High-performance ultraviolet-visible tunable perovskite photodetector based on solar cell structure

Mengni Xue, Hai Zhou*, Yang Xu, Jun Mei, Lu Yang, Cong Ye, Jun Zhang and Hao Wang*

ABSTRACT An ultraviolet (UV)-visible tunable photodetector based on ZnO nanorod arrays (NAs)/perovskite heterojunction solar cell structures is presented, in which the ZnO NAs are prepared using the hydrothermal method and annealed in different atmospheres. Based on solar cell structure perovskite photodetectors, it exhibited highly repeatable and stable photoelectric response characteristics. In addition, the devices with ZnO NAs annealed in a vacuum showed a high responsivity of about $10^{14} \text{ cm Hz}^{1/2} \text{ W}^{-1}$ in the visible region, whereas the devices with ZnO NAs annealed in air exhibited good detectivity in the UV region, especially at around 350 nm. Furthermore, when the annealing atmosphere of the ZnO nanorods was changed from vacuum to air, the dominant detection region of the photodetectors was altered from the visible to the ultraviolet region. These results enable potential applications of the ZnO NAs/perovskite photodetectors in ultraviolet and visible regions.

Keywords: annealing, UV-vis tunable, ZnO nanorod arrays, perovskite

INTRODUCTION

In the past decade, perovskite materials have progressed rapidly. Since they were first used in dye-sensitized solar cells [1], the power-conversion-efficiency (PCE) of perovskite solar cells has increased from about 4% to more than 20% in the last seven years [2–5]. Perovskite materials have many advantages, including a direct band gap with a large absorption coefficient, high electrical mobility, long charge carrier lifetime, and long diffusion length [6–11]. In perovskite solar cells, some scaffold materials, such as Al_2O_3 , TiO_2 , and ZnO, have been widely used [4,12–14]. Of these, ZnO nanostructures have been extensively investigated mainly because they are environmentally friendly and cheap with a wide bandgap of 3.3 eV at room temper-

ature, and have a large exciton binding energy of 60 meV [15–17]. However, it has been discovered that in these devices, the ZnO nanostructures have been treated either with the annealing process or without. Details on the effects of thermal annealing in different atmospheres on the performance of the devices have been seldom reported.

Perovskite solar cells are not only used as energy conversion devices but can also act as photodetectors [18–24]. In reports by Lin *et al.* [18], their photodetectors possessed a high detectivity beyond 10^{12} Jones and a PCE of more than 12%. A self-powered, ultraviolet-visible (UV-vis) perovskite photodetector based on TiO_2 nanorods was also reported with a PCE of 6.95% and the device exhibited good UV-visible photoresponse characteristics with a responsivity at zero bias reaching approximately 0.26 and 0.85 A W^{-1} at 364 and 494 nm, respectively [19]. We found that all the perovskite materials in these devices were used as a light absorbing layer. In this work, we present a self-powered photodetector based on ZnO nanorod arrays (NAs)/perovskite heterojunction solar cell structures with UV-vis tunable photoresponse characteristics. In our devices, the perovskite material can not only be used as a light absorbing layer but also function as a p-type material. In addition, the ZnO NAs as an n-type light absorbing layer were treated by post-annealing to reduce the carrier concentration associated with oxygen vacancies, resulting in UV-vis tunable photoresponse characteristics.

EXPERIMENTAL SECTION

Materials and device fabrication

A fluorine-doped tin oxide (FTO)-coated glass substrate ($14 \text{ } \Omega/\text{sq}$ sheet resistivity) was cleaned using deionized water, acetone, and alcohol, in that sequence, for 15 min and

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was then cleaned in a UV ozone atmosphere for 30 min. A ZnO seed layer was deposited on the FTO substrate using the spin coating method. A 0.15 mol L⁻¹ solution of zinc acetate dihydrate (Zn(CH₃COO)₂·2H₂O) was completely dissolved in methanol and was then spin-coated on the FTO glass at 4000 rpm for 20 s. Then, the samples were transferred into a muffle furnace to be annealed for 2 h. After annealing, 0.6 g of polyethylenimine (PEI), 50 mmol L⁻¹ of zinc nitrate hexahydrate (Zn(NO₃)₂·6H₂O), and 30 mmol L⁻¹ of hexamethylenetetramine (C₆H₁₂N₄) were dissolved after stirring for 30 min. The pH was maintained between 10.6 and 10.8. The ZnO NAs were grown using the hydrothermal method at 90°C for 2 h. The annealing treatment was carried out at 350°C for 2 h in air and vacuum.

