Energy Materials

Perspective

Homojunction perovskite solar cells: opportunities and challenges

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Abstract

Organometallic halide perovskites have rapidly become promising materials as a result of their outstanding properties in high-efficiency and low-cost next-generation solar cells. Perovskite materials can be adjusted to be p- or n-type by defect engineering through, for example, the self-doping method by controlling the precursor compositions and process conditions. Recently, a p-type perovskite/n-type perovskite homojunction has been proposed and constructed, which provides a possibility for the design of a novel type of perovskite solar cell (PSC). Following a brief overview of the physical fundamentals of perovskite homojunctions, a detailed discussion of the promising progress of recently reported homojunction PSCs is presented here, including theoretical simulations, extrinsic and interfacial doping and graded structures. Furthermore, the opportunities regarding higher doping concentrations, simpler device architectures, ion migration inhibition and device stability are discussed. Finally, an outlook that offers insights into the future development of highly efficient and stable homojunction PSCs is provided.

Keywords: Perovskite homojunctions, p-n junctions, electrical doping, solar cells

INTRODUCTION

Organometallic halide perovskites have become prominent semiconductor materials in recent years due to

their excellent optical and electrical characteristics. So far, perovskite materials have been utilized to realize high-performance solar cells[1,2], light-emitting diodes[3,4], photoelectric sensors[5,6] and other devices[7-10], most of which are based on heterojunction structures. Perovskite materials also benefit from their unprecedented ability to regulate their physical properties, including dimensions[11], direct bandgap[12] and electronically benign defects[13,14]. In particular, p- or n-type perovskite films can be fabricated by defect engineering through, for example, self-doping by controlling the precursor compositions and process conditions. Furthermore, the perovskite p-n homojunction structure[15] was proposed and demonstrated by precise regulation of the precursor stoichiometry. This homojunction was further integrated into planar perovskite solar cells (PSCs) to obtain excellent performance by introducing internal electric fields within the perovskite absorber layer[15]. Since then, researchers have dedicated significant attention to the perovskite homojunction architecture and investigated the electrical doping of perovskite materials[16], such as the conductivity type (p or n) and density of carriers.

The p-n junction is the basis of the semiconductor industry. The p-n homojunction is a junction between layers of similar materials with different doping types. The most common semiconductor materials, such as Si, Ge and GaAs, have excellent ambipolar doping characteristics, so they can form homojunction devices with outstanding performance. Similarly, the electrical doping of perovskite materials provides the possibility of perovskite homojunctions. Park *et al.*[17] reported the fabrication of homojunction PSCs with defect management by Cui *et al.*[15], thereby opening a new avenue for metal halide perovskite devices. Beyond existing planar heterojunction PSCs, the advent of perovskite homojunctions has brought an effective fresh route to achieve high power conversion efficiencies (PCEs) for PSCs. Moreover, perovskite homojunctions can draw on the mature experience and technologies established for classical inorganic solar cells, like silicon[18], which rely on homojunctions. Hence, homojunction PSCs have significant development prospects.

Although research into perovskite homojunction devices is still in its infancy, numerous high-quality studies continue to advance this field, as discussed in the following sections. Through simulation analysis, studies on performance optimization, structure design and defect management of homojunction PSCs provide theoretical guidance for this field. Moreover, experimental studies on extrinsic metal ion doping technology, interfacial doping strategies and graded homojunction designs have further expanded the development of perovskite homojunctions. Here, we introduce the physical fundamentals of perovskite homojunctions, further elucidate the significant research progress made so far, discuss research hot spots and opportunities and analyze the current technical bottlenecks to provide a critical reference for the development of PSCs.

