Space-confined growth of high-quality $\text{CsBi}_3\text{I}_{10}$ lead-free perovskite film for near-infrared photodetectors with high sensitivity and stability

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ABSTRACT As a lead-free perovskite, $\text{CsBi}_3\text{I}_{10}$ has attracted significant attention because of its high thermal tolerance and long electron diffusion length. Solution-processed high-performance $\text{CsBi}_3\text{I}_{10}$ perovskite devices, however, are hindered by the formation of a two-dimensional structure, which results in an extremely high surface roughness and many pinholes. In this paper, we reported a space-confined growth (SCG) method using a single-layer polystyrene (PS) sphere template to obtain high-smoothness, high-crystallinity, and dense $\text{CsBi}_3\text{I}_{10}$ perovskite films. Compared with traditionally spin-coated $\text{CsBi}_3\text{I}_{10}$ photodetectors (PDs), the metal-semiconductor-metal PDs made by SCG showed a higher photocurrent, a lower dark current, and a bigger on/off ratio. In addition, the photocurrent of our unencapsulated $\text{CsBi}_3\text{I}_{10}$ perovskite PDs was not attenuated under long-time illumination. In addition, when the device was stored in air for 30 d, its performance also showed no degradation, demonstrating ultra-high stability. Furthermore, the synthesis was free of antisolvents, such as chlorobenzene and toluene, which is beneficial for the environmentally friendly assembly of the devices. Our strategy opens up a new way to prepare high-quality lead-free perovskite, which may be useful for applications in light-emitting diodes and solar cells.

Keywords: photodetectors, perovskite, space-confined growth, lead-free

INTRODUCTION

Photodetectors (PDs) have attracted significant attention because of their wide applications in various fields, such as the military and national economy [1–3]. Today, lead halide perovskite materials have been widely studied in PDs because of their high light absorption coefficient, long carrier diffusion length, and low defect state density

[4–9]. The detectivity of perovskite PDs has reached 10^{15} Jones [6]. Although lead halide perovskite PDs have made excellent progress, commercial application of these devices has been limited by the presence of toxic lead [10]. Therefore, research on leadless or lead-free perovskite materials has become a hot topic [11–14], particularly on the exploration of lead-free perovskites, which exhibit the same merits as those in the perovskite family while still exhibiting high device performance and stability.

In recent years, excellent advances have been reported by replacing lead with tin for leadless or lead-free perovskite optoelectronic devices [15–18]. Waleed *et al.* [16] reported a $\text{CH}_3\text{NH}_3\text{SnI}_3$ ($\text{CH}_3\text{NH}_3=\text{MA}$, MASnI_3) nanowire array PD with a responsivity that reached 0.47 A W^{-1} and detectivity of 8.8×10^{10} Jones. Zhu *et al.* [18] prepared a $\text{MA}_{0.9}\text{Rb}_{0.1}\text{Sn}_{0.65}\text{Pb}_{0.35}\text{I}_3$ detector with a linear dynamic range (LDR) reaching 110 and a 3-dB cut-off frequency of 1 MHz. Other reports, however, have indicated more serious environmental implications following the use of tin compared with lead. In addition, the easy oxidation of Sn^{2+} to Sn^{4+} often results in the significant instability of Sn-based perovskite devices [19]. Germanium has been suggested as another lead replacement metal; however, this rare germanium is expensive and requires additional refinement [20]. Bismuth, a nontoxic metal that has similar properties to lead, is a good choice for Bi-based perovskite because of its long electron diffusion length ($>1.9 \mu\text{m}$) [21]. Therefore, Bi is expected to replace Sn as a next-generation, environmentally friendly perovskite material. In 2015, Park *et al.* [22] reported the application of $\text{Cs}_3\text{Bi}_2\text{I}_9$ perovskite material in a solar cell with an efficiency of 1.09%. Johansson *et al.* [20] synthesized black $\text{CsBi}_3\text{I}_{10}$ perovskite

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by adding BiI_3 in the $\text{Cs}_3\text{Bi}_2\text{I}_9$, lowering its band gap from 2.03 to 1.77 eV, which widened the light absorption range of the material and made it more suitable for the preparation of solar cells. The Bi-based perovskite more easily forms a two-dimensional structure, and its surface roughness is extremely large with lots of pinholes, which severely limits the application of the $\text{CsBi}_3\text{I}_{10}$ perovskite in optoelectronic devices.

