CsPbBr₃ 钙钛矿纳米片的制备及其发光性能

李倩倩, 李福山*, 刘洋, 胡海龙, 杨开宇, 郭太良

福州大学物理与信息工程学院, 福州 350116

* 联系人, E-mail: fsli@fzu.edu.cn

2019-01-09 收稿, 2019-01-28 修回, 2019-01-29 接受, 2019-04-04 网络版发表

国家重点研发计划(2016YFB0401305)和国家自然科学基金(U1605244)资助

摘要 通过精确地控制在高温注入法中的制备温度和合成时间, 利用高温注入法制备出了全无机CsPbBr₃钙钛矿纳米片(nanoplates, NPs), 并将所制备出来的CsPbBr₃钙钛矿纳米片用简单的溶液旋涂法和真空蒸镀的方法制备了以CsPbBr₃钙钛矿纳米片为钙钛矿发光层的发光二极管(light emitting diodes, LEDs). 同时对CsPbBr₃钙钛矿纳米片的结构、形貌和光学性能以及以CsPbBr₃钙钛矿纳米片为钙钛矿发光层的LEDs的光电性能进行了表征和分析. 分析表明, 利用经本文改良过的高温注入法可以获得尺寸均一的CsPbBr₃钙钛矿纳米片, 并且具有良好的光学性能. 通过使用溶液法所制备出的以CsPbBr₃钙钛矿纳米片为发光层的LEDs器件的外部量子效率(external quantum efficiency, EQE)为1.71%.

关键词 钙钛矿, 纳米片, 发光二极管, CsPbBr₃

在过去十几年中, 由于金属卤化物钙钛矿优异的光电性能和在光伏器件中的潜在应用, 金属卤化物钙钛矿系列引起了大量研究者极大的关注和浓厚的研究热情^[1-3]. 这种钙钛矿被归类为具有ABX₃结构的化合物^[4,5], 其中A是阳离子(有机甲基铵, 甲脒或无机Cs⁺等), B是与6个X的八面体配位的金属阳离子(Pb²⁺, Sn²⁺等), X为Cl⁻, Br⁻, I⁻卤素阴离子或它们的混合物的卤化物离子. 在半导体钙钛矿家族中, 全无机铯铅卤化物(CsPbX₃)受到越来越多的关注^[6]. 因为全无机钙钛矿优异的光电性能^[7], 半峰宽窄、高光致发光量子产率^[8]、可调荧光波长覆盖整个可见光谱和极窄线宽^[5], 已经广泛应用于各种光电器件, 如作为太阳能电池^[9,10]、发光二极管^[11,12]、光电探测器^[13-15]、柔性发光器件^[16]、激光器^[17]、生物细胞医学研究^[18,19]等. 目前, 研究者们也致力于研究全无机钙钛矿的形貌^[20,21], 合成大量不同维度纳米片^[22]或不同形貌, 如纳米线^[23]的钙钛矿材料, 并将各种形状的钙钛矿

量子点材料应用于显示器件中, 其中二维纳米片形貌更是由于其各向异性这一特点而备受关注. 研究者们也期望用这一特性制备出性能更优越的显示器件. 由此可见, 全无机钙钛矿材料是一种新兴且具有丰富研究价值的光电材料.

本文采用经过略微改进后的高温注入法^[5], 主要通过控制合成温度与反应时间, 合成出尺寸大小均一的全无机钙钛矿CsPbBr₃纳米片, 并将所合成出的CsPbBr₃纳米片利用溶液法制备了结构为ITO/PEDOT:PSS/TFB/CsPbBr₃ NPs/TPBI/LiF/Al的LEDs器件. 其中, ITO为氧化铟锡玻璃(indium tin oxide glass), PEDOT为聚(3,4-亚乙二氧基噻吩)(poly(3,4-ethylenedioxythiophene)), PSS为聚(苯乙烯磺酸)(poly(styrenesulfonate)), TFB为1,2,4,5-四(三氟甲基)苯(1,2,4,5-tetrakis(trifluoromethyl)benzene), TPBI为1,3,5-三(1-苯基-1H-苯并咪唑-2-基)苯(1,3,5-tris(1-phenyl-1H-benzimidazol-2-yl)benzene). 这类器件通过使用