FUNDAMENTALS OF PEROVSKITE HOMOJUNCTIONS: ELECTRICAL DOPING

Electrical doping is an important feature of optoelectronic semiconductor materials. The p- or n-type conductive properties of perovskite materials can be principally changed by intrinsic defects and extrinsic doping, resulting in the generation of holes or electrons. Intrinsic defects are mainly represented by point defects in the perovskite materials [Figure 1A] and can be induced and controlled through various methods, such as the film growth conditions[20], the temperature and time of the annealing treatment[21], the irradiation intensity[22] and the proportion of precursor components[19]. For example, there are numerous possible point defects in $MAPbI_3$ perovskite, including three vacancies (V_{MA}, V_{Pb} and V_I), three interstitials (MA_i, Pb_i and I_i), two cation substitutions (MA_{Pb} and Pb_{MA}) and four antisite substitutions (MA_i, Pb_i, I_{MA} and I_{Pb}). It is reported that I_i, MA_i, V_{MA}, V_{Pb}, MA_{Pb}, Pb_{MA} and V_I have low formation energies and can easily occur in bulk perovskite materials[23] [Figure 1B]. Among these defects, V_I, MA_i and MA_{Pb} can promote the transformation of perovskite films to n-type doping, while V_{Pb} and Pb_{MA} can lead to p-type doping.
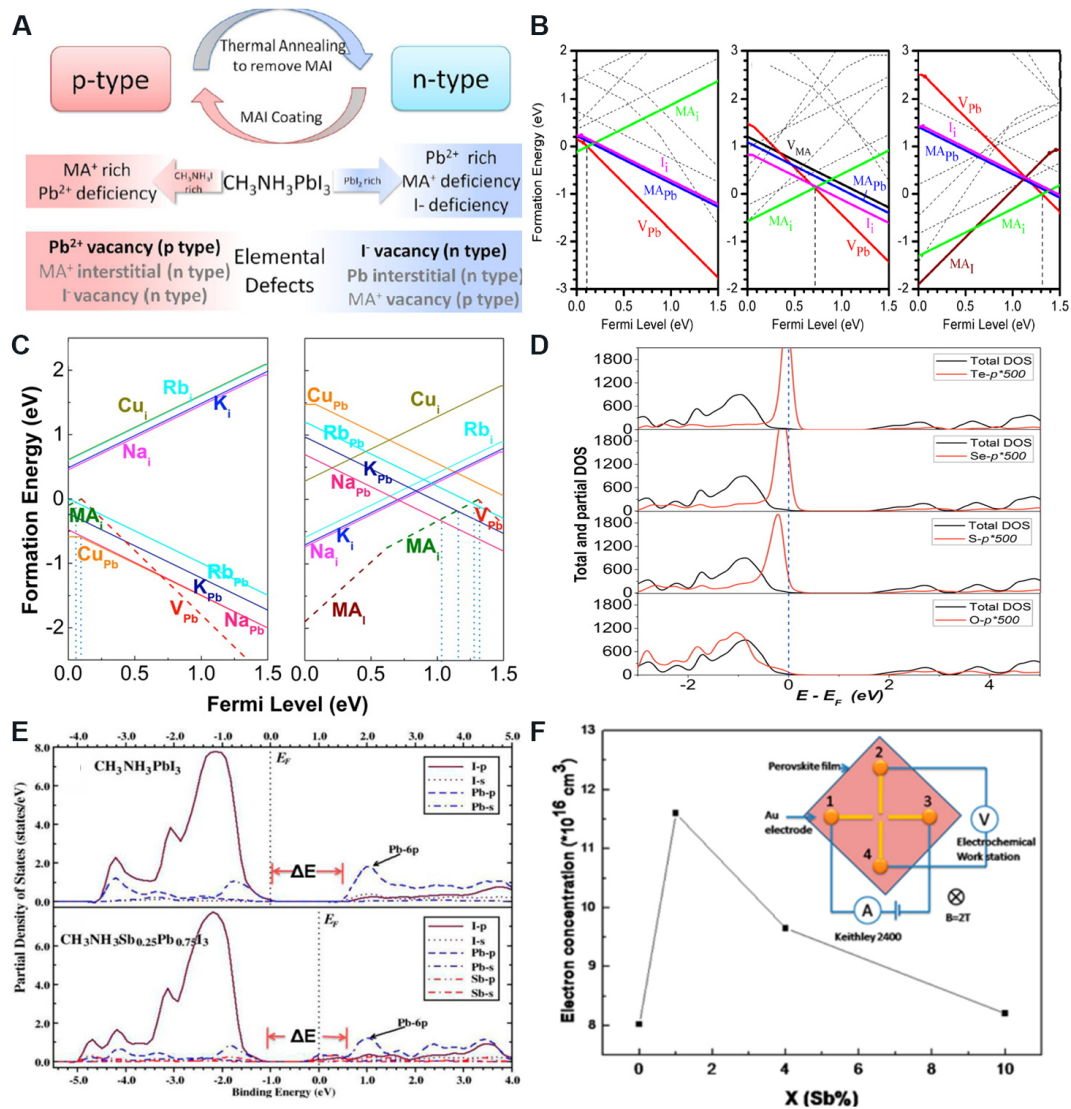
Figure 1. Characteristics of electrical doping. (A) Schematic of conductivity type conversions in perovskite films by self-doping. Reproduced from Wang *et al.*[19]. (B) Formation energies of intrinsic point defects in MAPbI$_3$, where the vertical dotted lines indicate Fermi level pinning and the Fermi levels are referenced to the valence band maximum. Reproduced from Yin *et al.*[23]. (C) Calculated formations energies of defects formed by group IA and IB elements as a function of the Fermi level under I-rich/Pb-poor and I-poor/Pb-rich conditions. (D) Calculated total density of states (DOS) and partial DOS for O$_I$, S$_I$, Se$_I$, and Te$_I$ acceptors. Reproduced from Shi *et al.*[24]. (E) Calculated partial DOS for MAPbI$_3$ and MASb$_{0.25}$Pb$_{0.75}$I$_3$. (F) Electron density of Sb-doped perovskite film by Hall effect measurements. Reproduced from Zhang *et al.*[27].

In contrast, extrinsic doping occurs via the introduction of impurity atoms to a crystal structure. For example, MAPbI$_3$ can be regulated by introducing elements of the first main group (IA), the first subgroup (IB) and the sixth main group (VIA)[24] [Figure 1C and D]. The introduction of Na, K, Rb, Cu and O elements (substitutionally or interstitially) can form acceptor impurities under the conditions of I-rich or Pb-poor, which can cause the Fermi energy level (E_F) of perovskite films to move down, i.e., p-type doping. Furthermore, n-type doping can be achieved through the partial substitution of Pb in perovskites with Sb or Sn[25], or the partial substitution of halogen group elements I in perovskite by Cl[26] [Figure 1E and F]. Hence, appropriate intrinsic and extrinsic defect strategies are key to tuning the carrier concentration and Fermi level position in perovskite materials for homojunction formation.

