Chapter

Perovskite Nanoparticles

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Abstract

2D perovskite nanoparticles have a great potential for using in optoelectronic devices such as Solar Cells and Light Emitting Diodes within their tuneable optic and structural properties. In this chapter, it is aimed to express "relation between chemical structures and photo-physical behaviours of perovskite nanoparticles and milestones for their electronic applications". Initially, general synthesis methods of perovskite nanoparticles have been explained. Furthermore, advantages and disadvantages of the methods have been discussed. After the synthesis, formation of 2D perovskite crystal and effects on shape factor, particle size and uniformity of perovskite have been explained in detail. Beside these, optic properties of luminescent perovskite nanoparticles have been summarized a long with spectral band tuning via size and composition changes. In addition, since their different optical properties and relatively more stable chemical structure under ambient conditions, a comprehensive compilation of opto-electronic applications of 2D perovskite nanoparticles have been prepared.

Keywords: perovskite, nanoparticle, nanocrystal, opto-electronics, solar cells, OLEDs, fluorescence

1. Introduction

Inorganic and/or hybrid perovskites have become prominent in solution-processed optoelectronics. Thousands of reports have been proposed about photovoltaics [1–3], light-emitting diodes (LEDs) [4–6], lasers [6, 7] and photodetectors [8–12] containing perovskite semiconductors per annum over the past decade. Halide perovskite nanostructures exhibit tremendous optic and electrical properties such as strong absorption and/or emission, higher photoluminescence quantum yields (PLQYs) [13–15], higher exciton binding energies and tuneable bandgaps than those of bulk perovskites and other nanomaterials. With these outstanding properties, they may offer many scopes for optoelectronics. Particularly, hybrid lead halide perovskite nanostructures (PNSs) offer unique opportunities for light-emitting diode (LED) applications. PNSs represent larger exciton binding energies and longer carrier decay times than those of bulk crystals. In addition to this, their narrow emission band makes them good candidates for LED [16] and laser [17]. Since Schmidt et al. reported the synthesis of first colloidal PNS by a simple procedure under ambient conditions in 2014 [18], many research groups have started working on these materials. In the synthesis of PNSs, it is possible to use organic ligands for capping to stop crystals` growth in the nanometer scale. Furthermore,

capping ligands can reduce surface defects in the same way of the traditional NC preparation. Thus, size and shape of PNSs can be tune finely from a single perovskite layer or below the exciton Bohr radius for using the effect to quantum confinement to multilayers which exhibits bulk-like properties. With this method, it is possible to prepare nanostructures like quantum dots (QDs), nanoplatelets (NPLs), nanosheets (NSs), and nanowires (NWs) [19, 20].

In a simple PNS growth process, the methylammonium cations are embedded in the voids of the corner-sharing PbX6 octahedra, the long alkyl chain cations only at the periphery of the octahedra with their chains hanging it. Therefore, long alkyl-ammonium ions can be used as the capping agents to limit the growth of the PNSs in three-dimension (3D). There are five common methods proposed in the literature which exhibits good prospects for obtaining various uniform and defect free PNSs. These are named as solvent-induced precipitation, hot injection, template assisted, ligand assisted reprecipitation and emulsion methods [13, 14].

In order to determine the structural and optic properties of PNSs, some characterization techniques such as small angle x-ray scattering (SAXS), scanning electron microscope (SEM), absorption and emission spectroscopy have been used extensively. It is crucial to know the shape and optical response of the nanocrystals for the further opto-electronic application of them.

As it is mentioned above, well-defined PNSs were used in many applications such as optical lasing and LEDs. Some of those applications have been investigated intensively by many groups all around the world. Some milestone studies have been presented comparatively.

2. Synthesis of nano-crystalline perovskites

There are many proposed methods for synthesis of PNSs by many groups in the literatures. Here we would like to express five of most common and essential methods (**Figure 1**) [21–23].

2.1 Solvent-induced precipitation

The physical properties of perovskite cluster such as size of NPs can be arranged by using long alkyl chain amine derivatives while oleic acid ensures the colloid stability via preventing the aggregation. In order to initiate the solvent-induced precipitation, and obtain colloidal $MAPbBr_3$ NPs, lead bromide ($PbBr_2$) and methyl ammonium bromide (CH_3NH_3Br) were mixed with Octylammoniumbromide (OABr) in acetone with oleic acid (OAc) and octylamine and the solution were kept at 80°C. The PLQY of obtained NPSs was about 20% as well as stable over three months. After this first attempt, PLQY of NPSs was increased up to 83% by optimization of the molar ratios of starting materials [22, 24].

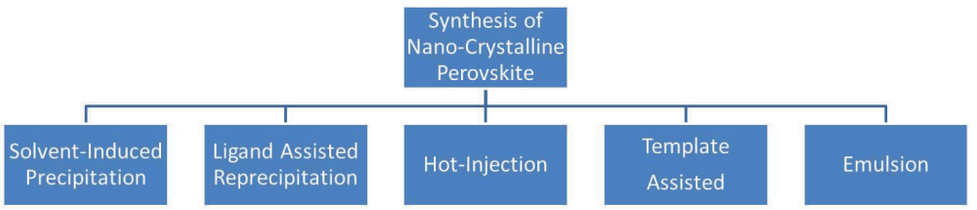

Figure 1.
Common synthesis methods for perovskite nano-crystals.