In this study, we obtained high-smoothness, high-crystallinity, and dense black $\text{CsBi}_3\text{I}_{10}$ perovskite thin films using space-confined growth (SCG) with a single-layer polystyrene (PS) sphere template. The performance of the metal-semiconductor-metal (MSM) PDs using SCG was better than that of the traditionally spin-coated $\text{CsBi}_3\text{I}_{10}$ PDs. Additionally, the photocurrent of our unencapsulated $\text{CsBi}_3\text{I}_{10}$ perovskite PDs was not attenuated under long-term illumination. In addition, when the device was stored in air for 30 d, its performance showed no degradation, indicating its ultra-high stability. Furthermore, this work did not require the use of toxic anti-solvents, such as chlorobenzene and toluene, suggesting its benefit for the environmentally friendly assembly of the devices.

EXPERIMENTAL SECTION

Traditionally spin-coated $\text{CsBi}_3\text{I}_{10}$ film

We prepared the precursors of perovskite by dissolving 0.2598 g CsI (99.999%) and 1.769 g BiI_3 (99.999%) in 1 mL dimethyl sulfoxide (99.9%) and keeping the mixture in the oven at 70°C for 24 h. Before use, we filtered the precursor with a 0.22- μm filter. Then, we added 80 μL of perovskite precursor solution to the substrate, which was rotated at 3,000 rpm for 30 s. The samples were then annealed at 100°C for 20 min.

SCG $\text{CsBi}_3\text{I}_{10}$ film

The $\text{CsBi}_3\text{I}_{10}$ precursor solution was spun on the substrate with a single-layer PS sphere (details are presented in our previous work [23]). The substrate was rotated at 3,000 rpm for 30 s and no other antisolvents were used. The samples were then annealed at 100°C for 20 min.

Device fabrication

A 70-nm Au electrode (Fig. S1) with a finger spacing of 100 μm was evaporated on the $\text{CsBi}_3\text{I}_{10}$ film to form an Au/ $\text{CsBi}_3\text{I}_{10}$ /Au MSM PD.

Characterization

We took high-resolution scanning electron microscopy

(SEM) images using field emission scanning electron microscopy (FESEM, JEOL, JSM-6700F), obtained X-ray diffraction (XRD) patterns using a D8 FOCUS X-ray diffractometer, and measured the absorption spectra using an ultraviolet-visible spectrophotometer. We measured the current-voltage (I - V) and current-time (I - t) curves using an Agilent B1500A electrometer. We used a 473-nm laser (50 mW) as the light source and calibrated its optical power by a standard Si diode.

RESULTS AND DISCUSSION

Fig. 1 shows the schematic diagram of the fabrication of the $\text{CsBi}_3\text{I}_{10}$ film according to the SCG method, and the traditional spin-coating method for the $\text{CsBi}_3\text{I}_{10}$ film is shown in Fig. S2. The details of the SCG method can be seen in our previous work [23]. Briefly, we added the ethanol solution of the PS spheres to water, allowing the PS spheres to uniformly disperse on the water surface (Fig. 1a). We then added sodium dodecyl sulfate (SDS) solution along the edge of the container to drive the PS spheres to form a dense film (Fig. 1b). The glass substrate was then inserted diagonally into the water and moved along the horizontal plane to transfer the PS spheres on the substrate (Fig. 1c, d). We heated the substrates on a heating table at 60°C for 1 h to remove the solution, thus generating a single-layer PS sphere film (Fig. 1f). The SEM images of the single-layer PS spheres on the glass substrate are shown in Fig. S3. After that, the $\text{CsBi}_3\text{I}_{10}$ precursor solution was spun on the substrate with a single-layer PS sphere. The substrate was rotated at 3,000 rpm for 30 s and no other antisolvents were used. We annealed the samples at 100°C for 20 min (Fig. 1g-i), thus producing the high-smoothness, high-crystallinity, and dense $\text{CsBi}_3\text{I}_{10}$ perovskite films.