Aside from the conductivity type and the carrier density of the semiconductor, electrical doping can also affect the carrier mobility and recombination lifetime, extraction and injection of charge and further the photoelectric performance of devices. Therefore, doping methods play a key role in optimizing perovskite materials and improving the performance of PSCs. For example, Han *et al.*[28] introduced $CaCl_2$ into $CsPbI_2Br$ to change its conductive properties with heavy n-type doping, which improved the performance of their established PSC. $CaCl_2$ passivates defects without entering the perovskite lattice, reduces the trap density and prolongs the carrier lifetime. Furthermore, the Fermi level upward shift of $CsPbI_2Br$ enhances the driving force for carrier extraction and transfer, and suppresses the carrier recombination in PSCs, thus resulting in a highest open-circuit voltage (V_{oc}) of 1.32 V and a PCE of 16.79%.

RECENT ADVANCES IN HOMOJUNCTION PSCS
Characterization method
Doping characterization
The electrical doping of perovskite materials can be realized by self-doping or the introduction of external ions or molecules. Firstly, doping changes the electrical conductivity and the carrier density of perovskite materials. The four-probe method to measure the electrical conductivity of the perovskite film is a simple characterization of the doping level but it cannot distinguish the conductivity type. Mott-Schottky analysis can obtain information, such as conductivity type, flat band potential and donor or acceptor density through the measurement of capacitance-voltage, which has been widely used to measure the doping characteristics of perovskite materials[29,30]. It should be noted that the appropriate device structure and signal frequency need to be selected to avoid the influence of the parasitic capacitance from charge transport layers in a PSC. Moreover, by measuring the Hall effect of perovskite materials, the conductivity type and carrier density can be confirmed[31,32].

To obtain accurate results, the high resistance and low mobility characteristics of perovskite materials need to be considered. Thus, researchers have developed a variety of Hall effect measurement methods to reliably assess perovskite materials[33]. X-ray and ultraviolet photoelectron spectroscopy can measure the change in the Fermi level position of materials, effectively indicating the change in doping level and type of perovskite materials[34,35]. In addition, Kelvin probe force microscopy (KPFM) can measure the contact potential difference of the semiconductor surface and obtain the change in the work function[36,37]. KPFM can be sensitive to the surface condition of perovskite materials, so the error caused by surface contamination and other factors should be eliminated before taking the measurements. Indeed, current techniques and analytical methods have their limitations, which need to be considered and optimized to prevent misleading results. Due to the common sample-to-sample variability in perovskite materials, statistics, as well as mutual corroboration by multiple methods, are crucial to verify their characteristics.

Homojunction characterization
The identification of a homojunction can be achieved using techniques, such as cross-sectional KPFM, current-voltage (*I-V*) diode characterization, time-resolved photoluminescence (TRPL) spectroscopy and high-resolution transmission electron microscopy (HRTEM). The significant advantage of cross-sectional KPFM is the *in situ* characterization of the internal potential distribution of the device under operating conditions. This technique can be carried out under light or bias voltage to obtain obvious potential changes caused by the transfer and extraction of carriers at the junction. Furthermore, the p-n homojunction has unidirectional conductivity. Therefore, by measuring the forward and reverse *I-V* curves in dark conditions, the changes in the curves can determine whether there is a rectification characteristic. In addition, TRPL spectroscopy can measure photoelectron deactivation processes and deduce information regarding the carrier transfer inside the device to provide indirect proof of the junction. Aside from the electrical

characteristics, p- and n-type perovskite films have differences in morphology. For example, the introduced dopants may form microcrystalline grains on the surface or be mixed into crystal lattices, thereby changing the perovskite crystallization, so HRTEM can visually observe the morphological characteristics of a homojunction. The electrical doping characterization technology is illustrated in Figure 2.

### Theoretical simulation of perovskite homojunctions

Perovskite homojunctions have been constructed experimentally and show excellent application potential. Numerical simulations are fundamental in testing the feasibility and predicting the performance of a new device and can be utilized to further understand the characteristics of perovskite homojunctions. For performance optimization, Sengar *et al.*[38] used experimentally verified device models to study the effects of junction thickness, electric field strength and junction defect density on device performance. A stronger electric field in the homojunction can reduce the carrier recombination rate. Moreover, Li *et al.*[39] systematically studied the effects of different electron transport layers (ETLs) and hole transport layers (HTLs), bulk and interfacial defect densities and absorber layer thickness on the performance of perovskite homojunction devices. The performance of an optimized homojunction PSC can reach 27.10% [Figure 3A], illustrating the significant performance potential of the homojunction device. For device design, Maram *et al.*[40] proposed an inverted PSC structure with a p-n homojunction and an ultrathin HTL layer [Figure 3B] based on the planar homojunction PSC reported by Cui *et al.*[15] and the inverted PSC with an ultrathin Cu_2O layer reported by Yu *et al.*[41]. Using a perovskite homojunction instead of an intrinsic perovskite can effectively improve the efficiency of the inverted PSC. In addition, Lin *et al.*[42] built a carbon-based omitting HTL perovskite homojunction PSC model to discuss the doping concentration, thickness, carrier mobility and defect density of the homojunction and obtained a calculated PCE of > 25%, which is significantly superior to traditional HTL-free PSCs [Figure 3C and D]. Through numerical simulation results, it can be seen that perovskite homojunctions have enhanced potential performance when applied in solar cells.