2.2 Ligand assisted reprecipitation (LARP) technique

In this method, a polar solvent such as dimethylformamide (DMF) which dissolve all starting materials and capping ligands have been used to prepare the precursor solution [25, 26]. This solution is added dropwise into vigorously stirred toluene which is not a good solvent for starting materials and perovskite crystal. Zhang et al. has demonstrated the synthesis of colour- tuneable PNSs (average particle size of 3.3 ± 0.7 nm) with a PLQYs of 50–70% (**Figure 2**) [25]. It was claimed that a slight descending of PLQY was observed by the ascending of the size of the perovskite crystal (2–8 μm, PLQY < 0.1%). In the nanometer scales, surface defects of the crystals can easily be passivated by ligands. Thus, most of the photo-generated charges can recombine before there are trapped by defects on the surface. However, due to the less ligand passivation, the number of defects on the bulk perovskite structure`s surface, which increased the number of trapped charges, are significantly high, resulting very low PLQY. In another study, well-defined cubic and thermally stable $FAPbX_3$ nanocrystals (about 10 m) has been prepared by LARP method. The reported PLQY for the NPS was 75% [27]. A new procedure, which was used to obtain a core-shell shape by using the LARP approach has been recently demonstrated. With this proposed method, a solution-processed, stable core–shell-type Methyl ammonium (MA^+) + Octyl ammonium (OA^+) lead bromide perovskite NPs (≈5–12 nm) with good PLQY was prepared. In addition to this, Core–shell-type NPs was accomplished by systematically changing the molar ratio of capping ligands, OABr, and MABr without altering total amount of alkylammonium bromide and synthesis conditions. The color tunability of NPs in the blue to green spectral region (438–521 nm), high PLQY, and reasonable stability under ambient condition are credited to the quantum confinement imparted by the crystal engineering associated with core–shell NP formation [28–30].

2.3 Hot injection method

The stability of inorganic perovskites is significantly higher than that of hybrid perovskite crystals. By changing the organic cation with an inorganic one (e.g., Cs),

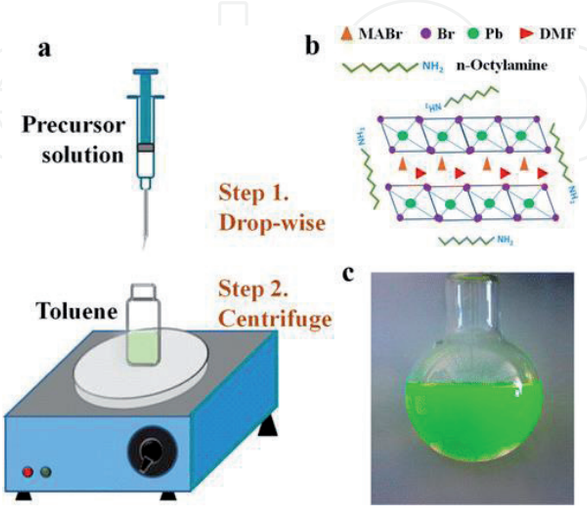

Figure 2.
(a) Schematic illustration of Set up for LARP; (b) starting materials and shape of perovskite nano-crystals; (c) image of typical solution containing CH3NH3PbBr3 nano-structures (reproduced with permission of Ref. [26]).

chemical and thermal stability of Perovskite material can be increased greatly (**Figure 3**) [31, 32]. It is possible to obtain various crystal phases by changing the temperature resulting a shifting in the optical responses. The hot injection method is a widespread method for synthesizing inorganic PNSs. In a typical synthesis procedure, a solution of PbX_2 (X = I/Br/Cl), in octadecene (ODE) along with oleic acid and oleyl amine is prepared. During stirring, Cs-oleate is injected into that solution quickly under dry condition at 140–200°C [32]. To quench the reaction (after 5–10 sec), the reactor is cooled with an ice bath. With this method, it is easy to obtain uniform nanocubes with the size of 4–15 nm edge length representing high PLQY, up to 50–90% and a very narrow emission band (12–42 nm) in the visible region (410–700 nm). As it was mentioned before, the optical properties of the NPSs are related to shape, size,

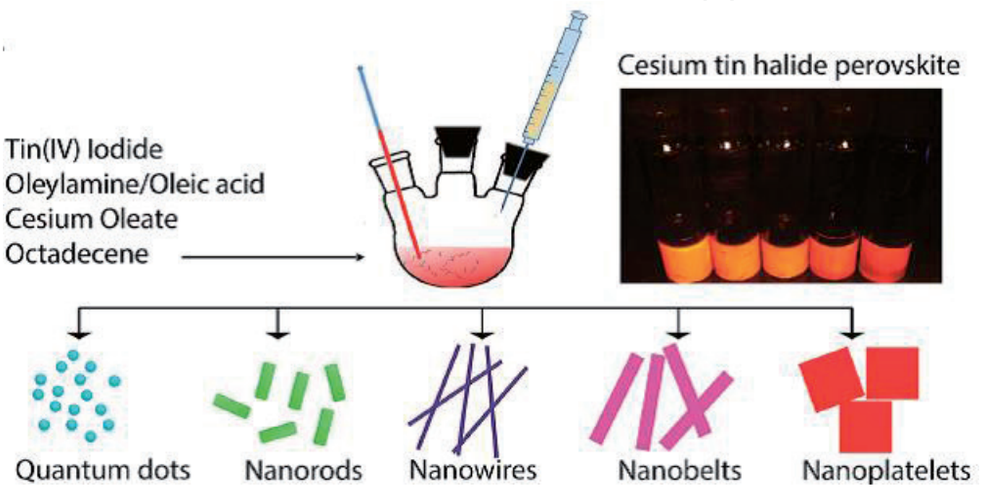

Figure 3.
Schematic illustration of Hot-injection method (left-hand), image of Cs2SnI6 samples under UV-light (right-hand) and possible crystal shapes obtained by hot-injection method (reproduced with permission of Ref. [33]).