引用格式: 李倩倩, 李福山, 刘洋, 等. CsPbBr₃ 钙钛矿纳米片的制备及其发光性能. 科学通报, 2019, 64: 1478–1484

Li Q Q, Li F S, Liu Y, et al. Preparation and photoelectric properties of CsPbBr₃ perovskite nanoplates (in Chinese). Chin Sci Bull, 2019, 64: 1478–1484, doi: 10.1360/N972019-00028

空穴迁移率较高的TFB为空穴传输层,改善了原有器件制备工艺,提高了空穴的传输效率,增加了电子与空穴的复合概率.由全无机钙钛矿CsPbBr₃纳米片为发光层的发光二极管(light emitting diodes, LEDs)器件的发光亮度为297 cd m⁻²,其外部量子效率(external quantum efficiency, EQE)为1.71%.

1 实验

1.1 CsPbBr₃纳米片的合成

(i) 油酸铯的制备. 在100 mL的三颈圆底烧瓶中,称取0.814 g的碳酸铯(Cs₂CO₃),加入40 mL的十八烯(octadecene, ODE)和2.5 mL的油酸(oleic acid, OA),在120℃的条件下干燥1 h.然后通入氮气,在氮气保护的环境下加热至150℃直至所有的Cs₂CO₃与OA反应完全.因为油酸铯在室温的环境下很容易从ODE中析出,所以在注入前一定要预加热至100℃.

(ii) CsPbBr₃纳米片的合成. 在100 mL的三颈圆底烧瓶中,称取0.276 g的PbBr₂,加入20 mL的ODE,在120℃的条件下抽真空干燥1 h.然后,持续充入氮气,在120℃的环境下,在上述溶液中注入2 mL干燥的油胺(oil amine, OLA)和2 mL干燥的油酸.在PbBr₂完全溶解于溶液时,即溶液变为澄清透明态,为了调节纳米晶体的尺寸大小,将温度调节至110℃.继而取1.6 mL(i)中合成出的油酸铯溶液快速注入反应的混合溶液中,等待5 s后,立刻将三颈圆底烧瓶浸入冰水浴中使反应停止并进行冷却,待溶液温度变为20℃时取出备用.

(iii) CsPbBr₃纳米片的提纯. 在原液通过冰水浴进行冷却之后,通过离心的方法将团聚的纳米片进行再次分散.在(ii)中合成的溶液中加入与原液比为1:1的乙酸乙酯,利用离心机以转速12000 r min⁻¹离心10 min后,倒掉上层清液,将沉淀后的量子点再次分散于正辛烷中.

1.2 CsPbBr₃纳米片发光二极管的制备

将刻蚀好的ITO玻璃先用清洁剂进行擦洗,再分别置于丙酮、乙醇、去离子水中依次超声清洗15 min,清洗完后在烘箱中烘干备用.将烘干的ITO放在等离子体机中等离子处理10 min,用0.45 μm的水性过滤器过滤PEDOT:PSS.从阳极到阴极QLEDs的制备顺序为:(1) 将已经过滤的PEDOT:PSS旋涂于ITO阳极