### Extrinsic doping for perovskite homojunctions

Except for the familiar self-doping strategy, extrinsic doping can also tune the carrier density and E_F position in perovskite materials for the formation of perovskite homojunctions. For example, Lu *et al.*[43] modified the surface of a perovskite film with a trivalent metal halide salt, $InBr_3$, converting the top surface to be more n-type. An n/n^+ perovskite homojunction between the bulk [weak n-type (n) component] and the surface [stronger n-type (n^+) component] was spontaneously formed [Figure 4A], with the electric field enlarged and the device performance improved [Figure 4B]. Chang *et al.*[44] adopted alkali metal ions (Na^+, K^+ and Rb^+) doped in perovskite films, which changed the majority carrier type from undoped n- to p-type. The carrier density of the perovskite films was increased by at least two orders of magnitude after doping, thereby enhancing the device performance. Furthermore, Ren *et al.*[45] modified the surface properties of perovskite films by Ar^+ bombardment [Figure 4C]. The original p-type perovskite film was transformed into n-type and a perovskite homojunction was then successfully induced *in situ*.

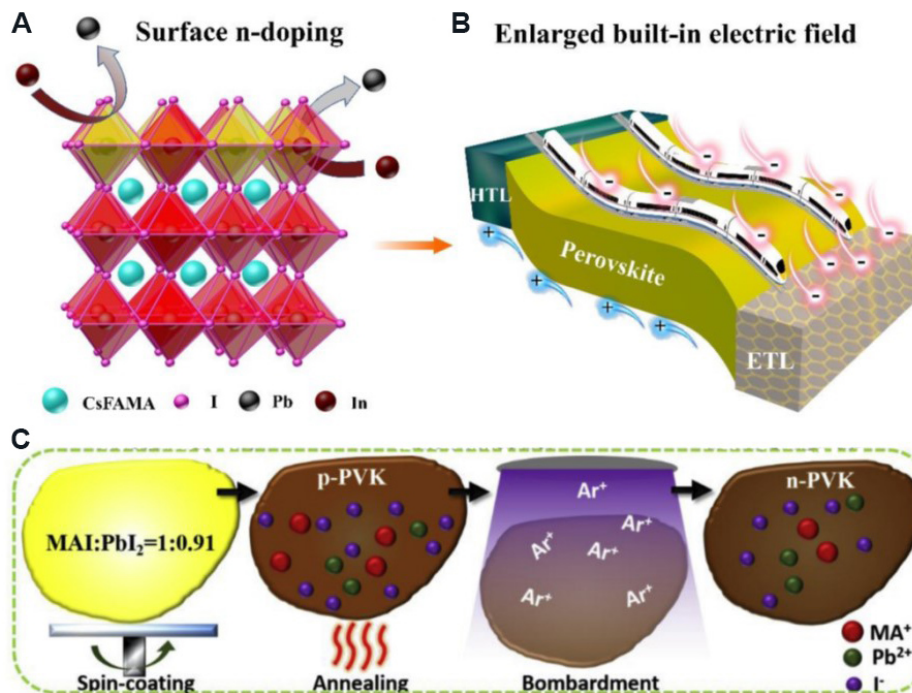### Interfacial doping for perovskite homojunctions

