

Solution-processed Al-doped ZnO nanowire arrays/CuSCN lateral heterojunctions for low-intensity ultraviolet photodetection

Yu Xu

East China University of Technology

Zhaolin Yuan

yzl1yx98@sina.com

East China University of Technology

Jianfeng He

East China University of Technology

Xueyuan Wang

East China University of Technology

Zhixiang Ye

East China University of Technology

Dongfang Pei

East China University of Technology

Research Article

Keywords: Ultraviolet photodetection, Al-doped ZnO nanowire arrays, CuSCN, Lateral heterojunction

Posted Date: September 16th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-10641506/v1>

License:   This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Additional Declarations: No competing interests reported.

Abstract

In this study, the different Al-doped ZnO nanowire arrays (Al-doped ZNWAs, Al/Zn = 0, 0.25, 0.5, 1 and 2 atom%) were grown on the interdigital patterned FTO substrates, five lateral p-n heterojunctions were built by depositing CuSCN layers onto the Al-doped ZNWAs. The results demonstrated that these heterojunctions could be used for low-intensity ultraviolet photodetection ($190 \mu\text{W}/\text{cm}^2$, 365 nm). Also, all the devices presented self-powered behaviors, when Al content was 0.5%, the device had the optimal performance, its sensitivity (S), responsivity (R_λ), external quantum efficiency (EQE), detectivity (D^*), rise time (t_r) and decay time (t_d) were up to 65320 (-0.3 V), $2202.6 \text{ mA}\cdot\text{W}^{-1}$ (5 V), 748.2%, 1.1×10^{13} Jones, 36.0 s and 1.9 s, respectively.

1. Introduction

Ultraviolet photodetector (UV PD), an important optoelectronic device [1–4], has been attracted considerable attention in recent years due to its extensive applications in many fields [5], such as environmental monitoring, optical communication, medical diagnostics and biochemical analysis [6–9]. In general, the conventional UV PDs require an external power source to operate, which have become a bottleneck for their extensive applications [10–13]. In contrast, self-powered UV PDs can operate without an external power supply, which have recently been received a lot of interest due to their notable advantages, such as light weight, low energy consumption and sustainability [14–18].

As an important functional inorganic semiconductor, zinc oxide (ZnO) has a direct wide bandgap (3.37 eV), a large exciton binding energy (60 meV) excellent photoelectric properties and potential applications in catalyses, sensors, solar cells, piezoelectric devices and UV PDs [19–21]. Especially, substantial effort has recently been devoted to the development of ZnO-based UV PDs [22], significant progress has been made in self-powered ZnO-based heterojunction UV PDs [23, 24]. Recently, Banari et al. [25] fabricated several self-powered $\text{CeO}_2\text{:ZnO-Cu}_2\text{O}$ heterojunction UV PDs, the highest R_λ was $2.69 \times 10^{-6} \text{ A/W}$. Chu et al. [26] developed a self-powered ZnO/CuPc heterojunction UV PD, the R_λ , D^* and EQE of the device at 0 V bias were 0.39 mA/W, 7.53×10^9 Jones and 0.14%, respectively. Nandi et al. [27] reported a self-powered UV PD based on a 2D $\text{Bi}_2\text{Se}_3\text{-ZnO}$ nanoparticle heterojunction, its R_λ and D^* were 2.89 mA/W and 9.2×10^8 Jones, respectively. However, most of these self-powered devices still have shortcomings, such as poor performance, high cost and complex process. Copper thiocyanate (CuSCN), a good p-type semiconductor, has been extensively used in solar cells as the hole-transport layer [28]. Interestingly, CuSCN has been also demonstrated to use in UV PDs, some works on ZnO/CuSCN heterojunction UV PDs [29–33] have been available. In particular, significant progress has made in self-powered ZnO/CuSCN heterojunction UV PDs in recent years. Hatch et al. [29] achieved a self-powered ZnO nanorod/CuSCN UV PD, R_λ of the device was 7.5 mA/W. Garnier et al. [30] investigated the performance of self-powered UV PDs based on annealed ZnO nanowire/CuSCN heterojunctions, its R_λ was $0.02 \text{ A}\cdot\text{W}^{-1}$ at 0 V. Li et al. [31] observed self-powered UV photoresponse property in ZnO nanorod arrays/CuSCN heterojunction. Shi et al. [32] developed self-powered ZnO nanorod arrays/CuSCN heterojunctions UV

PDs, a high R_{λ} of $1.57 \text{ A}\cdot\text{W}^{-1}$ was obtained. To the best of our knowledge, few works on ZnO/CuSCN lateral heterojunction UV PDs have been available so far.