上,旋涂工艺参数为低速500 r min⁻¹,时间1 s,高速3000 r min⁻¹,时间40 s,在120℃下退火15 min;(2) 将8 mg mL⁻¹的TFB氯苯溶液旋涂于PEDOT:PSS膜上,旋涂工艺参数为低速500 r min⁻¹,时间1 s,高速3000 r min⁻¹,时间40 s,在120℃下退火20 min;(3) 将CsPbBr₃纳米片旋涂沉积到TFB膜上,旋涂工艺参数为低速500 r min⁻¹,时间1 s,高速2000 r min⁻¹,时间40 s,在50℃下退火2 min;(4) 真空蒸镀电子传输层TPBI层,蒸镀所采用蒸发源的沉积速率为1 Å s⁻¹,厚度为50 nm;(5) 真空蒸镀电子注入层LiF层,蒸镀所采用蒸发源的沉积速率为0.1 Å s⁻¹,厚度为1 nm;(6) 最后真空热蒸镀Al电极,蒸镀所采用蒸发源的工作电流为3 Å s⁻¹,厚度为150 nm.

1.3 CsPbBr₃纳米片光学性能和形貌表征

通过使用耦合到单色仪的Xe灯激发样品,用Shimadzu F4600荧光分光光度计收集稳态PL光谱.用UV分光光度计(Shimadzu UV-3600)来测量紫外可见吸收光谱.通过荧光寿命测量系统(Horiba scientific)收集时间分辨PL测量.使用JEOL JEM-2100F显微镜,电压为100 kV来观察CsPbBr₃纳米片的透射电子显微镜(transmission electron microscope, TEM)图像.通过原子力显微镜(atomic force microscope, AFM Bruker Multimode 8)表征将CsPbBr₃纳米片沉积在TFB上的薄膜的表面形态.

1.4 LEDs的光电性能测试

采用计算机控制的光谱仪(Ocean optic USB2000+)测试所制备的LEDs器件的EL光谱,*I*-*V*特性由Keithley 2400和Keithley 6485测试得到,由Keithley 2400(Tektronix)仪器提供-0.6~10 V的直流扫描电压.

2 结果与讨论

2.1 CsPbBr₃纳米片光学性能与透射电子显微镜分析

图1为钙钛矿CsPbBr₃纳米片的光学性能图,其中(a)为通过高温注入法合成出的CsPbBr₃纳米片白光灯下照片(左)和在紫外灯光激发下的荧光照片(右).可以看出,CsPbBr₃纳米片发出了均匀稳定的蓝绿光,并且发光效果好.图1(b)是CsPbBr₃纳米片的光致发光

图1 (网络版彩色)CsPbBr₃纳米片的光学性能图。(a) CsPbBr₃纳米片的日光灯下照片(左)与紫外灯下照片(右);(b) CsPbBr₃纳米片的PL光谱和吸收光谱;(c) CsPbBr₃纳米片的荧光衰减寿命图谱

Figure 1 (Color online) Optical performance of CsPbBr₃ nanoplates. (a) Photograph of CsPbBr₃ nanoplates under fluorescent light (left) and photo under UV light (right); (b) PL spectra and absorption spectra of CsPbBr₃ nanoplates; (c) CsPbBr₃ nanoplates fluorescence decay lifetime map

光谱图(photoluminescence, PL)和吸收光谱图。测试结果表明,使用激发光波长为365 nm的紫外激发光照射CsPbBr₃纳米片时,CsPbBr₃纳米片的PL发光峰位于500 nm,半峰宽为26 nm,表明利用高温注入法所合成出的CsPbBr₃纳米片发光均匀且色纯度高。从测试图中也可以观察到CsPbBr₃纳米片的吸收峰明显,且吸收峰位于480 nm,与PL光谱相比有20 nm的蓝移,这是由于斯托克斯位移造成的。图1(c)为CsPbBr₃纳米片的荧光衰减寿命图谱,可以得出,CsPbBr₃纳米片的荧光衰减寿命为17 ns。

图2为钙钛矿CsPbBr₃纳米片的TEM图。通过观测CsPbBr₃纳米片的TEM图片,从(a)中可以看出钙钛矿CsPbBr₃纳米片分布均匀、尺寸较为均一,大部分CsPbBr₃纳米片处于面向上的平铺状态,有一部分是侧边向上地立着的状态。图2(b)展示了合成出的CsPbBr₃纳米片的平均尺寸长为20~21 nm,厚度为3~5 nm。通过将所合成出CsPbBr₃纳米片溶液再加入