Compared with the construction of two independent high-quality perovskite films with different doping types, interfacial doping is a simpler strategy to obtain an efficient homojunction. Chen *et al.*[46] adopted a guanidinium bromide solution to adjust the effective doping of the surface of perovskite films. After the interfacial treatment, the junction at the perovskite/ETL interface was significantly increased [Figure 5A and B], inducing an increase in the V_{oc} and PCE. Furthermore, Noel *et al.*[47] treated the perovskite film surface with a strongly oxidizing molybdenum tris(dithiolene) complex [Figure 5C], thereby shifting the work function. Xiong *et al.*[48] passivated the defects by using a natural additive, capsaicin, with the spontaneous formation of a perovskite p-n homojunction observed [Figure 5D-F]. The energetic transformation and
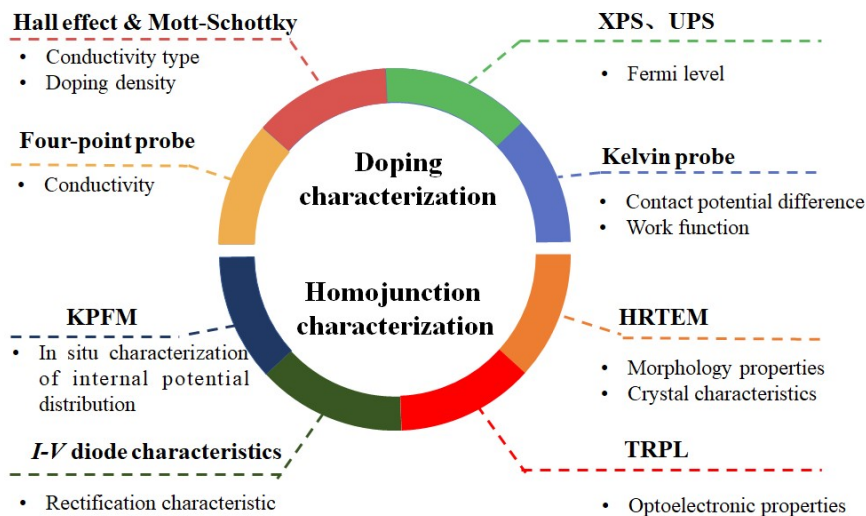
Figure 2. Current electrical doping characterization methods for perovskite thin films and homojunction structures. XSP: X-ray spectroscopy; UPS: ultraviolet photoelectron spectroscopy; KPFM: Kelvin probe force microscopy; HRTEM: high-resolution transmission electron microscopy; TRPL: time-resolved photoluminescence.
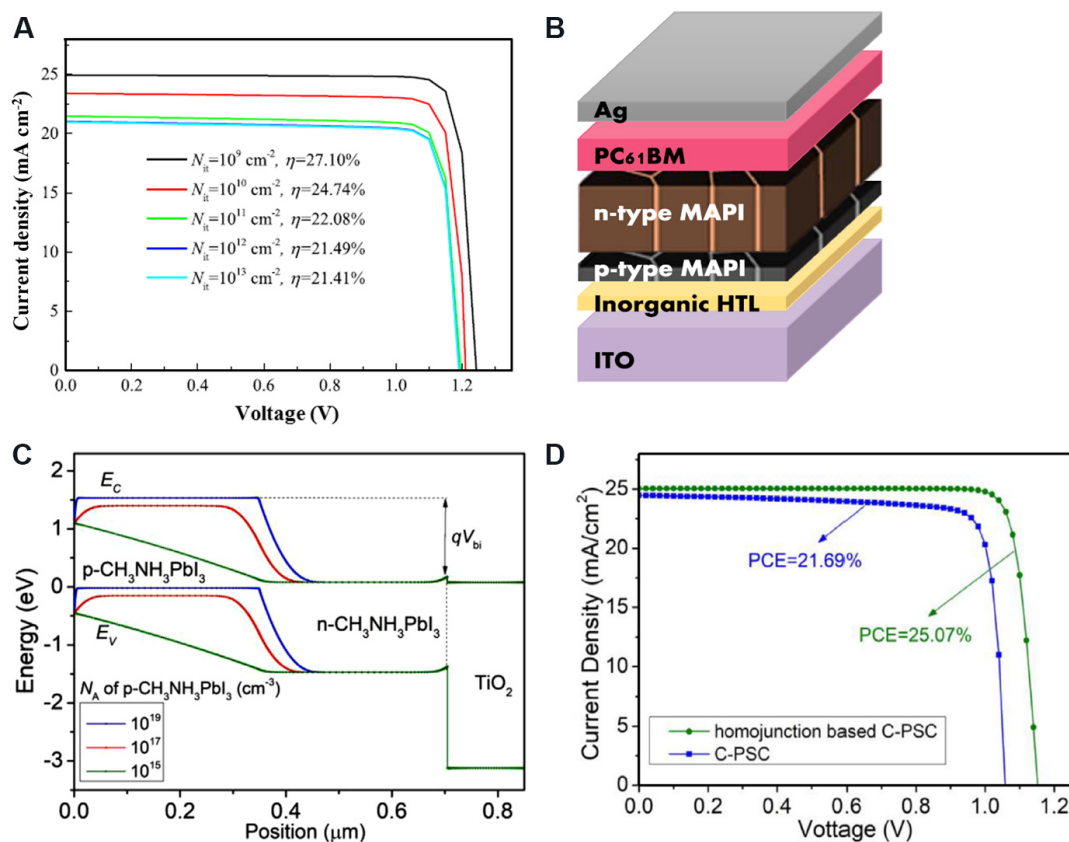
Figure 3. Simulation results of perovskite homojunction devices. (A) *J-V* curves with various values of N_A at a p-type MAPbI$_3$/Spiro-OMeTAD interface. Reproduced with permission from Li *et al.*[39]. (B) Schematic of inverted p-n homojunction PSC with ultrathin HTL. Reproduced with permission from Maram *et al.*[40]. (C) Energy band diagram as a function of N_A in p-MAPbI$_3$ (at fixed N_D of 10^{17} cm^{-3}). (D) *J-V* curves of optimized C-PSC and homojunction PSC. Reproduced with permission from Lin *et al.*[42]. PSC: Perovskite solar cell; HTL: hole transport layer.