In this work, different Al-doped ZNWAs (Al/Zn = 0, 0.25, 0.5, 1 and 2 atom%) were first grown on the interdigital patterned fluorine-doped tin oxide (FTO) coated glass substrates, their morphology and crystal structure were investigated. Furthermore, five Al-doped ZNWAs/CuSCN lateral heterojunctions UV PDs were constructed, the effects of Al doping content on the performance of the devices were focused on investigating.

2. Experimental

2.1. Growth of Al-doped ZNWAs

Al-doped ZNWAs were grown by a hydrothermal technology according to our previous similar work [34]. In brief, ZnO seed layers were first prepared on the interdigital patterned FTO coated glass substrates, 0.595 g of zinc nitrate hexahydrate ($\text{Zn}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$), 0.280 g of hexamethylenetetramine ($\text{C}_6\text{H}_{12}\text{N}_4$) and a certain mass of aluminum nitrate nonahydrate ($\text{Al}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$) were mixed together, the atomic ratios of Al to Zn were 0%, 0.25%, 0.5%, 1% and 2%, respectively, then dissolved in 80 ml of deionized water, the aqueous solution was stirred for 20 min using a magnetic stirrer, and transferred into a 100 ml Teflon-lined autoclave, the ZnO seed layers coated substrates were immersed into the aqueous solution, the autoclave was sealed, and placed in an oven. The reaction was maintained at 93°C for 2 h. Subsequently, the substrates were removed from the solution and washed with deionized water and ethanol, and then air-dried in the oven at 50°C for 7 h.

2.2. Fabrication of Al-doped ZNWAs/CuSCN lateral heterojunctions UV PDs

All the as-grown Al-doped ZNWAs were first annealed in a muffle furnace at 450°C for 1 h. CuSCN was dispersed into ammonia with a concentration of 20 mg/ml in air, a small volume of CuSCN solution was then spin-coated on the top of the treated Al-doped ZNWAs at 2000 rpm for 40 s. Finally, the samples were naturally dried in air. The schematic illustration of Al-doped ZNWAs/CuSCN lateral heterojunction UV PDs is shown in Fig. 1.

2.3. Characterization

Morphology of the samples was observed by a field-emission scanning electron microscopy (FE-SEM, Zeiss Sigma 300). Crystal structure was characterized by an X-ray diffractometer (XRD, Rigaku Ultima IV). Room temperature photoluminescence (PL) spectra were examined by a spectrophotometer (-Edinburgh, FLS 1000) with excitation wavelength of 325 nm. UV-visible absorption spectra were carried out with a spectrophotometer (Shimadzu, UV-3600). Both current-voltage (I-V) and current-time (I-t) characteristics of all the PDs were recorded using a Keithley 2400 semiconductor parameter analyzer, a

12 W handheld UV lamp ($\lambda = 365$ nm) was used as the light source, light intensity was calibrated to be $190 \mu\text{W}\cdot\text{cm}^{-2}$ with a UVA365 radiometer.