Fig. 2a, b show the top and cross-sectional SEM views of $\text{CsBi}_3\text{I}_{10}$ perovskite prepared by the traditional spin-coating method. A $\text{CsBi}_3\text{I}_{10}$ perovskite film thickness of about 3.8 μm was clearly observed, which guaranteed the absorption of light. The $\text{CsBi}_3\text{I}_{10}$ thin film was composed of many large grains with significant gaps among them, which lowered the device performance. In contrast, a very flat, high-quality, dense, and pinhole-free $\text{CsBi}_3\text{I}_{10}$ perovskite thin film was grown using the SCG method (Fig. 2c, d), which guaranteed carrier separation and transport as well as the production of high-performance perovskite PDs. The typical atomic force microscopy (AFM) morphologies of the $\text{CsBi}_3\text{I}_{10}$ perovskite are shown in Fig. 2e and f. The perovskite film prepared by the traditional spin-coating method displayed uneven grain sizes with a root mean square roughness (R_q) of 0.641 μm

Figure 1 Schematic diagram of the fabrication of a $\text{CsBi}_3\text{I}_{10}$ PD by a SCG method.

Figure 2 (a) Top and (b) cross-sectional SEM images of the $\text{CsBi}_3\text{I}_{10}$ perovskite prepared by traditional spin-coating method. (c) Top and (d) cross-sectional SEM images of the $\text{CsBi}_3\text{I}_{10}$ perovskite thin films prepared by the SCG method. AFM images of the $\text{CsBi}_3\text{I}_{10}$ perovskite thin films prepared by different methods: (e) the traditional spin-coating method and (f) the SCG method.

(Fig. 2e). The film prepared using the SCG method, however, was very flat and had an R_q as low as 15.3 nm (Fig. 2f), indicating that the SCG method greatly improved the quality of $\text{CsBi}_3\text{I}_{10}$ thin film and rendered the produced films more suitable for device fabrication.

For the traditional spin-coating method, the precursor

solution on the common substrate volatilized quickly, such that the perovskite grains lacked shelf support during the growth to produce uniform grain shapes, which affected their stacking on the substrate. This enabled the loose and porous perovskite films to form, which is illustrated in Fig. 3a. In this SCG method

Figure 3 The formation mechanism of the $\text{CsBi}_3\text{I}_{10}$ perovskite film prepared by the two methods: (a) the traditional spin-coating method and (b) the SCG method.

(Fig. 3b), we used the single-layer PS nanospheres as the template for the SCG of perovskite film. When the $\text{CsBi}_3\text{I}_{10}$ perovskite precursor solution was spun on the PS template, a large amount of precursor solution was locked among the PS spheres and the bottom of the perovskite precursor among the PS balls first crystallized slowly because of the geometry of the confined space, which had to be filled with less solution. After the samples were annealed on a hot plate, the evaporation of solvent was alleviated because of the restricted growth space, which further slowed down the perovskite crystallization process and achieved a higher-quality $\text{CsBi}_3\text{I}_{10}$ perovskite film [24]. Then, these large-size and high-crystallinity perovskite grains among the PS spheres created a seed layer for the continuous growth of the dense and high-smoothness perovskite film. Finally, we obtained smooth, high-crystallinity, and dense black $\text{CsBi}_3\text{I}_{10}$ perovskite films.

The high-quality $\text{CsBi}_3\text{I}_{10}$ perovskite film by the SCG encourages us to use it in a PD. According to the XRD patterns (Fig. 4a), it was evident that the $\text{CsBi}_3\text{I}_{10}$ perovskite thin films prepared by the two methods showed almost the same diffraction peaks at (003), (006), (300), and other weak peaks, which was consistent with previously reported results [20]. In addition, compared with

Figure 4 Device performances of the $\text{CsBi}_3\text{I}_{10}$ PDs prepared by the SCG and the traditional spin-coating methods. XRD patterns (a) and absorption characteristics (b) of the $\text{CsBi}_3\text{I}_{10}$ perovskites. The inset of (b) shows the $(\alpha h\nu)^2$ versus $h\nu$ curves. (c) I - V curves of the $\text{CsBi}_3\text{I}_{10}$ PDs. (d) I - t curves of the SCG $\text{CsBi}_3\text{I}_{10}$ PD with various light intensities at 5 V. (e) Current density versus light intensity curve. The LDR of the PD is 71 dB at 5 V bias. (f) Responsivity and detectivity as a function of the light intensity for the SCG $\text{CsBi}_3\text{I}_{10}$ PD.