Figure 4. Extrinsic doping for perovskite homojunctions. (A, B) A simple heterovalent metal halide surface treatment strategy enables the self-assembly of an n/n$^+$ perovskite homojunction, which synergistically enlarges the built-in electric field. Reproduced from Lu *et al.*[43]. (C) Schematic process of Ar$^+$ bombardment to induce an n-type perovskite. Reproduced from Ren *et al.*[45].
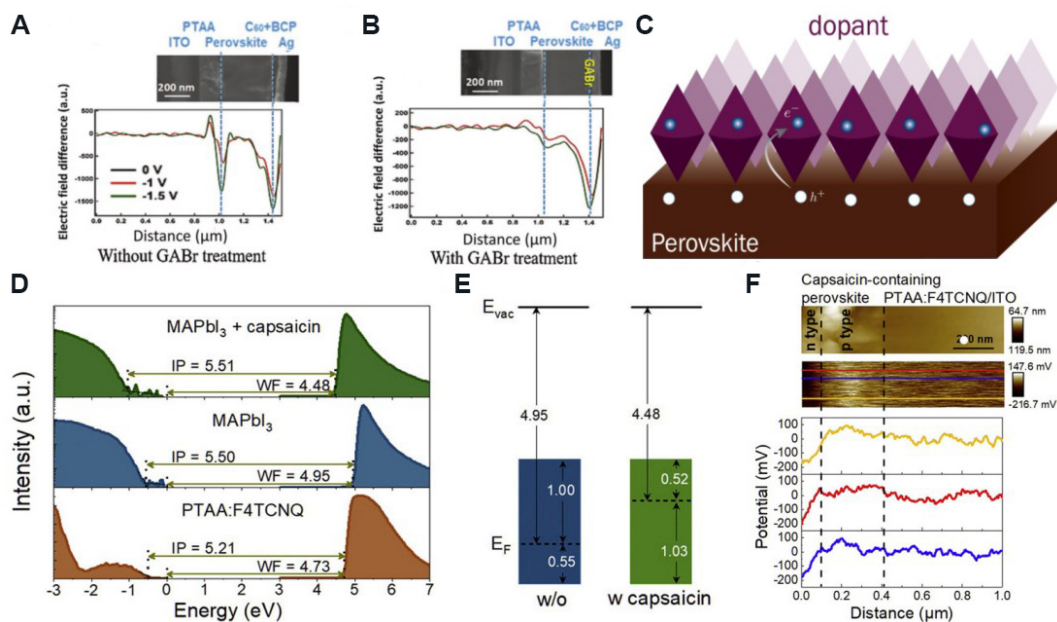
Figure 5. Interfacial doping for perovskite homojunctions. Electric field distribution as a function of depth within p-i-n PSCs (A) without and (B) with GABr treatment through cross-sectional KPFM. Reproduced from Chen *et al.*[46]. (C) A method for controlled p-doping of a halide perovskite surface using molecular dopants. Reproduced from Noel *et al.*[47]. (D, E) UPS spectra of secondary electron cutoff region and valence band region of PTAA:F4TCNQ and perovskite films with and without 0.1 wt.% capsaicin grown on PTAA:F4TCNQ. (F) Cross-sectional atomic force microscopy topographies and corresponding KPFM images and potential profiles under zero-voltage bias of perovskite/PTAA:F4TCNQ/ITO without capsaicin. Reproduced from Xiong *et al.*[48]. PSCs: Perovskite solar cells; KPFM: Kelvin probe force microscopy; UPS: ultraviolet photoelectron spectroscopy.

defect passivation promoted charge transport at the interface, suppressed both defect-assisted recombination and interfacial carrier recombination, thereby improving the device performance.

Graded structure for perovskite homojunctions

To facilitate the carrier transport in PSCs, the electric field enhancement induced by the graded junction architecture is an effective route. For both heterojunctions and homojunctions, the graded architecture with continuous band bending can construct a high-speed channel for charge transfer. For example, introducing SnI_2 into perovskite films by a three-step dynamic spin coating strategy, Sun *et al.*[49] obtained the bandgap of the perovskite layer, which gradually decreased from 1.53 eV at the bottom to 1.27 eV at the top and the electrical doping from n- to p-type. A graded bandgap perovskite homojunction was constructed [Figure 6A], which promoted the carrier directional transport in PSCs and reduced the dependence on the ETL/HTL. Furthermore, the combination of two- (2D) and three-dimensional (3D) perovskites to prepare a graded homojunction is a method for improving the stability of PSCs. Xiang *et al.*[50] combined a quasi-2D PMA/Cs/FA/MA perovskite with a 3D Cs/FA/MA perovskite to construct graded perovskite homojunctions [Figure 6B and C], thereby promoting the transport and extraction of carriers and improving the PCE of the PSCs [Figure 6D]. Furthermore, Yuan *et al.*[51] constructed a graded perovskite quantum dot homojunction [Figure 6E] with three layers of $CsPbI_3$, which facilitated the charge extraction and increased the carrier diffusion length due to the additional driving force of the homojunction.