正辛烷进行浓度稀释,可以进一步使得大面积CsPbBr₃纳米片处于平铺的状态,更有利于将CsPbBr₃纳米片制备成表面均匀的膜。当将CsPbBr₃纳米片旋涂在ITO/PEDOT:PSS/TFB上时,使用AFM进行观测,得到如图2(c)所示的CsPbBr₃纳米片形貌图。可以看出,CsPbBr₃纳米片非常均匀致密,这将会有利于发光二极管器件性能的提升。

2.2 CsPbBr₃纳米片发光二极管的光电性能的测试与分析

图3(a)是CsPbBr₃纳米片发光二极管的结构示意图。我们采用了ITO/PEDOT:PSS/TFB/CsPbBr₃ NPs/TPBI/LiF/Al的器件结构。在制备的过程中,使用已经光刻好图形的ITO玻璃,通过旋涂法沉积空穴注入层PEDOT:PSS,空穴传输层TFB和发光层CsPbBr₃纳米片,利用真空蒸镀沉积电子传输层TPBI,电子注入层LiF和阴极Al电极。众所周知,在I-III-VI族的化合

图2 (网络版彩色)CsPbBr₃纳米片的形貌图。(a) 标尺为50 nm的CsPbBr₃纳米片的TEM测试图;(b) 标尺为20 nm的CsPbBr₃纳米片的TEM测试图;(c) CsPbBr₃纳米片旋涂于ITO/PEDOT:PSS/TFB上的AFM形貌图

Figure 2 (Color online) Morphology of CsPbBr₃ nanoplates. (a) TEM image of chart of 50 nm CsPbBr₃ nanoplates; (b) TEM image of chart of 20 nm CsPbBr₃ nanoplates; (c) AFM topography of CsPbBr₃ nanoplates spin-coated on ITO/PEDOT:PSS/TFB

图3 (网络版彩色)LEDs的结构示意图(a)和能带结构示意图(b)

Figure 3 (Color online) Schematic diagram of the LEDs (a) and its energy band structure (b)

物中, 最常在发光二极管中的空穴传输层为聚乙烯基咔唑(polyvinylcarbazole, PVK), 聚[双(4-苯基)(4-丁基苯基)胺](poly[*N,N'*-bis(4-butylphenyl)-*N,N'*-bis(phenyl)-benzyl], poly-TPD). 但是, 这些空穴传输层具有比较低的空穴迁移率(PVK的空穴迁移率 $10^{-6} \sim 10^{-5} \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$, poly-TPD的迁移率为 $10^{-4} \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$). 采用这些材料所制备出来的QLEDs有比较低的电流密度, 并且有较高的开启电压. 所以, 我们选择了TFB(空穴迁移率为 $10^{-2} \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$)这一具有较高空穴迁移率的材料作为空穴传输层, 以期望器件能达到较高的电流密度和较低的开启电压. 图3(b)为器件各薄膜层的材料的能带结构示意图, 可以看出各层的最高已占轨道(highest occupied molecular orbital, HOMO)和最低未占轨道(lowest unoccupied molecular orbital, LUMO)能级. CsPbBr₃ 纳米片的HOMO和LOMO分别为3.6和5.2 eV^[15], 并且空穴是由阳极的ITO层依次通过PEDOT:PSS层、TFB层到达发光层, 而电子是由阴极Al层通过TPBI层到达CsPbBr₃纳米片发光层. 从阳极来的空穴与从阴极来的电子在电

压的作用下复合产生光子, 从而进行电致发光, 这就是本实验所制备出的器件的工作原理.