the traditionally spin-coated film, the intensity of the diffraction peaks of the $\text{CsBi}_3\text{I}_{10}$ perovskite thin film prepared by the SCG was significantly enhanced, indicating that the crystallization of perovskite prepared by using the SCG method improved, which is beneficial for the device performance. Moreover, the optical absorption characteristic of the $\text{CsBi}_3\text{I}_{10}$ perovskite thin films is shown in Fig. 4b, and the higher absorption of the SCG $\text{CsBi}_3\text{I}_{10}$ film displayed higher light harvest efficiencies. In addition, the band gap of the SCG $\text{CsBi}_3\text{I}_{10}$ film showed a small increase from 1.76 to 1.77 eV, which may be attributed to the reduced number of grain defects in the high-crystallinity and dense $\text{CsBi}_3\text{I}_{10}$ perovskite films [25].

Fig. 4c shows the I - V curves of the $\text{CsBi}_3\text{I}_{10}$ PDs, for which the intensity of the 473 nm laser was 370 mW cm^{-2} . Compared with the traditionally spin-coated $\text{CsBi}_3\text{I}_{10}$ PD with a photocurrent (I_p) of 80 nA and a dark current (I_{dark}) of 2.47 nA at 5 V, the SCG $\text{CsBi}_3\text{I}_{10}$ perovskite film PD showed a larger I_p (169 nA) and a smaller I_{dark} (1.08 nA). This contributed to a bigger on/off ratio (156), which was almost five fold that of the traditionally spin-coated $\text{CsBi}_3\text{I}_{10}$ PD (32). A higher I_p tends to generate a lower I_{dark} and bigger on/off ratio because the high-quality perovskite film prepared by the SCG method offered higher light harvest efficiency and faster carrier

separation and transport speed, benefiting superior device performance. The high on/off ratio of the SCG PDs is beneficial for the performance of the I - t characteristic at different light intensities (0.107 to 370 mW cm^{-2}), as shown in Fig. 4d, wherein we observed good repeatability and stable I_p and I_{dark} . In addition, an increase in the light intensity generated an almost linear I_p increase. Linear fitting of the data produced a R^2 coefficient of 0.98621 for the $\text{CsBi}_3\text{I}_{10}$ PD (Fig. 4e), which indicated that the dense $\text{CsBi}_3\text{I}_{10}$ film had a good ability to collect photogenerated carriers. This ability can be characterized by the LDR:

$$\text{LDR} = 20 \log(P_{\text{sat}}/P_{\text{low}}), \quad (1)$$

where $P_{\text{sat}}(P_{\text{low}})$ is the optical power when the incident light intensity is stronger (weaker) than that at which the photocurrent begins to deviate from linearity. When the light intensity increased from 0.107 to 370 mW cm^{-2} , the current increased from the I_{dark} of 37 nA cm^{-2} to $6.05 \text{ } \mu\text{A cm}^{-2}$, corresponding to an LDR of 71 dB. From the responsivity and detectivity of the SCG PD shown in Fig. 4f, we obtained optimal responsivity and detectivity values of 0.45 mA W^{-1} and $4.14 \times 10^9 \text{ Jones}$, respectively.

Fig. 5a shows the response time curve of the device at 5 V, which shows a rising time of 0.62 ms and a falling time of 0.81 ms, demonstrating a fast response speed that is comparable to those of other lead-free MSM structural

Figure 5 (a) Time response of the device under 5 V bias. (b) Normalized spectral photoresponse of the MSM PD at 5 V bias. (c) Normalized I - t curve of the PD without encapsulation in air for 30 min. The intensity of the 473 nm laser is 7.54 mW cm^{-2} . (d) I - t attenuation curves of the device within 30 d.

devices (Table S1). Fig. 5b shows the normalized responsivity *versus* the wavelength curve, which shows a maximum responsivity at 670 nm. As the wavelength decreased, the device responsivity decreased.