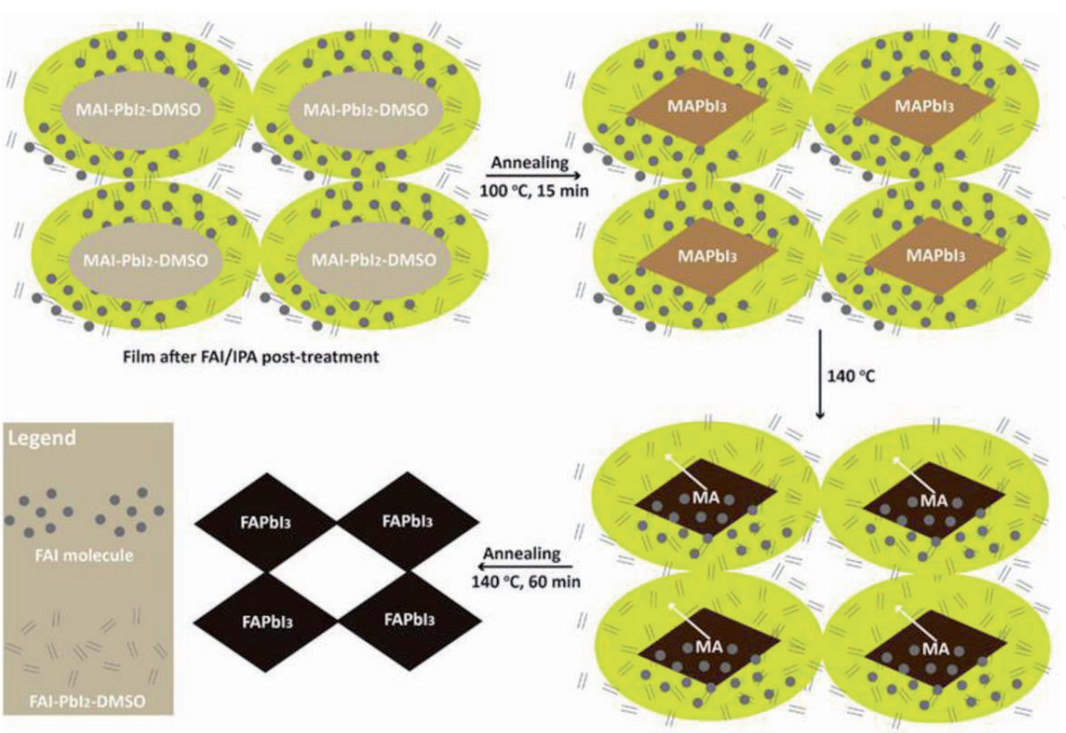

Figure 4.
Schematic illustration of perovskite nano-crystal preparation by the template-assisted method (reproduced with permission of Ref. [36]).

and surface chemistry of them due to the significant changes in the band structures. Therefore, by the variation of the surfactants, ligands, reaction temperature and time, the perovskite precursor composition can be adjust [33] to realize the formation of nanowires, nanoplatelets, spherical dots, and nanorods (**Figure 3**) [33–35]. A critical point for the hot injection is the reaction temperature effecting the size of the NPSs. To overcome this disadvantage, new methods have been developed for hybrid perovskites.

2.4 Template-assisted method

In this synthesis approach, NP formation is induced by a specific substrate such as mesoporous silica and aluminum oxide film as a template [36–38]. NPSs is obtained on the films which exhibits intensive light. This technique is suitable for formation of mono disperse NPSs with various narrow emissions (full wind of half maximum (FWHM) is less than 40 nm) bands from green (FWHM: 22 nm) to near infrared (FWHM: 36 nm) by template optimization [37–39]. In a recent study, perovskite nanocrystals have been prepared in a nano-porous structure. By this kind of strategies, it is possible to confine PNSs (<10 nm) without any capping agents (**Figure 4**). In other words, the emission wavelength of perovskite nanoparticles can be arranged precisely for sophisticated photonic applications such as lasers [36, 37].

2.5 Emulsion method

In order to control the crystallization of perovskite and obtain uniform NPs, emulsion synthesis method was modified [40]. By using this method, it is possible to tune the size of PNSs under 10 nm with an PLQY up to 92% [41]. In this method, an emulsion is prepared with two immiscible solvents. After that, a demulsifier is added into this for initiating solvent mixing and start crystallization (**Figure 5**). For this procedure, DMF and n-hexane are very good candidates as immiscible solvents while tert-butanol or acetone is used as demulsifier solvent [41]. This method is suitable to obtain PNSs in solid state which can be used in another solvent matrix for an application later. Furthermore, long alkyl ammonium halides are used as capping agent.

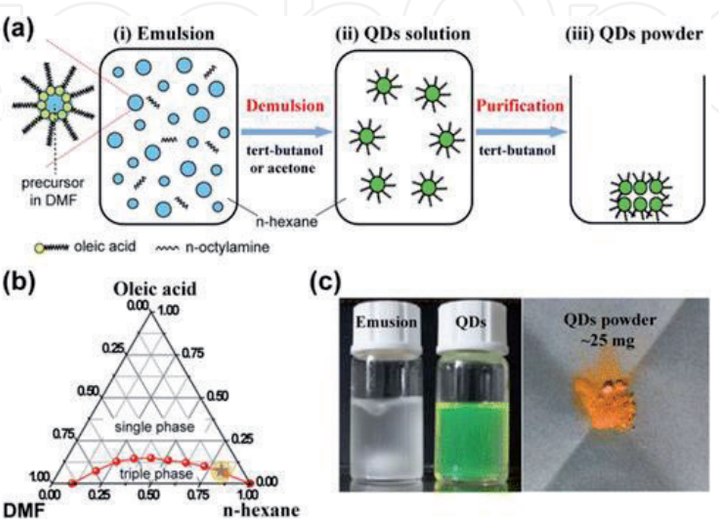

Figure 5.
(a) Schematic illustration of preparation of nano-crystals by emulsion method; (b) ternary phase diagram (DMF/OA/n-hexane); (c) image of a typical CH3NH3PbBr3 emulsion, colloidal NP solution and solid-state powder of CH3NH3PbBr3 NPs (reproduced with permission of Ref. [41]).

3. Form factor of perovskite nano-crystals

3.1 Crystal shape of perovskite nano structures

As it is well known, semiconductor perovskite crystalline structure has a general formula of ABX_3 where A is an organic or inorganic cation, organic methylammonium (MA^+), formamidinium (FA^+) or inorganic cesium (Cs^+); B is a metal cation typically lead (Pb^{2+}) or tin cations (Sn^{2+}); and X is a halide anion. Cation A is slightly larger than centred cation B having 6 co-ordination number. There is a significant relationship, which is called "Goldschimidt Tolerance Factor" between the size of the ions and the formation and the shape of the crystal structure:

$$t' = \frac{r_A + r_X}{\sqrt{2}(r_B + r_X)} \quad (1)$$

Where, r_A and r_B are cationic diameters of A and B respectively, and r_X is the anionic diameter of halide in Å. When cation A is too big or cation B is too small (>1), hexagonal perovskite crystal is formed. If cation A and has the ideal size ($0.9 < t < 1$), cubic perovskite crystal is formed. Finally, if cation is too small to fit into the space between metal cations (B) ($0.7 < t < 0.9$), orthorhombic perovskite structure is formed [42].