## PROMISING DIRECTIONS AND OPPORTUNITIES

Enhancing electric fields of perovskite homojunctions

The study of perovskite homojunctions is still in its infancy and requires more in-depth research to further boost device performance. Referring to the classical semiconductor theory, the carrier separation efficiency depends mainly on the built-in electric field of the junction. Theoretically, the higher doping concentration of p-/n-type perovskite layers can cause an increase in the electric field, thus enhancing the performance. Recently, Kirchartz and Cahen[52] estimated the doping densities in perovskite materials for a p-n junction and stated a minimum doping concentration of ~10^{16} cm^{-3} for a ~500 nm-thick perovskite homojunction with a built-in voltage (V_{bi}) of ~1 V. In fact, the traditional theory could provide a certain reference for the junction by organic-inorganic perovskite materials but the V_{bi} of the planar homojunction PSC reported is formed by the upper and lower charge transport layers and the perovskite homojunction together. It would be unreasonable to ignore the contribution of the ETL/HTL and only equate the homojunction with the whole device, which concluded the insufficient doping concentration of the homojunction. Certainly, further increasing the doping concentration of perovskite materials would obtain a homojunction with a stronger electric field to remove charge transport layers and obtain a pure perovskite homojunction device. In contrast, the doping concentration of $MAPbI_3$ can reach 10^9-10^{17} cm^{-3} according to experimental and calculation results[25,53,54], while $FASnI_3$[55] can reach ~10^{20} cm^{-3}. Thus, perovskite materials have potential for sufficiently high doping concentrations for enhanced electric fields. However, the augment of doping concentration also leads to an increase in defect density. It is crucial to balance the relationship between high doping concentration and low defect density, which requires exploring more appropriate perovskite self-doping and extrinsic doping strategies.

Simplifying device structures

PSCs with a p-i-n structure rely on charge transport layers at both ends to selectively extract photogenerated electrons and holes. Perovskite homojunctions can achieve the selection and transport of photogenerated carriers by an built-in electric field. Therefore, the direct combination of the homojunction and electrodes can construct a very simple solar cell without the traditional ETL and HTL, thereby avoiding the expensive organic materials and complex craft process. Recently, Lin *et al.*[42] designed a carbon electrode perovskite homojunction solar cell without a HTL, of which the theoretical calculation results show an optimal PCE of
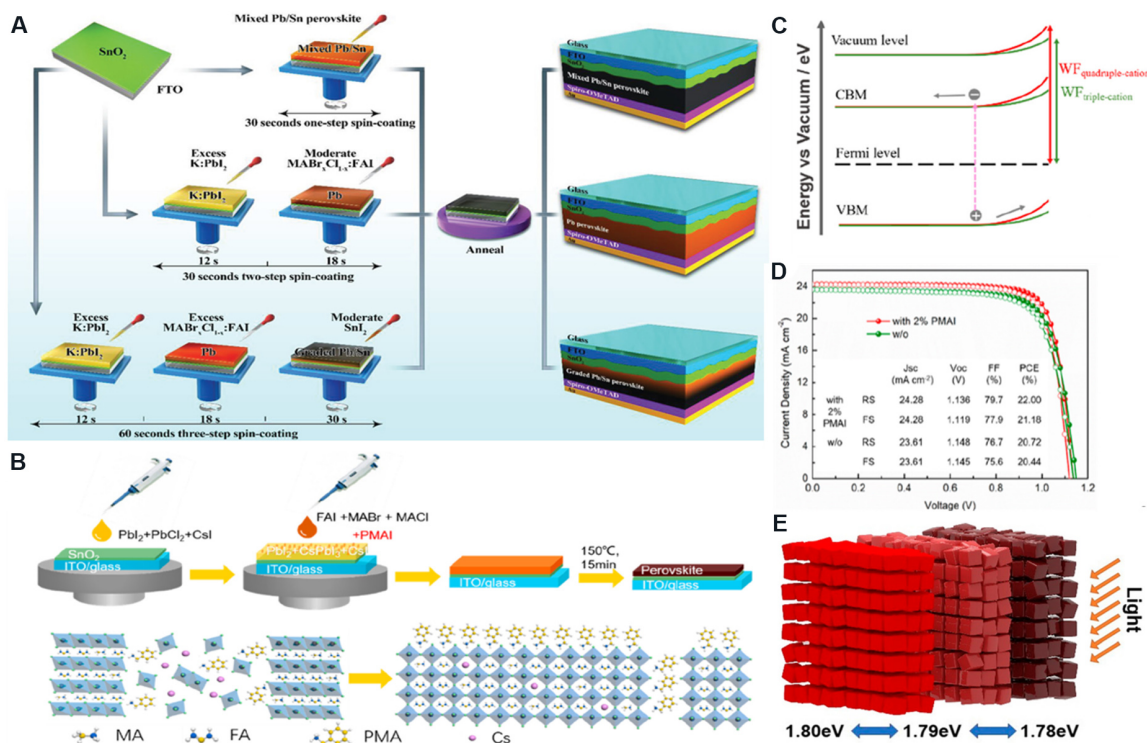
Figure 6. Preparation process, device performance and structure diagram of graded perovskite homojunction. (A) Schematic illustration of the fabrication process of mixed Pb/Sn, Pb based and graded Pb/Sn for graded perovskite homojunction. Reproduced with permission from Sun *et al*.[49]. (B) Preparation process and material structure model of perovskite. (C) Schematic band diagram of perovskite films and quadruple-cation PSCs. (D) Performance of cells with 2% PMAI and without PMAI. Reproduced with permission from Xiang *et al*.[50]. (E) Graded band alignment homojunction structure in solar cells. Reproduced with permission from Yuan *et al*.[51]. CBM: Conduction band minimum; VBM: valence band maximum.