The perovskite as a light absorbing layer was prepared using the two-step method. First, 1 mol L⁻¹ of PbI₂ was dissolved in *N,N*-dimethylformamide (DMF) solution and was then maintained at 70°C for 15 h until the PbI₂ was completely dissolved. Subsequently, CH₃NH₃I was dissolved in the isopropyl alcohol solution and was stirred for 10 min. CH₃NH₃I was synthesized using the method described by Lee *et al.* [22]. Hydroiodic acid (30 mL, 0.227 mol, 57 wt.% in water, Aldrich) and methylamine (27.8 mL, 0.273 mol, 40% in methanol, TCI) were mixed and stirred in an ice bath for 2 h. After stirring at 0°C for 2 h, the resulting solution was evaporated at 50°C for 1 h, generating the chemicals (CH₃NH₃I). The PbI₂ solution was spin-coated onto the ZnO NAs at 3000 rpm for 30 s and was then dried at 70°C for 10 min. When it was completely dry, the film was dipped into a solution of CH₃NH₃I for 2 min. Finally, the samples above were annealed at 70°C for 30 min.

After the deposition of perovskite materials, a hole transport material, which consisted of 55 mmol L⁻¹ of 4-*tert*-butylpyridine (TBP), 26 mmol L⁻¹ of lithium bis(trifluoromethylsulfonyl)imide (Li-TFSI), and 68 mmol L⁻¹ of spiro-OMeTAD dissolved in acetonitrile and chlorobenzene (1:10, *v/v*), was coated on the perovskite film by spin-coating at a speed of 2000 rpm for 30 s. Finally, the 50-nm-thick Au electrode was deposited by thermal evaporation under a pressure of 5 × 10⁻⁵ Torr. The structure of the devices is illustrated in Fig. 1.

Characterization

The morphology and crystallinity of the samples were characterized by field emission scanning electron microscopy (FE-SEM, JEOL, JSM-6700F) and X-ray diffraction (XRD, D8 FOCUS X-ray diffraction), respectively. The photovoltaic properties of the cells were measured with a solar

Figure 1 Structure of the ZnO NA/perovskite heterojunction device.

simulator (Newport 69920, powder supply) under an AM 1.5G illumination at 1000 W m⁻². The current-voltage (*I*-*V*) and current density-voltage (*J*-*V*) characteristics were measured by a Keithley 4200 electrometer. The photosensitivity was performed using a 66984 Xe Arc source (300 W Oriel) and Oriel Cornerstone™ 260 1/4 m Monochromator. The sample was under direct illumination and the optical power of light was measured by a UV-enhanced Si detector.

RESULTS AND DISCUSSION

Fig. 2a and b displays the surface and cross-section SEM images of the ZnO nanorods, and Fig. 2c and d displays the surface and cross-section SEM morphology of the ZnO/perovskite structure, respectively. We can observe that the surface of the ZnO typically has a regular hexagonal structure and the length of a ZnO nanorod is approximately 800 nm. The top view of the ZnO/perovskite structure reveals that the perovskite completely covers the ZnO surface. There is no gap and the diameter of the perovskite is about 200–300 nm. From the ZnO/perovskite cross-section, it is observed that the perovskite has completely permeated into the ZnO NAs. The crystal structure of ZnO NAs characterized through XRD in different annealing atmospheres is shown in Fig. 2e. We can observe a wurtzite crystal structure with a *c*-axis orientation of NAs for all the samples. Fig. 2f shows the absorption of the ZnO NAs and the CH₃NH₃PbI₃ on ZnO NAs. In Fig. 2f, the region of main UV absorption is attributed to ZnO, while that of visible absorption is due to CH₃NH₃PbI₃. Thus, based on the above absorption characteristics, the photoresponse of the ZnO NAs/perovskite heterojunction should be performed in UV and visible regions.

Fig. 3a presents the *J*-*V* characteristic curves of the solar cell devices measured under an AM 1.5G illumination at 1000 W m⁻² and the parameters determined from Fig. 3a are displayed in Table 1. Table 1 indicates that the cell without ZnO annealing shows a short-circuit current density (*J*_{sc}) of 21.2 mA cm⁻², open-circuit voltage (*V*_{oc}) of 0.87

Figure 2 (a, b) Top view and cross-section of the ZnO NAs SEM morphology. (c, d) Top view and cross-section of the perovskite SEM morphology. (e) XRD of the ZnO NAs without annealing and with annealing in air and vacuum, respectively. (f) Absorption of the ZnO NAs and ZnO NAs/perovskite.