3. Results and discussions

Figure 2 shows the typical FE-SEM images of different Al-doped ZNWAs/CuSCN. It can be observed from the top-view image of undoped sample (Fig. 2a) that a great number of ZnO nanowires densely grow on the FTO substrates to form a well-aligned array, the inset in Fig. 2a displays the corresponding high-magnification FE-SEM image, it can be noted that the hexagon-shape top section of all the nanowires with diameter in 40–50 nm. a small amount of CuSCN is found on the surface of ZnO nanowires, most CuSCN may be embedded into the gaps among the nanowires. After Al doping (Fig. 2b-e), the average diameters of ZnO nanowires gradually increase with enhancing Al doping content, which is similar with the results of previous report [34]. Notably, when the Al content is raised to 2%, a large number of nonstanding nanowires can be observed (Fig. 2e), this may be because the high content of aluminum nitrate reacts with HMTA in advance, many Al-doped ZnO nanowires can not grow vertically along the substrate due to the lack of adequate HMTA [35]. In addition, it can be clearly found that some thick CuSCN layers adhere to the surface of the nanowires (Fig. 2e). Figure 2(f) presents the cross-sectional FE-SEM image of 0.5% Al-doped ZNWAs/CuSCN. The result further demonstrates that a lot of Al-doped ZnO nanowires vertically grow onto the substrate with a length of ~ 400 nm, many CuSCN layers fill into the gaps among the nanowires.

XRD patterns of all the Al-doped ZNWAs/CuSCN are presented in Fig. 3. As clearly seen, for all the samples, several distinct diffraction peaks at $2\theta = 34.6^\circ$, 36.6° , 47.8° , and 63.1° are assigned to ZnO with hexagonal wurtzite structure, corresponding to the (002), (101), (102) and (103) planes (JCPDS card No. 36-1451). In addition, a higher peak located at $2\theta = 32.6^\circ$ can be found for all the samples, which is indexed to the (0012) plane of CuSCN (JCPDS card No. 73-1855), confirming the presence of the CuSCN in all the samples. In particular, for 0.5% Al-doped ZNWAs/CuSCN, the intensities of all the ZnO diffraction peaks are greater than those of the other samples, indicating that the moderate Al doping content can improve the crystal quality of ZnO nanowires.

Figure 4 presents optical properties of different Al-doped ZNWAs/CuSCN. Room temperature PL spectra of all the samples are shown in Fig. 4(a), for the comparison, PL spectrum of ZNWAs is also presented in Fig. 4(a). Obviously, the distinct peaks centered at around 397 nm for all the samples can be observed, which are attributed to near band edge (NBE) emission of ZnO [36], the energy of free exciton is estimated to be about 3.12 eV for all the samples from their NBE emissions. In addition, ZNWAs display a strong defect-related broad emission band in the range from 500 to 700 nm, suggesting a high density of deep-level defects and surface states in the ZnO nanowires [37, 38]. After introducing CuSCN, the NBE emission is significantly enhanced, while the defect-related emission is suppressed, the enhancement of NBE emission may be because the surface defect states in the ZnO nanowires are passivated, nonradiative recombinations decrease, the defect-related emission become weak, which can play a vital role in reducing the charge carriers recombination of the ZNWAs/CuSCN [39]. In particular, for the 0.5%

Al-doped ZNWAs/CuSCN, the defect-related emission almost disappear, indicating that the charge carriers recombination is efficiently suppressed. Figure 4(b) present UV-visible spectra of different Al-doped ZNWAs/CuSCN. Clearly, all the samples reveal strong absorption in UV region, the sharp absorption edges (~ 370 nm) for the ZNWAs/CuSCN can be observed, with the increase of Al doping content, the absorption edges blue-shift slightly. According to the method reported previously [33], the bandgaps of 0, 0.25, 0.5, 1 and 2% Al-doped ZNWAs can be estimated, the values are 3.13, 3.10, 3.20, 3.21 and 3.17 eV, respectively.