3.2 Geometry of perovskite nano-crystals

A typical "bulk" perovskite structure is called three-dimensional (3D) which is usually comply to the ABX_3 formula completely [43–45]. In this situation, "3D" refers to the growth in every dimension without any confinement. X anions are combined through corner sharing to form a 3D network. Beside this, the cation A occupies the site in the middle of eight octahedra, and each element needs to owe the proper valence state to keep a whole charge balance [43]. To obtain nano crystalline perovskites, crystal growth must be restricted with at least one dimension by a capping agent or a matrix. Thus, It is possible to prepare various dimensioned PNSs such as zero, one or two dimension (0D, 1D or 2D respectively) (**Figure 6**) [1, 46].

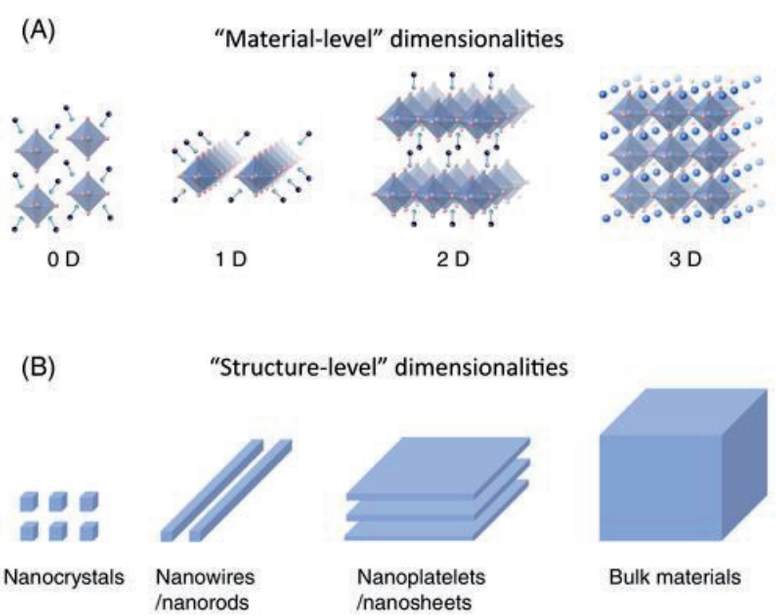

Figure 6.
Schematic illustration of low-dimensional perovskites and 3D perovskite crystal structures (reproduced with permission of Ref. [47]).

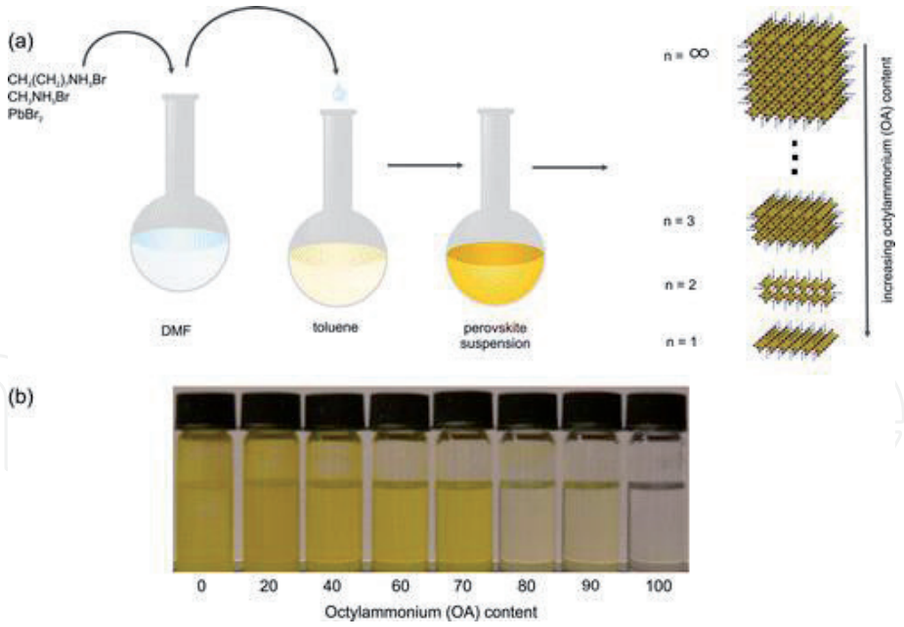

Figure 7.
(a) Schematic illustration of the perovskite nanopelets preparation. (b) Image of OA/MA perovskite suspensions in toluene under ambient light (reproduced with permission of Ref. [49]).

0D PNSs have been synthesized, by LARP [25], hot-injection [32] and template-assisted method [36] by different groups. Crystal growth is prevented in all dimensions by a ligand or a metal-oxide matrix to obtained quantum-dot-like NPs representing good Photoluminescence (PL). Prepared nanostructures have been used in many opto-electronic applications such as solar cells, LEDs and laser.

Perovskite nanowires or nanorods are basically *1D PNSs* which represent outstanding anisotropic optical and electrochemical properties with very high PLQFs [41]. 1D PNSs have been proposed by Horvath et al. for the first time in the literature. Nanowires with 50–400 nm wide and 10 μm length has been prepared in DMF solution phase. Obtained NPSs have been used in Solar Cells [48], LED [4] and photodetector [8] applications.

Consequently, *2D PNSs* are nano pellet or nano sheet shaped materials which consist of several unit cells leading larger binding energy for the exciton and more intense PL. These types of NPs have similar networks with corresponded 3D perovskite, however the general formula of ABX_3 is changed when the NP is very thin. Number of sheets in a nano pellet NPS can be determine by using absorption and emission spectroscopy. Differences of Absorption and emission maximum of nanosheets (n = 1, 2, 3 and 4) are very significant. Maximum absorption peak is red shifted with the increasing of number of unit cell (nano- pellet) (**Figure 7**).