图4(a)是CsPbBr₃纳米片发光二极管的电致发光亮度测试图, 可以看出, 当电压为4.5 V左右时, 器件开始发光. 4.5 V为器件的开启电压, 随着电压以0.2 V的步进值逐步升高, 器件的亮度也随着越来越亮. 当电压为8.6 V时, 器件的亮度值达到最大峰值, 器件的发光亮度有297 cd m^{-2} . 当电压超过8.6 V时, 器件的发光亮度也逐渐变弱, 慢慢开始衰减. 图4(b)是LEDs的电流密度测试图, 在施加0~12 V的外部电压时, 电流密度随之升高. 经过计算可以得出外部量子效率EQE为1.71%. 因为CsPbBr₃纳米片的表面缺陷, 外部量子效率虽然没有达到较高的值, 但是证明了我们可以将CsPbBr₃纳米片应用于发光二极管领域, 并且提供了一定的思路.

图5(a)是CsPbBr₃纳米片发光二极管的电致发光光谱和CsPbBr₃纳米片溶液的光致发光光谱的归一化对比图. 可以看出, CsPbBr₃纳米片发光二极管的电致发光光谱相较于CsPbBr₃纳米片溶液的光致发光

图4 (网络版彩色)LEDs的亮度测试图(a)和LEDs的电流密度测试图(b)

Figure 4 (Color online) Brightness test chart (a) and current density (b) of LEDs

光谱的峰值红移了25 nm左右, 可以将其归因于CsPbBr₃纳米片层在制备成器件的过程中, 与其上下两层(电子注入层和空穴注入层)之间的相互作用造成的. 此外, 在施加外部电压产生外部电场的时候, 也会对其产生一定的影响. 图5(b)是CsPbBr₃纳米片发光二极管的电致发光效果图, 可以看出, 由CsPbBr₃纳米片所制备而成的器件的发光效果非常均匀, 并没有发现中间不亮或变亮的情况. 可以证明, 在制备器件的过程中, 旋涂沉积所获得的薄膜层与真空蒸镀所获得的薄膜层都是十分致密均一的, 且比较平滑.

3 结论

通过控制高温注入法中的合成温度和反应时间,

我们合成出了发光峰窄、峰值位于500 nm, 半峰宽为26 nm的CsPbBr₃纳米片. CsPbBr₃纳米片的尺寸均一, 平均尺寸约长20~21 nm, 厚度为3~5 nm, 分布均匀. 并且利用工艺流程简单的溶液旋涂法结合真空蒸镀法制备出了以CsPbBr₃纳米片为发光层, 器件结构为ITO/PEDOT:PSS/TFB/CsPbBr₃ NPs/TPBI/LiF/Al的发光二极管器件, 其具有明显的二极管发光特性. 采用空穴迁移率较大的TFB作为空穴传输层, 选取TPBI作为电子传输层, 制备出了开启电压为4.5 V, 最大亮度达到297 cd m⁻²(外部电压为8.6 V), 外部量子效率EQE为1.71%的CsPbBr₃纳米片发光二极管. 这一结果为今后制备高效率的发光二极管器件奠定了基础, 并且提供了一种较为简单的CsPbBr₃纳米片合成方法, 以及一种重复性好的薄膜器件制备工艺.

图5 (网络版彩色)钙钛矿LEDs的发光特性. (a) 器件的电致发光和光致发光的光谱对比图; (b) 器件的电致发光效果图

Figure 5 (Color online) Luminescent properties of perovskite LEDs. (a) Comparison of electroluminescence and photoluminescence of devices; (b) electroluminescence of devices