V, fill factor (FF) of 51.48%, and high PCE of 9.65%. Meanwhile, the cell with ZnO annealing in a vacuum exhibits the highest FF and the cell with ZnO annealing in air shows the lowest PCE. The decrease in PCE may be attributed to the annealing treatment, which will decrease the carrier density, resulting in a decrease in electrical conductivity and increase in series resistor. The inset of Fig. 3a presents the Ohmic contact curve between the hole transporting layer and gold electrode, which indicates that Au is a good choice as the top electrode, which is consistent with a previous report [23].

The dark I - V curves and $I_{\text{ph}}/I_{\text{dark}}$ ratios (the ratio of photocurrent to dark current) of the devices, demonstrating

strong anti-noise ability and weak light detection [24], are shown in Fig. 3b and c, respectively, and we can note that all devices exhibit good diode rectifier characteristics with little dark current and maintain a high $I_{\text{ph}}/I_{\text{dark}}$ ratio exceeding 10^3 , especially at zero bias.

Fig. 4a presents the spectral responsivity curves obtained from ZnO NAs/perovskite heterojunctions at 0 V. From the curves, we can observe that from 300 to 800 nm, the responsivity of all devices decreases at 650 nm, and the ZnO NAs annealed in a vacuum, as well as those without annealing, reach maximum values at 450 nm in which the region is attributed to the perovskite, while the ZnO NAs annealed in air reach a peak value at 365 nm. The reason may be that

Figure 3 (a) J - V characteristic curves of the solar cell devices. (b) Dark current of devices in different annealing atmospheres. The inset image shows a different dark current at a negative bias. (c) Ratio of photocurrent to dark current at reverse biases. (d) Schematic of ZnO NA/perovskite solar cell heterojunction device.

Table 1 Performance parameters of solar cells

	V_{oc} (V)	J_{sc} (mA cm ⁻²)	FF	IF
Air	0.48	21.0	39.57	4.65%
As-grown	0.87	21.2	51.48	9.56%
Vacuum	0.51	20.0	57.41	6.71%

for the devices, when the ZnO NAs are annealed in air, the oxygen vacancies decrease, decreasing the carrier concentration. According to the equation $N_A X_p = N_D X_n$, the depletion region is mainly in ZnO, thus, the photogenerated carriers are mainly produced in ZnO and the responsivity of ZnO NAs annealed in air reaches a peak value at 365 nm. Moreover, we can notice that the highest value of the responsivity is 7.8 A W⁻¹ for the device without annealing. Then, the responsivity values of all the devices decrease sharply and, at 365 nm, the values reach another peak, which is attributed to the photon absorption property of ZnO in the UV region. This response trend indicates that our devices exhibit high responsivity in both the

UV and visible light regions.

When the dark current is dominated by the shot noise, the detectivity can be expressed by the following equation [21],

$$D^* = \frac{R}{(2qJ_d)^{1/2}} = \frac{J_{ph}}{L_{light}} \frac{1}{(2qJ_d)^{1/2}}, \quad (1)$$

where R is the responsivity of the photodiode, J_d is the dark current, J_{ph} is the photocurrent density, and L_{light} is the light intensity. The detectivity curves are presented in Fig. 4b. The approximate trend of detectivity is similar to the responsivity. From the curves, we can note that the device with ZnO NAs annealed in vacuum shows the highest detectivity, which exceeds 10¹⁴ cm Hz^{1/2} W⁻¹ at 450 nm and is comparable to that reported in other papers (see Table 2) [25–27].

This may be due to its larger photocurrent and smaller dark current compared with the other devices at zero bias (in the inset of Fig. 3b). Fig. 4c presents the curves of the UV-vis ratio (R_{365}/R_{450}). The results indicate that the $R_{365}/$

Figure 4 Spectral responsivity curve obtained at zero bias. (b) Spectral detectivity curve obtained at zero bias. (c) Ratio of responsivity at 365 and 500 nm. (d) Photocurrent with light-on and light-off cycles for the photodetectors at zero bias.