4. Applications of perovskite nanoparticles

4.1 Optical properties of perovskite nanoparticles

In recent years, perovskite is a very important milestone in solar cell research, thanks to its perfect exciton and charge carrier properties. This excellent performance has allowed perovskite to be used as outstanding light emitters in Light Emitting Diodes (LEDs) and other optoelectronic applications [4, 7, 25, 50–56]. One of the most attractive features of perovskites is their emissions, which can be easily adjusted in the visible range compared to traditional III–V and II–VI groups. All inorganic-perovskite ABX_3 emissions, including quantum dots and nanoplatelets,

can cover the entire visible area, even close to the infrared or ultraviolet region, by substituting halide elements from chloride to iodine [26, 34, 51, 57, 58]. Another way to adjust the emission is to insert other organic molecules into it or replace anions/cations.

4.2 High quantum efficiency

Perovskites are considered superior light emitters owing to their large absorption coefficients and high quantum yields [59, 60]. The high quantum yield generally indicates that most of the absorbed photons are transformed by radiative recombination processes. High quantum yields (90%) have been reported in inorganic ABX_3 and organic-inorganic methyl-ammonium halide perovskite nanocrystals without further surface treatment [26, 34]. However, the main reason for reduced quantum efficiency in conventional III –V and II –VI groups is that these nanocrystalline structures are often affected by surface defects or donor-receptor levels. In perovskite, where there are very few electrical charge trapping conditions, high quantum efficiency is the result of the formation of a clear band gap that greatly supports exciton radial recombination efficiency [61].

4.3 Quantum confinement effect

Optical absorption and emission characteristics of a semiconductor can be adjusted by changing the size of the semiconductor. If the size of such materials is in the nanocrystal range, changes in band gaps can be observed. The reduction of the crystal size causes the quantum capture effect to be observed and the bandwidth to shift to blue. If the semiconductor size is too small to compare with the Bohr radius of excitons, quantum trapping can be seen in the optical properties of the semiconductors. For example, the quantum capture effect is quite evident in completely inorganic $CsPbBr_3$ perovskite nanocrystals and in organic-inorganic methyl ammonium lead halide perovskite nanocrystals. This can usually be observed when the nanocrystalline size is comparable to the exciton Bohr radius. **Figure 8a** and **b** demonstrate that the emission of CsPbBr3 perovskite nanocrystals can actually be adjusted from 2.7 eV to 2.4 eV, with a size ranging from 4 nm to 12 nm, which is compatible with the theoretical calculation [34].

4.4 Linear absorption and emission

Many groups have focused on improving the band spacing, excitonic characteristic and optical properties of photoluminescent quantum yields of halide perovskite nanocrystals for optoelectronic applications in recent years [18, 62]. The most interesting of these features is that bandwidth is adjustable. It is possible to adjust the bandwidth by changing the individual components of the metal halide perovskites (MHP). Optical properties of bulk perovskite thin films could be changed across the entire visible spectrum. Thus, it has been shown that the optical properties of $MAPbBr_3$ nanocrystals, which have an emission of approximately 529 nm, can also be altered throughout the entire visible spectrum [63, 64]. For $CsPb(X = Cl, Br \text{ or } I)_3$ nanocrystals, using halide components, the emission wavelength is from 410 nm (X = Cl), (X = Br) to 512 nm, (X = I) It has been shown that it can be shifted to 685 nm (**Figure 9**).

Adjustable optical features of perovskite nanocrystals are based on the electronic structure of these materials (**Figure 10**). The conduction band consists of external p orbitals of halid and antibonding orbitals of hybridization of Pb 6p orbitals. The valence band consists of antibonding of the hybridization of Pb 6s

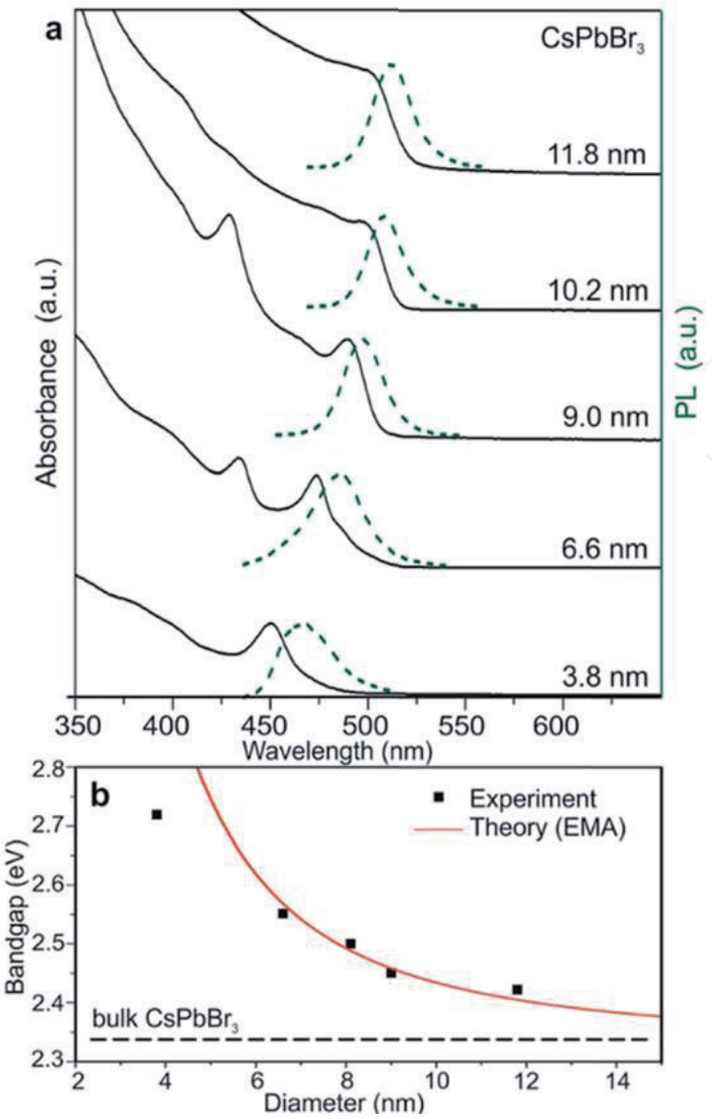

Figure 8.
(a) The emission spectra of CsPbBr3 NCs Quantum-size effects in the absorption and (b) experimental versus effective mass approximation size (theoretical technique) with respect to the band gap energy range (reproduced with permission of Ref. [34]).