25%. Cui *et al*.[15] preliminarily tried to remove the ETL and HTL to form a simple device containing an independent homojunction with a PCE of ~8%. While simplifying the device structure, interfacial recombination becomes serious because of the direct contact between the Au electrode and perovskite film, thereby restricting the device performance. Issues, such as interfacial breakage, metal ion diffusion and carrier recombination cannot be bypassed. Therefore, it is necessary to further optimize the simple device with interfacial engineering, defect passivation, doping concentration regulation and other means for superior performance.

Challenges of ion migration

Research in the perovskite field is ever increasing, but there are still many unresolved research issues, including polarity, lattice expansion and ion migration. Current research indicates that ion migration is one of the intrinsic characteristics of organometallic halide perovskite materials. In PSCs, the numerous mobile ions in perovskite films induce phase segregation, material degradation, photocurrent hysteresis and other problems, which severely damage the carrier transfer and device stability. Thus, it is also essential to explore the ion migration influence on perovskite homojunctions for their further progress. To better understand the mobile ions in perovskite homojunctions, both theoretical and experimental advances are required to answer the following basic questions. What is the exact concentration of mobile ions in PSCs and homojunction devices? What is the precise influence of external conditions on ion migration, such as heat, light illumination, moisture and so on? What is the impact of mobile ion concentration on the performance of perovskite homojunctions?

Calado and Barnes[56] used their own software simulation to raise the question of whether a homojunction can continue operating in the presence of mobile ions. However, the extremely large ion concentration as an ideal input would result in simulation results inconsistent with the actual PSC. Homojunctions have been persistent at the common ion concentration of perovskites (e.g., less than 10^{17} cm^{-3}). Moreover, Yuan *et al.*[51] have employed transient absorption spectroscopy to inspect the ground-state bleaching mapping of a gradient perovskite homojunction with an aging test for 15 days. There was no obvious change, demonstrating the good stability of the homojunction structure during potential ion migration. This homojunction formed by the same composition could avoid the migration of doping ions to some extent. In addition, to further improve the performance and stability of the homojunction, it is a valuable research direction to inhibit ion migration and diffusion by the effective strategies widely used in common PSCs, such as decreasing grain boundaries, cation or alkali metal ion doping and low-dimensional perovskite materials.

Investigating device stability

Device stability is of great importance since it is a major obstacle to the practical process of PSCs. At present, the reported homojunction PSCs demonstrate excellent operating stability. For example, Lu *et al.*[43] have shown a homojunction device with an enlarged built-in electric field retains more than 93% of its initial efficiency after 1000 h of maximum power point (MPP) operation, which reveals greater stability than the control device (degrading to ~80%). Sun *et al.*[49] evaluated the thermal stability of homojunction devices with MPP tracking under a 85 °C/85% RH environment. The devices containing the Spiro-OMeTAD break down in such a harsh environment, while the homojunction devices without HTL still work, showing a superior material stability for perovskite homojunction with graded Pb/Sn. Regarding common PSCs, numerous stability studies have focused on light, humidity, heat and oxygen factors, which are the main causes of the decomposition of perovskite crystals, resulting in a serious decrease in device performance. The common decomposition problems arising from perovskite materials may also exist in the perovskite homojunction structure. Therefore, the influencing factors (like electric field, illumination, moisture and so on) on the stability of perovskite homojunctions need to be further investigated and given special attention.

SUMMARY AND OUTLOOK

With the advantages of enhanced electric fields, effective performance improvements and simple device structures, perovskite homojunctions exhibit substantial development prospects and have therefore attracted significant interest. Here, we give a brief account of the story of perovskite homojunctions and discuss in detail the electrical doping characteristics and recent advances of perovskite homojunctions. Furthermore, the potential technical obstacles and a roadmap for perovskite homojunctions are also included and proposed.

We look forward to the extensive research on perovskite homojunctions to boost their development and practical application. Firstly, obtaining a stronger built-in electric field is critical for efficient carrier transfer in perovskite homojunctions. It is noteworthy to improve the doping concentration of perovskite materials and explore the oriented electrical doping strategy. Secondly, perovskite homojunctions provide the potential for simple devices without ETLs and HTLs. To realize more efficient PSCs, it is significant to optimize the perovskite crystalline quality and passivate the interface of the electrode and perovskite. It is then helpful to investigate the ion migration dynamics in perovskite materials and explore inhibition strategy in homojunction devices, such as low-dimensional perovskite engineering, interfacial modification, multi-defect passivation and so on. Nonetheless, it is expected that the continuing investigation of perovskite homojunctions will positively evolve and facilitate the transition of this promising technology from the laboratory to the market.

DECLARATIONS

Authors' contributions
Supervised this research: Li M
Wrote the first manuscript: Cui P
Contributed to the discussion, review, and revision of the manuscript: Cui P, Qu S, Zhang Q, Liu B, Yan L, Du S, Wang X, Huang H, Ji J, Li M

Availability of data and materials
Not applicable.

Conflicts of interest
All authors declared that there are no conflicts of interest.

Ethical approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

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