Table 2 Comparison with similar perovskite photodetector

Materials	Responsivity (A W^{-1})	Rise/decay time (ms)	On/off ratio	Reference
$\text{CH}_3\text{NH}_3\text{PbI}_3$	7.8	288/322	$> 10^3$	This work
$\text{CH}_3\text{NH}_3\text{PbI}_3$	0.85	~	~	[19]
$\text{CH}_3\text{NH}_3\text{PbI}_3$	23	150/150	< 1	[25]
$\text{CH}_3\text{NH}_3\text{PbI}_3$	1.32	0.3/0.3	~	[26]
$\text{CH}_3\text{NH}_3\text{PbI}_3$	5×10^{-3}	0.5/0.5	~	[27]

R_{450} ratio of the device with the ZnO NAs annealed in air is greater than 1 (about 1.6), which displays a UV-dominant response mode. However, for the R_{365}/R_{450} ratio of the device with the ZnO NAs annealed in vacuum or without annealing, which is less than 1 (about 0.6 and 0.7, respectively), it exhibits a visible dominant response mode. Therefore, we can conclude that we can achieve a UV-vis tunable photodetector by changing the ZnO NAs annealing conditions.

In our devices, the photoresponse behavior of the ZnO NAs/ $\text{CH}_3\text{NH}_3\text{PbI}_3$ heterojunction was characterized by measuring the current as a function of time at zero bias

when the light was periodically turned on and off, as shown in Fig. 4d. The results indicate that at room temperature, our ZnO-based perovskite photodetector possesses great repeatability and stability characteristics. Meanwhile, at 450 nm, the as-grown sample exhibits the highest photocurrent. In addition, the response time of the devices is small with the rise and fall time of 288 and 322 ms, respectively.

Oxygen vacancies in the ZnO NAs are very important for the performance of the photodetector, which has been analyzed by X-ray photoelectron spectroscopy (XPS) and presented in Fig. 5. There are three peaks labeled as low

peak (LP), middle peak (MP), and high peak (HP), which are centered at 530.4, 531.5, and 532.4 eV, respectively [28]. Herein, the LP is attributed to the Zn–O bonds for the wurtzite structure and the HP is usually attributed to chemisorbed oxygen. The MP is associated with O^{2-} in the oxygen-deficient regions with the matrix of ZnO, and the intensity of MP is related to the variations in concentration of oxygen vacancies [29]. From the figures, we can notice that the ZnO NRs without annealing displays a large number of oxygen vacancies. When the ZnO NRs are annealed in vacuum, the crystal quality of ZnO NRs improves, but the oxygen vacancies decrease by a small amount because of the entry without oxygen in vacuum. For annealing in air, the oxygen vacancies of the ZnO decrease significantly.

In the ZnO-based perovskite photodetectors, ZnO acts as an n-type material, while perovskite acts as a p-type material (the schematic is shown in Fig. 3d). Under illumination, when the energy of the photons is larger than the band gap of the semiconductor, the light will be absorbed and the electron-hole pairs will be generated in the depletion layer. Under the internal electric field, electron-hole pairs will be

separated at the ZnO/perovskite interface. Electrons arrive at the FTO anode and holes arrive at the Au cathode. Based on this, the device captures the light signal and converts it into an electric signal. For a unit area of the p-n junction, all negative-space charges at the p-type side are equal to all positive-space charges at the n-type side, i.e.,

$$N_A x_p = N_D x_n, \quad (2)$$

where N_A is the acceptor impurity concentration, x_p is the width of the p-type depletion layer, N_D is the donor impurity concentration, and x_n is the width of the n-type depletion layer. Thus, from the equation above, the higher impurity concentration in the semiconductor will result in a smaller depletion layer width in this layer. Based on the photoresponse mechanism, the small R_{365}/R_{450} ratio of the device with the ZnO NAs annealed in vacuum or without annealing indicates that the carrier concentration of the ZnO NAs is very large. This is because before annealing, the existence of many defects, especially oxygen vacancies (Fig. 5a and b), results in a high carrier density [30,31]. Therefore, the depletion layer is mainly located at the side

Figure 5 O 1s XPS spectroscopic spectra of the ZnO NAs (a) obtained without annealing, (b) annealed in vacuum, and (c) annealed in air.

of the perovskite, and the devices with the ZnO NAs annealed in vacuum as well as those without annealing show a visible dominant response trend. However, when the ZnO NAs are annealed in air, the inherent defects of ZnO NAs synthesized by the hydrothermal method and the defect-related carrier density will decrease, resulting in a decrease in carrier density [32]. Thus, the device with the ZnO NAs annealed in air shows a large R_{365}/R_{450} ratio and UV-dominant response trend. We can conclude that the UV-vis tunable photodetector can operate based on the ZnO NAs/perovskite heterojunction solar cell structure through annealing treatment in different atmospheres.