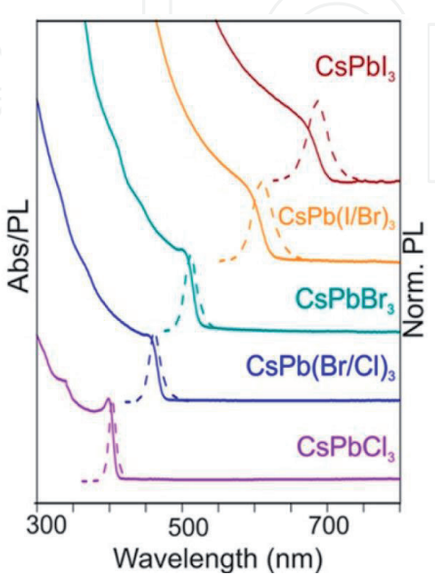

Figure 9.
UV–vis and photoluminescence spectra shows that the band gap could be tuned by controlling of CsPbX3 NCs as a function of halide (reproduced with permission of Ref. [34]).

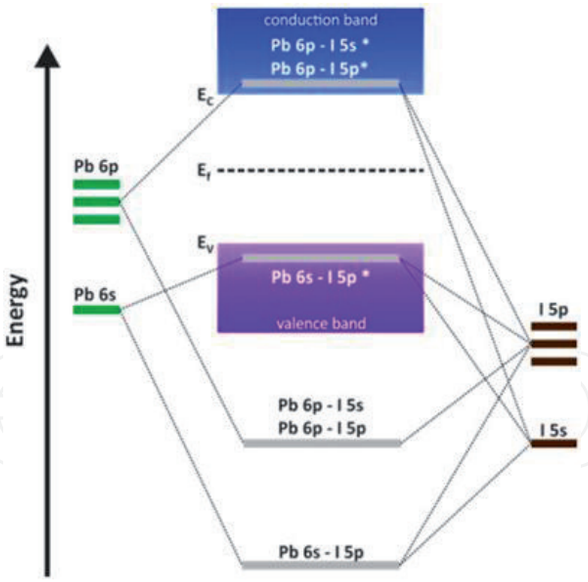

Figure 10.
The energy bands forms in a lead iodide perovskite by the crossing of lead and iodide orbitals (reproduced with permission of Ref. [23]).

and the same halide p-orbitals. The conduction band is generally p-like owing to the high density energy bands lead density contribution [65]. However, as the opposite of this situation, the band gap of gallium arsenide occurs between bonding and antibonding orbitals. As the halide component changes, the valence energy band shifts at the limit value, while only small changes occur in the energy limit value of the transmission band [66]. The cation A does not contribute considerably to the conduction and valence orbitals, but has an important effect on the band gap of perovskite [67]. As a result, emission energies of MA-based perovskite nanocrystals have been demonstrated to range from halide to 407 to 734 nm. It is understood that the FA emissions of nanocrystalline FAs shifted to 408 nm with Cl, to 535 nm with Br and to I and 784 nm, that is, to red [68–70]. In addition, the B cation has a significant mission in changing the optical properties of metal halide perovskites nanocrystals. As is known, the lead is a harmful element for the nature, instead of using the band [71], the band gap and PL emissions of the metal halide perovskites nanocrystals shifted from Cl to 443 nm and from I to 953 nm. The reason is probably a result of the higher electronegativity of Sn_2 than Pb_2 [72]. But, the stability of Sn^{2+} and similarly Ge^{2+} based on perovskite compounds is too weak owing to the reduction of non-interacting electron pair effects corresponding to a decrease in the stability of the divalent oxidation state [73]. As a result, PL emissions or energy band gaps of nanocrystalline structures obtained by various methods depend only on stoichiometry [74]. Stokes shift is an important parameter at the absorption and emission spectra that LHP nanocrystals show typically small, ranging from 20 to 85 meV [75–77]. Stokes shift increases as nanocrystals decrease in size. This is clarified by the creation of a compatible hole state that can be delocalized across the whole nanocrystal [78]. PL line widths of metal halide perovskites are another important point, particularly for LED applications. In fact, the line widths are commonly in the range of 70-110 meV and have been found to vary significantly with respect to the halide content. In many articles, the halide component greatly varies the PL spectra in terms of wavelength, for instance for Cl-perovskites reaches to 10–12 nm and for I-perovskites 40 nm. In terms of photoluminescent quantum yields, LHP nanocrystals display high values with the more epitaxial shell range the more chalcogenide QDs without electronic passivation [69]. Some article abot MA based halide perovskites have been reached to 80 % to 95 % for photoluminescent

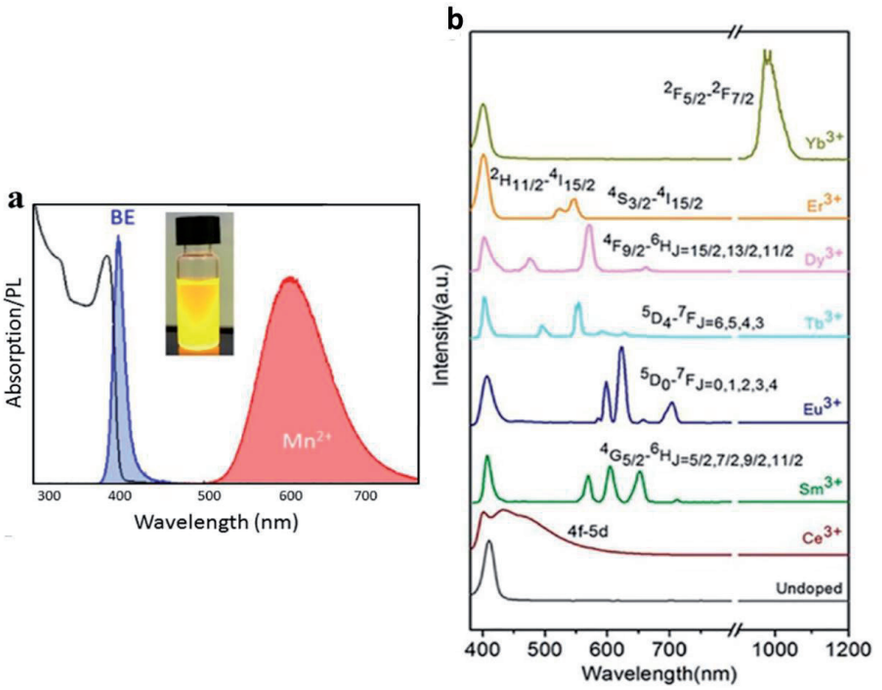

Figure 11.
(a) Photoluminescence emission & absorption of Mn-doped CsPbCl3 NCs, (b) photoluminescence curves of CsPbCl3 NCs doped with different lanthanide ions (reproduced with permission of Refs. [23, 87]).