Device stability is crucial for its commercialization. Fig. 5c shows the stability of our unencapsulated device when it was continuously irradiated with a laser for 30 min in air at 473 nm and with a light intensity of 7.45 mW cm^{-2} . Although our device was not encapsulated, the photocurrent of the device had almost no attenuation, illustrating the long-time operation stability of our devices under conditions with and without light. Fig. 5d presents the I - t curves after long-term storage of our unencapsulated devices (conditions: room temperature of 25°C ; 60% humidity in air). After 17 and 30 d, the photocurrent of our device showed no degradation. The ultra-high stability of our SCG $\text{CsBi}_3\text{I}_{10}$ perovskite film was attributed to (1) the good tolerance of the all-inorganic $\text{CsBi}_3\text{I}_{10}$ to water and air; and (2) the SCG method using the PS template for growing a flat, dense, and pinhole-free $\text{CsBi}_3\text{I}_{10}$ perovskite thin film with high crystallinity, which effectively blocked the penetration of water and oxygen in the air and improved the stability of the device. In comparison, the $\text{CsBi}_3\text{I}_{10}$ perovskite film prepared by the traditional spin-coating method showed significant degradation, and its color changed from black to red after storage in air for three months, which further confirmed the degradation by using the XRD patterns (Fig. S4).

CONCLUSIONS

In the present study, the $\text{CsBi}_3\text{I}_{10}$ perovskite films were prepared by SCG without any antisolvent. These films showed higher crystal quality and better optical properties compared with traditionally spin-coated films. The performance of the MSM PD prepared by SCG was better than that of the traditionally spin-coated $\text{CsBi}_3\text{I}_{10}$ PD. In addition, the photocurrent of the SCG device showed no degradation when it was illuminated for 30 min or stored in air for 30 d, demonstrating its ultra-high stability. This work opens up a new way to prepare high-quality lead-free perovskite, which may be useful for applications in many fields, such as light-emitting diodes and solar cells.

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- Mahabadi SEJ, Wang S, Carruthers TF, *et al.* Calculation of the impulse response and phase noise of a high-current photodetector using the drift-diffusion equations. *Opt Express*, 2019, 27: 3717–3730
- Zhou H, Zhu Y, Wang H, *et al.* Electroluminescence transition from visible- to ultraviolet-dominant mode in $n\text{-Mn}_{0.04}\text{Zn}_{0.96}\text{O}/i\text{-ZnGa}_2\text{O}_4/n\text{-GaN}$ structure with highly ultraviolet detection performance. *IEEE Electron Device Lett*, 2013, 34: 423–425
- Han L, Peng M, Wen Z, *et al.* Self-driven photodetection based on impedance matching effect between a triboelectric nanogenerator and a MoS_2 nanosheets photodetector. *Nano Energy*, 2019, 59: 492–499
- Cao Y, Wang N, Tian H, *et al.* Perovskite light-emitting diodes based on spontaneously formed submicrometre-scale structures. *Nature*, 2018, 562: 249–253
- Lin K, Xing J, Quan LN, *et al.* Perovskite light-emitting diodes with external quantum efficiency exceeding 20 percent. *Nature*, 2018, 562: 245–248
- Feng J, Gong C, Gao H, *et al.* Single-crystalline layered metal-halide perovskite nanowires for ultrasensitive photodetectors. *Nat Electron*, 2018, 1: 404–410
- Burschka J, Pellet N, Moon SJ, *et al.* Sequential deposition as a route to high-performance perovskite-sensitized solar cells. *Nature*, 2013, 499: 316–319
- Lee MM, Teuscher J, Miyasaka T, *et al.* Efficient hybrid solar cells based on meso-superstructured organometal halide perovskites. *Science*, 2012, 338: 643–647
- Domanski K, Alharbi EA, Hagfeldt A, *et al.* Systematic investigation of the impact of operation conditions on the degradation behaviour of perovskite solar cells. *Nat Energy*, 2018, 3: 61–67
- Babayigit A, Ethirajan A, Muller M, *et al.* Toxicity of organometal halide perovskite solar cells. *Nat Mater*, 2016, 15: 247–251
- Tong J, Song Z, Kim DH, *et al.* Carrier lifetimes of $>1 \mu\text{s}$ in Sn-Pb perovskites enable efficient all-perovskite tandem solar cells. *Science*, 2019, 36: 475–479
- Hao F, Stoumpos CC, Cao DH, *et al.* Lead-free solid-state organic-inorganic halide perovskite solar cells. *Nat Photon*, 2014, 8: 489–494
- Ke W, Kanatzidis MG. Prospects for low-toxicity lead-free perovskite solar cells. *Nat Commun*, 2019, 10: 965
- Ji C, Wang P, Wu Z, *et al.* Inch-size single crystal of a lead-free organic-inorganic hybrid perovskite for high-performance photodetector. *Adv Funct Mater*, 2018, 28: 1705467
- Wang W, Zhao D, Zhang F, *et al.* Highly sensitive low-bandgap perovskite photodetectors with response from ultraviolet to the near-infrared region. *Adv Funct Mater*, 2017, 27: 1703953
- Waleed A, Tavakoli MM, Gu L, *et al.* Lead-free perovskite nanowire array photodetectors with drastically improved stability in nanoengineering templates. *Nano Lett*, 2016, 17: 523–530
- Du Z, Fu D, Yang T, *et al.* Photodetectors with ultra-high detectivity based on stabilized all-inorganic perovskite $\text{CsPb}_{0.922}\text{Sn}_{0.078}\text{I}_3$ nanobelts. *J Mater Chem C*, 2018, 6: 6287–6296
- Zhu HL, Liang Z, Huo Z, *et al.* Low-bandgap methylammonium-rubidium cation Sn-rich perovskites for efficient ultraviolet-visible-near infrared photodetectors. *Adv Funct Mater*, 2018, 28: 1706068
- Liao Y, Liu H, Zhou W, *et al.* Highly oriented low-dimensional tin halide perovskites with enhanced stability and photovoltaic performance. *J Am Chem Soc*, 2017, 139: 6693–6699
- Johansson MB, Zhu H, Johansson EMJ. Extended photo-conversion spectrum in low-toxic bismuth halide perovskite solar cells. *J Phys Chem Lett*, 2016, 7: 3467–3471
- Brandt RE, Kurchin RC, Hoyer RLZ, *et al.* Investigation of bismuth triiodide (BiI_3) for photovoltaic applications. *J Phys Chem Lett*, 2015, 6: 4297–4302