CONCLUSIONS

We presented a UV-vis, tunable, self-powered photodetector based on a ZnO NA/perovskite solar cell structure, and the ZnO NAs experienced different annealing conditions. We presented a solar cell that possessed a PCE of 9.56% without annealing. Meanwhile, the devices demonstrated good photoelectric properties at 0 V with the highest responsivity of 7.8 A W^{-1} for the devices without annealing and a detectivity of $10^{14} \text{ cm Hz}^{1/2} \text{ W}^{-1}$ for the devices with the ZnO NAs annealed in vacuum. Furthermore, our devices demonstrated UV-vis tunable characteristics through annealing treatment in different atmospheres.

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- Kojima A, Teshima K, Shirai Y, *et al.* Organometal halide perovskites as visible-light sensitizers for photovoltaic cells. *J Am Chem Soc*, 2009, 131: 6050–6051
- Zhou H, Chen Q, Li G, *et al.* Interface engineering of highly efficient perovskite solar cells. *Science*, 2014, 345: 542–546
- Yang WS, Noh JH, Jeon NJ, *et al.* High-performance photovoltaic perovskite layers fabricated through intramolecular exchange. *Science*, 2015, 348: 1234–1237
- Anaraki EH, Kermanpur A, Steier L, *et al.* Highly efficient and stable planar perovskite solar cells by solution-processed tin oxide. *Energ Environ Sci*, 2016, 9: 3128–3134
- Fang Y, Huang J. Resolving weak light of sub-picowatt per square centimeter by hybrid perovskite photodetectors enabled by noise reduction. *Adv Mater*, 2015, 27: 2804–2810
- Stranks SD, Eperon GE, Grancini G, *et al.* Electron-hole diffusion lengths exceeding 1 micrometer in an organometal trihalide perovskite absorber. *Science*, 2013, 342: 341–344
- Xing G, Mathews N, Sun S, *et al.* Long-range balanced electron- and hole-transport lengths in organic-inorganic $\text{CH}_3\text{NH}_3\text{PbI}_3$. *Science*, 2013, 342: 344–347
- Lee Y, Kwon J, Hwang E, *et al.* High-performance perovskite-graphene hybrid photodetector. *Adv Mater*, 2015, 27: 41–46
- Liu C, Wang K, Yi C, *et al.* Ultrasensitive solution-processed perovskite hybrid photodetectors. *J Mater Chem C*, 2015, 3: 6600–6606
- Saidaminov MI, Haque MA, Savoie M, *et al.* Perovskite photodetectors operating in both narrowband and broadband regimes. *Adv Mater*, 2016, 28: 8144–8149
- Murali B, Saidaminov MI, Abdelhady AL, *et al.* Robust and air-stable sandwiched organo-lead halide perovskites for photodetector applications. *J Mater Chem C*, 2016, 4: 2545–2552
- Guarnera S, Abate A, Zhang W, *et al.* Improving the long-term stability of perovskite solar cells with a porous Al_2O_3 buffer layer. *J Phys Chem Lett*, 2015, 6: 432–437
- Son DY, Im JH, Kim HS, *et al.* 11% efficient perovskite solar cell based on ZnO nanorods: an effective charge collection system. *J Phys Chem C*, 2014, 118: 16567–16573
- Kumar MH, Yantara N, Dharani S, *et al.* Flexible, low-temperature, solution processed ZnO-based perovskite solid state solar cells. *Chem Commun*, 2013, 49: 11089–11091
- Zhou H, Zhu Y, Wang H, *et al.* Electroluminescence transition from visible- to ultraviolet-dominant mode in n- $\text{Mn}_{0.04}\text{Zn}_{0.96}\text{O}/\text{i-ZnGa}_2\text{O}_4/\text{n-GaN}$ structure with highly ultraviolet detection performance. *IEEE Electron Device Lett*, 2013, 34: 423–425
- Xu Y, Liu T, Li Z, *et al.* Preparation and photovoltaic properties of perovskite solar cell based on ZnO nanorod arrays. *Appl Surface Sci*, 2016, 388: 89–96
- Zhou H, Gui P, Yu Q, *et al.* Self-powered, visible-blind ultraviolet photodetector based on n-ZnO nanorods/i-MgO/p-GaN structure light-emitting diodes. *J Mater Chem C*, 2015, 3: 990–994
- Lin Q, Armin A, Lyons DM, *et al.* Low noise, IR-blind organohalide perovskite photodiodes for visible light detection and imaging. *Adv Mater*, 2015, 27: 2060–2064
- Zhou H, Song Z, Tao P, *et al.* Self-powered, ultraviolet-visible perovskite photodetector based on TiO_2 nanorods. *RSC Adv*, 2016, 6: 6205–6208
- Yu J, Chen X, Wang Y, *et al.* A high-performance self-powered broadband photodetector based on a $\text{CH}_3\text{NH}_3\text{PbI}_3$ perovskite/ZnO nanorod array heterostructure. *J Mater Chem C*, 2016, 4: 7302–7308
- Dou L, Yang YM, You J, *et al.* Solution-processed hybrid perovskite photodetectors with high detectivity. *Nat Commun*, 2014, 5: 5404
- Lee MM, Teuscher J, Miyasaka T, *et al.* Efficient hybrid solar cells based on meso-superstructured organometal halide perovskites. *Science*, 2012, 338: 643–647
- Ke W, Fang G, Wan J, *et al.* Efficient hole-blocking layer-free planar halide perovskite thin-film solar cells. *Nat Commun*, 2015, 6: 6700
- Hu X, Zhang X, Liang L, *et al.* High-performance flexible broadband photodetector based on organolead halide perovskite. *Adv Funct Mater*, 2014, 24: 7373–7380
- Huo C, Cai B, Yuan Z, *et al.* Two-dimensional metal halide perovskites: theory, synthesis, and optoelectronics. *Small Methods*, 2017, 1: 1600018
- Li X, Cao F, Yu D, *et al.* All inorganic halide perovskites nanosystem: synthesis, structural features, optical properties and optoelectronic applications. *Small*, 2017, 13: 1603996
- Li X, Yu D, Chen J, *et al.* Constructing fast carrier tracks into flexible perovskite photodetectors to greatly improve responsivity. *ACS Nano*, 2017, 11: 2015–2023
- Zhou H, Fang GJ, Zhu Y, *et al.* Flexible resistive switching memory based on $\text{Mn}_{0.20}\text{Zn}_{0.80}\text{O}/\text{HfO}_2$ bilayer structure. *J Phys D-Appl Phys*, 2011, 44: 445101
- Wang J, Wang Z, Huang B, *et al.* Oxygen vacancy induced band-gap narrowing and enhanced visible light photocatalytic activity of ZnO. *ACS Appl Mater Interfaces*, 2012, 4: 4024–4030
- Ji LW, Peng SM, Su YK, *et al.* Ultraviolet photodetectors based on selectively grown ZnO nanorod arrays. *Appl Phys Lett*, 2009, 94:

203106

- 31 Zhou H, Fang G, Liu N, *et al.* Ultraviolet photodetectors based on ZnO nanorods-seed layer effect and metal oxide modifying layer effect. *Nanoscale Res Lett*, 2011, 6: 147
- 32 Tam KH, Cheung CK, Leung YH, *et al.* Defects in ZnO nanorods prepared by a hydrothermal method. *J Phys Chem B*, 2006, 110: 20865–20871

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Conflict of interest The authors declare that there is no conflict of interest.

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基于太阳能电池结构高性能紫外-可见可调型钙钛矿探测器

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摘要 本文报道了一种基于ZnO纳米棒阵列/钙钛矿电池结构的紫外-可见可调的光电探测器, 其中ZnO纳米棒阵列采用水热法制备并在不同气氛下退火. 基于电池结构的钙钛矿光电探测器具有较好的光电响应重复性和稳定性. ZnO纳米棒阵列真空退火的器件在可见光区域达到了1014 Jones的响应度, 而ZnO纳米棒阵列在空气中退火的器件在紫外光区域, 尤其在365 nm处有较好的探测性能. 进一步研究发现, 通过不同氛围退火, 实现了紫外-可见可调的光电探测性能. 以上结果表明ZnO纳米棒阵列/钙钛矿光电探测器在紫外和可见光区域存在潜在应用.