Figure 5 displays I-V characteristics of all the Al-doped ZNWAs/CuSCN UV PDs in the dark and under 365 nm light illumination from -5 to $+5$ V. In the dark (Fig. 5a), it is evident that all the devices exhibit good rectifying behaviors, indicating the formation of Al-doped ZNWAs/CuSCN heterojunctions. Also, they have very low dark currents, this behavior may be mainly attributed to two aspects: On one hand, when the devices were operated under reverse bias, built-in electric field (E_{bi}) exhibited low collection efficiency for thermally excited electron-hole pairs. On the other hand, good interface of all the Al-doped ZNWAs/CuSCN had few defects, which minimized both the recombination current and surface leakage current [40–42]. Under 365 nm light illumination (Fig. 5b), the currents of all the devices significantly increased. compared to their dark components, indicating that they produce robust photoresponses and efficient photoelectric conversions to 365 nm light. Notably, for the 0.5% Al-doped ZNWAs/CuSCN PD, its current at 0 V increases from 2.09×10^{-9} A in the dark to 2.06×10^{-6} A, an increase by three orders of magnitude is achieved. To further evaluate performances of these devices, the sensitivity (S), responsivity (R_λ), external quantum efficiency (EQE), and detectivity (D^*) of all the devices at 0 V bias can be calculated by the reported methods [43, 44], the results are summarized in Table 1. It is noted that all the devices can be operated at self-powered mode, the value of R_λ for the 0.5% Al-doped ZNWAs/CuSCN PD is up to $24.9 \mu\text{A}\cdot\text{W}^{-1}$. Also, the S, R_λ , EQE and D^* of all the devices at a certain low bias were estimated, as shown in Table 2.

Table 1
The main performance parameters of different Al-doped ZNWAs/CuSCN UV PDs at 0 V bias

Al doping content	S	$R_\lambda(\mu\text{A}\cdot\text{W}^{-1})$	$D^*(\text{Jones})$	EQE(%)	$t_r/t_d(\text{s})$
0%	0.81	1.5	4.5×10^8	0.0051	51.9/8.0
0.25%	2.51	1.0	2.3×10^8	0.0004	51.9/8.0
0.5%	10.14	24.9	6.8×10^9	0.0084	41.9/0.9
1%	2.65	7.2	1.8×10^9	0.0020	51.9/8.0
2%	1.25	5.0	3.3×10^8	0.0020	10.0/0.9

Table 2
The performance parameters of different Al-doped ZNWAs/CuSCN UV PDs at a certain low bias

Al doping content	S at 0.3V	R_{λ} at 5V($\text{mA}\cdot\text{W}^{-1}$)	D^* (Jones)	EQE (%)	$t_r/t_d(\text{s})$
0%	629	4.3	2.2×10^{10}	1.5	33.0/2.9
0.25%	32572	7.2	4.2×10^{11}	2.4	57.0/0.9
0.5%	65320	2202.6	1.1×10^{13}	748.2	36.0/1.9
1%	6170	71.0	2.5×10^{11}	24.1	62.9/0.9
2%	719	4.6	4.5×10^{10}	1.6	26.9/3.9

Figure 6 shows I-t characteristics and the typical normalized responses of different Al-doped ZNWAs/CuSCN UV PDs. Figure 6(a) exhibits I-t characteristics of all the PDs at 0 V bias. Evidently, all the devices reveal self-powered behavior, which is agreement with the results of Table 1. Furthermore, I-t characteristics of all the devices at 2 V bias were examined, as presented in Fig. 6(b). Interestingly, all the devices have fast response, good stability and excellent repeatability. Especially, the maximum photocurrent exceeds 300 μA for 0.5% Al-doped ZNWAs/CuSCN UV PD, which is significantly higher than those of the other devices, this is mainly because 0.5% Al-doped ZNWAs have optimal electrical properties (see the results of Fig. 5), well-defined morphology (see the results of Fig. 2) and the best crystallinity (see the results of Fig. 3), as well as the defect states density of 0.5% Al-doped ZNWAs/CuSCN are the lowest (see the results of Fig. 4a). A representative cycle was extracted from I-t characteristics of each devices (Fig. 6a), the corresponding normalized responses were plotted in Fig. 6(c), the rise time (t_r) and decay time (t_d) were estimated according to the reported method [34, 45], the values of t_r and t_d for all the devices at 0 V bias are listed in Table 1. Figure 6(d) presents the normalized responses of all the devices at 2 V bias, their values of t_r and t_d were also estimated, as given in Table 2.