- 22 Park BW, Philippe B, Zhang X, *et al.* Bismuth based hybrid perovskites $A_3Bi_2I_9$ (A: methylammonium or cesium) for solar cell application. *Adv Mater*, 2015, 27: 6806–6813
- 23 Liu R, Zhou H, Song Z, *et al.* Low-reflection, (110)-orientation-preferred $CsPbBr_3$ nanonet films for application in high-performance perovskite photodetectors. *Nanoscale*, 2019, 11: 9302–9309
- 24 Zeng J, Li X, Wu Y, *et al.* Space-confined growth of $CsPbBr_3$ film achieving photodetectors with high performance in all figures of merit. *Adv Funct Mater*, 2018, 28: 1804394
- 25 Ke X, Yan J, Zhang A, *et al.* Optical band gap transition from direct to indirect induced by organic content of $CH_3NH_3PbI_3$ perovskite films. *Appl Phys Lett*, 2015, 107: 091904

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Author contributions Liu R designed the research and performed the data processing. Wang R, Wu D, Pan X, and Pan G interpreted the data. Liu R and Zhou H co-wrote and revised the manuscript. Zhou H and Wang H provided experimental support.

Conflict of interest The authors declare no conflict of interest.

Supplementary information Supporting data are available in the online version of the paper.

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空间限域生长 $CsBi_3I_{10}$ 无铅钙钛矿用于高质量、高灵敏度和高稳定性近红外光电探测器

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摘要 因具有较高的耐热性和较长的电子扩散长度, 无铅钙钛矿 $CsBi_3I_{10}$ 备受关注. 然而, 由于二维结构 $CsBi_3I_{10}$ 钙钛矿的表面极其粗糙且存在大量针孔, 导致 $CsBi_3I_{10}$ 钙钛矿器件性能不高. 本文报道了一种利用空间限域生长(SCG)获得高平滑度、高结晶度和致密 $CsBi_3I_{10}$ 钙钛矿薄膜的方法. 相对于传统旋涂法制备的探测器, 采用SCG方法获得的金属-半导体-金属结构 $CsBi_3I_{10}$ 光电探测器(PDs)具有更高的光电流、更低的暗电流, 以及更大的开/关比. 此外, 在长时间测试下, 未封装的 $CsBi_3I_{10}$ 钙钛矿PDs的光电流没有衰减; 在空气中储存30天后, 器件的性能也没有明显的退化, 表现出了超高的稳定性. 研究表明空间限域生长方法为制备高质量无铅钙钛矿开辟了一条新途径, 有望在发光二极管、太阳能电池等领域得到应用.