参考文献

- Bao J, Bawendi M G. A colloidal quantum dot spectrometer. *Nature*, 2015, 523: 67–68
- Bhaumik S, Veldhuis S A, Ng Y F, et al. Highly stable, luminescent core-shell type methylammonium-octylammonium lead bromide layered perovskite nanoparticles. *Chem Commun*, 2016, 52: 7118–7121
- Buchtlova H, Strmiska V, Dostalova S, et al. Design and testing of lanthanide-based quantum dots for live cell and *in vivo* imaging. *Int J Mol Med*, 2017, 40: S55
- Klimov V I, Mikhailovsky A A, Xu S, et al. Optical gain and stimulated emission in nanocrystal quantum dots. *Science*, 2000, 290: 314–317
- Protesescu L, Yakunin S, Bodnarchuk M I, et al. Nanocrystals of cesium lead halide perovskites (CsPbX₃, X=Cl, Br, and I): Novel optoelectronic materials showing bright emission with wide color gamut. *Nano Lett*, 2015, 15: 3692–3696
- Di Stasio F, Imran M, Akkerman Q A, et al. Reversible concentration-dependent photoluminescence quenching and change of emission color in CsPbBr₃ nanowires and nanoplatelets. *J Phys Chem Lett*, 2017, 8: 2725–2729
- Dong Y H, Gu Y, Zou Y S, et al. Improving all-inorganic perovskite photodetectors by preferred orientation and plasmonic effect. *Small*, 2016, 12: 5622–5632
- Swarnkar A, Chulliyil R, Ravi V K, et al. Colloidal CsPbBr₃ perovskite nanocrystals: Luminescence beyond traditional quantum dots. *Angew Chem Int Ed*, 2015, 54: 15424–15428

- 9 Liang J, Wang C X, Wang Y R, et al. All-inorganic perovskite solar cells. *J Am Chem Soc*, 2017, 139: 2852
- 10 Nejand B A, Nazari P, Gharibzadeh S, et al. All-inorganic large-area low-cost and durable flexible perovskite solar cells using copper foil as a substrate. *Chem Commun*, 2017, 53: 747–750
- 11 Dai X L, Zhang Z X, Jin Y Z, et al. Solution-processed, high-performance light-emitting diodes based on quantum dots. *Nature*, 2014, 515: 96–99
- 12 Li J H, Xu L M, Wang T, et al. 50-Fold eqe improvement up to 6.27% of solution-processed all-inorganic perovskite CsPbBr₃ QLEDs via surface ligand density control. *Adv Mater*, 2017, 29: 1603885
- 13 Grim J Q, Manna L, Moreels I. A sustainable future for photonic colloidal nanocrystals. *Chem Soc Rev*, 2015, 44: 5897–5914
- 14 Shoaib M, Zhang X H, Wang X X, et al. Directional growth of ultralong CsPbBr₃ perovskite nanowires for high-performance photodetectors. *J Am Chem Soc*, 2017, 139: 15592–15595
- 15 Li X M, Yu D J, Chen J, et al. Constructing fast carrier tracks into flexible perovskite photodetectors to greatly improve responsivity. *ACS Nano*, 2017, 11: 2015–2023
- 16 Kim D, Fu Y, Kim S, et al. Polyethylenimine ethoxylated-mediated all-solution-processed high-performance flexible inverted quantum dot-light-emitting device. *ACS Nano*, 2017, 11: 1982–1990
- 17 Schafer J, Mondia J P, Sharma R, et al. Quantum dot microdrop laser. *Nano Lett*, 2008, 8: 1709–1712
- 18 Michalet X, Pinaud F F, Bentolila L A, et al. Quantum dots for live cells, *in vivo* imaging, and diagnostics. *Science*, 2005, 307: 538–544
- 19 Walling M A, Novak J A, Shepard J R E. Quantum dots for live cell and *in vivo* imaging. *Int J Mol Sci*, 2009, 10: 441–491
- 20 Imran M, Di Stasio F, Dang Z Y, et al. Colloidal synthesis of strongly fluorescent CsPbBr₃ nanowires with width tunable down to the quantum confinement regime. *Chem Mater*, 2016, 28: 6450–6454
- 21 Oksenberg E, Sanders E, Popovitz-Biro R, et al. Surface-guided CsPbBr₃ perovskite nanowires on flat and faceted sapphire with size-dependent photoluminescence and fast photoconductive response. *Nano Lett*, 2018, 18: 424–433
- 22 Sichert J A, Tong Y, Mutz N, et al. Quantum size effect in organometal halide perovskite nanoplatelets. *Nano Lett*, 2015, 15: 6521–6527
- 23 Zhang D D, Eaton S W, Yu Y, et al. Solution-phase synthesis of cesium lead halide perovskite nanowires. *J Am Chem Soc*, 2015, 137: 9230–9233

