
C13-FAS triethoxy-1H,1H,2H,2H-tridecafluoro-*n*-octylsilane
CBL cathode buffer layer
CIL chemical inhibition layer
CIS CuInSe
CIGS CuInGaSe
CL compact layer
ClB cells cells with HTL prepared using chlorbenzene as solvent
ClF cells cells with HTL prepared using chloroform as solvent
CN 1-chloronaphthalene
CTAB cetyltrimethylammonium bromide
CTE coefficient of thermal expansion
cTiO_2 compact TiO_2
CuPc copper Phthalocyanine
CzPAF-SBF (7-(9,9'-spirobifluorene-2-yl)-*N*-(7-(9,9'-spirobifluorene-2-yl)-9,9-dioctyl-9H-fluoren-2-yl)-*N*-(4-(9H-carbazol-9-yl)phenyl)-9,9'-dicotyl-9H-fluoren-2-amine)
DIO 1,8-diiodooctane
DMOAP *N*,*N*-dimethyl-*N*-octadecyl(3-aminopropyl) trimethoxysilyl chloride silane
DPP diketopyrrolopyrrole
DR3TBDTT oligothiphenes containing a backbone structure of a benzodithiophene (BDT) unit as the central block and ethylrhodanine as the end group
DS down shifting
DSSC dye sensitized solar cell
EAI ethylammonium iodide
EC ethyl cellulose
EDA enthylenediamine
EH44 2,7-Di(*N*,*N*-dimethoxyphenylamino)-*N*-(2-ethylhexyl) carbazole
ETL electron transport layer
ETM electron-transporting materials
EVA ethylene vinyl acetate
F4-TCNQ tetrafluoro-tetracyanoquinodimet-hane
F4TCNQ 2,3,5,6-tetrafluoro-7,7,8,8-tetracyano-quinodimethane
FA formamidine
$FAPbI_3$ $NH_2CH{=}NH_2PbI_3$
FEAI 1,1,1-trifluoro-ethyl ammonium iodide
FF fill factor
GO graphene oxide
GO-Li lithium-neutralized graphene oxide
H101 2,5-bis(4,4'-bis(methoxyphenyl)aminophen-4″-yl)3,4-ethylene dioxythiophene
HA hydrazinium
HAT-CN 1,4,5,8,9,11-hexaazatriphenylenehexacarbonitrile
HS-PhF5 thiols containing highly hydrophobic motifs (HS−C_6F_5)
HTL hole transport layer
HTM hole-transporting materials
HTMs hole transport materials
HXRPES hard X-ray photoelectron spectroscopy
J_{SC} short circuit current
KEML Kunudsen effusion mass loss
KEMS Knudsen effusion-mass spectroscopy
Li-TFSI lithium bis(trifluoromethylsulfonyl) imide
LTO lithium titanium oxide
m-Al_2O_3 mesoporous Al_2O_3
m-TiO_2 mesoporous TiO_2
MA methylammonium
$MAPbI_3$ $CH_3NH_3PbI_3$
mCVT modified chemical vapor transport
MOTPA MeO-triphenylamine
mp-GP mesopours graphene/polymer
MPSC mesoporous perovskite solar cells
MUTAB 11-mercaptoundecyl trimethylammonium bromide
MW microwire
NC-TiO_2 nano-columnar 1-dimensional TiO_2 porous film
NGONRs nitrogen-doped graphene oxide nanoribbons
NMP *N*-methyl-2-pyrrolidone
NPB N,N′-Di(1-naphthyl)-N,N'-diphenyl-(1,1'-biphenyl)-4,4'-diamine
NP nanoparticle
NPs nanoparticles
NRs nanorods
NTs nantube arrays
ODA-FeS2 bi-functional octadecylamine-capped pyrite
OPV organic solar cells
oxo-G1 oxo-functionalized graphene
P3HT poly(3-hexylthiophene-2,5-diyl)
P3TAA poly(3-thiophene acetic acid)
PCE power conversion efficiency
PCBDAN [6,6]-phenyl-C61-butyric acid 2-((2-dimethylamino) ethyl)(methyl)-amino-ethyl ester
PCBM [6,6]-pheynl-C_{61}-butyric acid methyl ester
PDMS polydimethylsiloxane
PDMT poly(3,4-dimethoxythiophene)
PDMS polydimethylsiloxane
PDPP3T poly(diketo-pyrrolopyrrole-terthiophene)
PDPPDBTE Poly[2,5-bis(2-decyldodecyl)pyrrolo[3,4-c]pyrrole-1,4(2H,5H)-dione-(E)-1,2-di(2,20-bithiophen-5-yl) ethene]
PEA phenylethylammonium
PEDOT:PSS (poly(3,4-ethyllenedioxythiophene)):Polystyrene sulfonate
PEI polyethylene-imine
PEI poly(ethyleneimine)
PEG poly(ethyleneglycol)
PET polyethylene terephthalate
PFN-P1 poly[(9,9-bis(3'-(N,Ndimethylamino) propyl)-2,7-fluorene)-alt-2,7-(9,9-dioctylfluorene)
PhNa-1T 1,4-bis(4-sulfonatobutoxy)benzene and thiophene moieties
P(NDI2OD-T2) poly{[N,N'-bis(2-octyldodecyl)-naphthalene-1,4,5,8-bis(dicarboximide)-2,6-diyl]-alt-5,5'-_2,2'-bithiophene}
PMAA poly(methylmethacrylate)
PSC perovskite solar cell
PSCs perovskite solar cells
PTAA polytriarylamine
PVA polyvinyl alcohol
PVP polyvinypyrrolidone
RGO reduced graphene oxide
RH relative humidity