quantum yields, bromide and iodides, respectively [79–82]. The defect tolerance of halide perovskite gives new properties due to orbital structure and the bandgap that forms between two antibonding orbitals. FA-based nanocrystals also reach to 70–90% photoluminescent quantum yield. There is alternative method that doping with additional ions to handle the optical emission of LHP nanocrystals. The addition of Mn^{2+} ions leads to a strong Stokes shift emission by the band gap given by the perovskite matrix and the emission from the atomic states of the Mn^{2+} ions (**Figure 11a**) [83]. Mn^{2+} doping can result in a pair of controllable emissions from both localized Mn^{2+} states and band gap recombination [84, 85]. In contrary, $CsPbBr_3$ nanocrystals have been shown to cause blue shift of doping, band boundary and PL emission with other divalent cations such as Sn^{2+}, Cd^{2+} and Zn^{2+}. In these cases, an important portion (0.2–0.7%) of the original Pb ions have been exchanged by new metal cations that produce alloy nanocrystals. CsPbBr3 alloy nanocrystals with 0.2% content of AI^{3+} ions have a blue shear PL emission with a centre of 456 nm and a relatively high 42% photoluminescence quantum yield [86]. In all these cases, perovskite nanocrystals act as an absorbent host that stimulates dopants through energy transfer. In addition, by selecting specific dopant atoms, the emission wavelengths of the nanocrystals obtained can be easily adjusted. When lanthanide ions are doped, the emission of $CsPbCl_3$ nanocubes ranges from 400 nm to 1000 nm and their quantum yields are 15% and 35%, respectively (**Figure 11b**) [87].

5. Optoelectronics applications of perovskite

5.1 Optical lasing

High absorption coefficient and strong photoluminescence is the most powerful side of metal halide perovskite. It is possible to obtain a laser with a high quantum efficiency material and a suitable optical band spacing. With the understanding

that amplified spontaneous emission can be obtained from perovskite material, research has focused on this subject. Especially, laser obtaining studies were carried out by using perovskite crystal. It has also been shown that perovskite nanowires in high crystalline feature can have a Fabry-Perot gap to obtain a laser in the material [88]. By manipulating the content of the halide in the composition of the perovskite lead to control the emission wavelength and obtain the laser in the entire visible spectrum (**Figure 12a** and **b**) [57]. Zhu et al. showed that laser exposure in $CH_3NH_3PbX_3$ with an exponentially low current threshold (220 nJ cm^{-2}) and a corresponding carrier density as low as 1.5×10^{16} cm^{-3}.

5.2 Light emitting diodes

Metal halide perovskite has great potential due to its easy preparation, low cost and high-performance light emitting diodes. Perovskites in LED applications show well a high colour purity, usually 15–25 nm full width half-colour purity for electroluminescence spectra. The point is here that the colour adjustment can cover the entire visible part of the spectrum by changing the content of different halides within the compounds. Therefore, many researchers have achieved high performance in perovskite quantum dot LED because of their quantum dots, strong luminescence, and high external quantum yields (**Figure 13a**) [25]. The stability problem of organic-inorganic hybrid perovskite can be eliminated by synthesizing the inorganic perovskites (ie $CsPbX_3$) as quantum dots for LED applications (**Figure 13b**) [89]. The performance of perovskite nanoplatelets in LED applications was lower than the quantum dots (**Figure 13c**). As a result, perovskite has a great potential for lighting and display applications as a new generation LED material.

5.3 Alternative applications

FETs, photodetectors, and single photon emitters are the other potential optoelectronic application devices. Liu et al. [90] used perovskite nanoplatelets to produce a FET on a Si/SiO_2. For this device, the current-voltage curve showed ohmic contact between the perovskite nanoplatelets and electrodes, and a linear dependency was noted. In that study, they revealed a strong light-material interaction and broadband light harvesting capability of perovskite. Many photodetectors were fabricated based on a horizontal $CH_3NH_3PbI_3$ nanowire array [49]. The

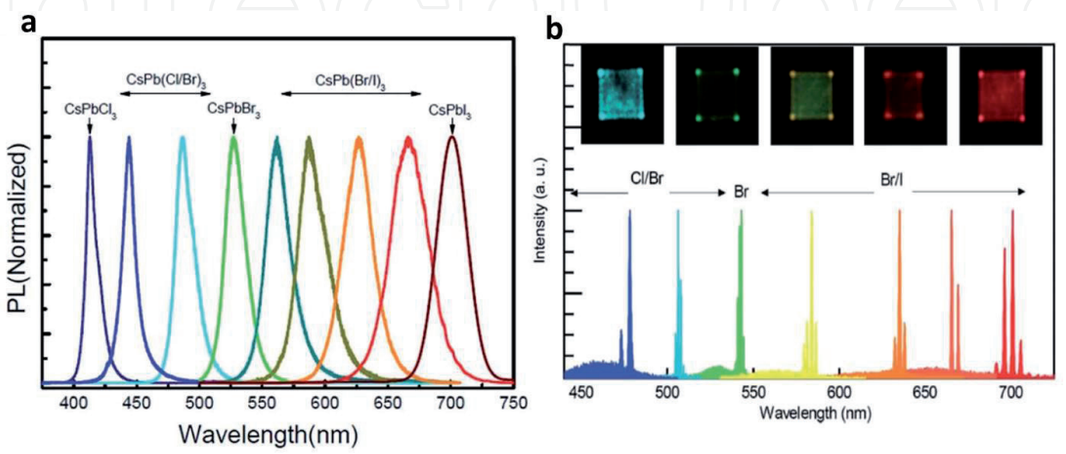

Figure 12.
(a) Photoluminescence spectra of CsPb (X = Cl, Br, I)3 nanoplatelets and (b) wavelength adjustment of perovskite lasing by controlling the content of halide in CsPbX3 perovskite [6, 7, 57]. There is really an extraordinary point about nanowires is that they have very little carrier capture area and the laser quantum efficiency reaches to 100% (reproduced with permission of Ref. [6]).