Summary for “CsPbBr₃ 钙钛矿纳米片的制备及其发光性能”

Preparation and photoelectric properties of CsPbBr₃ perovskite nanoplates

Qianqian Li, Fushan Li*, Yang Liu, Hailong Hu, Kaiyu Yang & Tailiang Guo

College of Physics and Information Engineering, Fuzhou University, Fuzhou 350116, China

* Corresponding author, E-mail: fsl@fzu.edu.cn

All inorganic cesium lead halide (CsPbX₃, X=Cl, Br, I) perovskites, as a best candidate in perovskite family, have attracted great interest due to their fascinating optical, chemical and semiconducting properties and have demonstrated as potential building blocks in various applications such as photodetectors, light-emitting diodes, solar cells and lasers. Numerous efforts have been made to develop various CsPbBr₃ perovskites with tunable morphology such as quantum dots (0-D), nanowires (1-D) and nanoplates (2-D) to achieve desired properties. Among them, anisotropic colloidal quasi-two-dimensional nanoplates have been attracting a great deal of research enthusiasm. In this work, all-inorganic CsPbBr₃ perovskite nanoplates were prepared by precisely controlling the synthesis temperature and time in the hot-injection method. The reaction was performed under the protective atmosphere of nitrogen, at 110°C for 5 s and the reaction mixture was cooled by ice-water bath. Afterwards, the solution was purified by centrifugation at 12000 r min⁻¹ and the precipitates were dissolved in n-octane. The structure, morphology and optical properties of as-synthesized CsPbBr₃ perovskite nanoplates were characterized and analyzed by the series of characterization techniques. The results show that a sharp PL emission was detected at the peak of 500 nm with a narrow full width at the half maximum (FWHM) of 26 nm. The high-resolution transmission electron microscopy (HR-TEM) showed that the as-prepared CsPbBr₃ nanoplates were uniform in size, with an average length of 20–21 nm and a thickness of 3–5 nm. All the above studies evidenced that, the improved high temperature-injection method have yielded the CsPbBr₃ perovskite nanoplates with uniform size distribution, high color purity and improved optical properties. In addition, light emitting diode (LED) with CsPbBr₃ perovskite nanoplates as the perovskite luminescent layer were fabricated by the simple solution spin-coating and vacuum evaporation technique. The device structure of the LED is ITO/PEDOT:PSS/TFB/CsPbBr₃ NPs/TPBI/LiF/Al. In the device configuration, the patterned ITO is used as the anode, the spin-coated TFB with larger hole mobility is used as the hole transport layer, vacuum evaporated TPBI is chosen as the electron transport layer, as-prepared CsPbBr₃ perovskite nanoplates are used as the light emitting active layer, and the vacuum evaporated LiF as the electron injection layer with Al cathode. The external quantum efficiency (EQE) of 1.71% and the luminous brightness of 297 cd m⁻² was achieved for the LED devices fabricated by the solution method. Moreover, the densification and roughness of CsPbBr₃ perovskite nanoplates as the luminescent layers were measured by atomic force microscopy (AFM). The improved efficiency and performance of our device was directly related to the compact and smooth surface of CsPbBr₃ luminescent active layer. This result lays a foundation for the fabrication of high efficiency light emitting diode devices by utilizing all-inorganic CsPbBr₃, and provides a relatively simple method for the synthesis of CsPbBr₃ nanoplates, as well as good repeatability of thin film device fabrication process.

perovskite, nanoplates, light emitting diode, CsPbBr₃

doi: 10.1360/N972019-00028