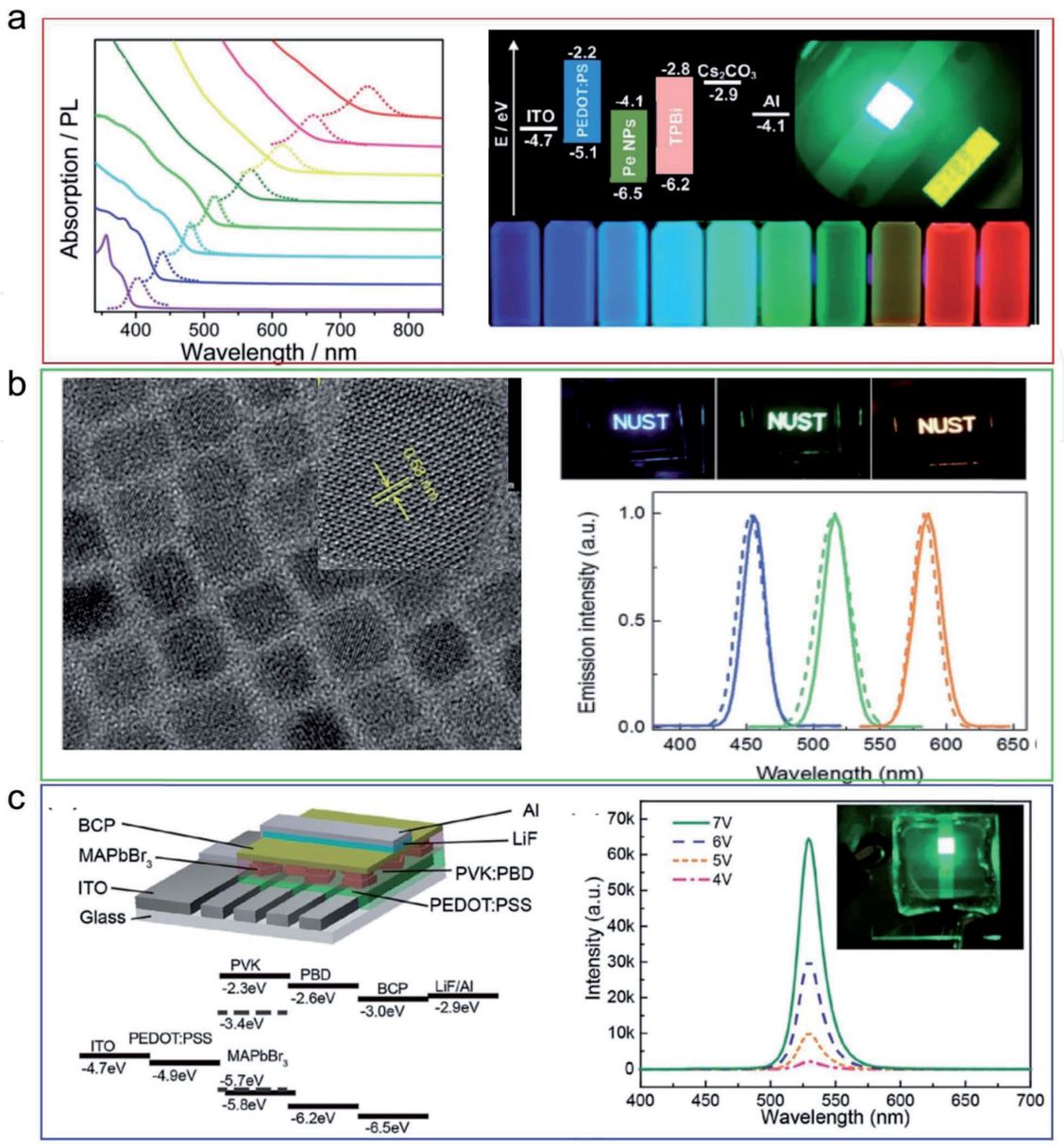

Figure 13.
In LED applications are generally used a low dimensional perovskite. (a) CH3NH3PbX3 quantum dots are applied to fabricate LED, (b) CsPbX3 quantum dots are used to form LED, (c) CH3NH3PbX3 nanoplatelets are performed to obtain LED (reproduced with permission of Refs. [25, 89, 91]).

response time compared to the obtained photodetectors bulk perovskite and other inorganic nanowire photodetectors is higher in terms of response time of 0.3 ms, 1.3 A W^{-1} response and a detectivity of 2.5 × 10^{12} Jones. Park et al. show a remarkable perovskite nanomaterials application that Quantum dots were used as a single photon emitter at standard conditions. $CsPbX_3$ perovskite was used as the leading material to synthesize cubic shapes and quantum dots with an average size of 10 nm. Perovskite quantum dots displayed an excellent photon beam of emitted light and photoluminescence (PL) intensity fluctuations associated with PL life. It is defined that phenomenon as "A-type flashing" that is popular in the quantum dot system.

6. Conclusion

In this chapter, preparation methods and applications of 2D perovskite nanoparticles were reviewed. The most crucial points for synthesis method are uniformity

and form factor of synthesised nanoparticles. Furthermore, structural, optic, and electrochemical properties of 2D perovskites have been introduced in detail. Due to the low ionic interaction in the crystal structures, organo-halide perovskites exhibit low stability under ambient conditions. However, 2D perovskite nanoparticles still offer a great potential due to the structure-dependent optic and electronic properties.

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