Obviously, it can be seen from Table 1 and Table 2 that the performance of Al-doped ZNWAs/CuSCN UV PDs gradually improves with increasing Al doping content from 0% to 0.5%, when Al doping content is 0.5%, the PD has the optimal overall performance, further increasing Al doping content, the device performance is declining rapidly. It is believed that the performances of Al-doped ZNWAs/CuSCN UV PDs mainly depend on the electrical properties of Al-doped ZNWAs and the defect states density of Al-doped ZNWAs/CuSCN, on one hand, after Al doping, the electrical properties of ZNWAs can be obviously enhanced [46], such as the carrier concentration and mobility, because the ionic radius of Al^{3+} (0.53 Å) is much smaller than that of Zn^{3+} (0.74 Å), Al^{3+} is readily incorporated into the ZnO lattice and substituted for Zn^{2+} as a dominant donor, consequently, a large number of free electrons are released into the conduction band (V_c) of ZnO, which increases concentration and mobility of free electrons, the resistance of the Al-doped ZNWAs thus reduces. When ZNWAs are doped with an appropriate Al content (0.5%), the Al-doped ZNWAs have optimal electrical performance, the minimum resistance can be obtained (see the dark I-V characteristics), on the other hand, 0.5% Al-doped ZNWAs/CuSCN has the

lowest defect density among these samples (see the results in Fig. 4(a)), which also play a key role on improving the device performance. After Al doping content exceeds 0.5%, however, excessive free electrons reduce their mobility via ionized-impurity and scattering effects, the electrical performance of Al-doped ZNWAs gradually become poor. Moreover, excessive free electrons significantly increase scattering of incident photons and reduce UV light absorption according to our previous works [34]. In a word, 0.5% Al doping content is optimum. In addition, the prolonged response and recovery observed in all the photodetectors may be attributed to few recombination centers in different Al-doped ZNWAs [47]. In Table 3, a comparison in device performance was made between 0.5% Al-doped ZNWAs/CuSCN UV PD and the reported ZnO-based heterojunction PDs. The results indicate that the 0.5% Al-doped ZNWAs/CuSCN PD reveals good performance.

Table 3
Comparison of the main performance parameters for several UV PDs based on ZnO heterojunctions.

Active materials	R_{λ} at 0V ($\text{mA}\cdot\text{W}^{-1}$)	D^* (Jones)	t_r/t_d (s)	Ref.
ZnO nanorod/CuSCN	1570	2.2×10^{10}	6/501	[32]
ZnO nanorod/CuSCN/rGO	18.65	3.7×10^{11}	0.105 /0.1	[33]
ZnO/Cu ₂ O	1.27	1.6×10^{11}	0.19/0.32	[48]
Ga + In-ZnO nanowire/GaN	5.29	8.0×10^9	9.9/11.4	[49]
Al-doped ZNWAs/CuSCN	0.0294	1.1×10^{13}	41.9/0.9	This work

4. Conclusions

In summary, the different Al-doped ZNWAs were successfully grown on the interdigital patterned FTO substrates, a series of lateral heterojunction UV PDs were subsequently built by depositing CuSCN layers onto the Al-doped ZNWAs. The results exhibited that all the devices under 365 nm light irradiation presented the pronounced photoresponses and stable self-powered behaviors. Furthermore, it was found that the Al doping content had significant effects on the device performance. Of these devices, the 0.5% Al-doped ZNWAs/CuSCN PD had the optimum performance. This work provides a simple, low-cost and efficient route for achieving high-performance self-powered ZnO-based heterojunction UV PDs.

Declarations

CRedit authorship contribution statement

Yu Xu: Data curation. Methodology, Writing-original draft. **Zhaolin Yuan:** Methodology, Conceptualization, Writing–review & editing. **Jianfeng He:** Supervision. **Xueyuan Wang:** Investigation. **Zhixiang Ye:** Writing – review & editing. **Dongfang Pei:** Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests.

Data availability

Data will be made available on reasonable request.

Acknowledgements

This work was partially financial supported by Jiangxi Provincial Natural Science Foundation(No. 20253BAC280025), the Academic and Technical Leaders Project of Major Disciplines in Jiangxi Province (No. 20225BCJ22004), National Key Laboratory of Uranium Resources Exploration-Mining and Nuclear Remote Sensing, (East China University of Technology) (No. 2024QZ-TD-10), Jiangxi Provincial Graduate Innovation Foundation (No. YC2025-S551).

References

1. B. Zou, H. Wang, R. Dong, J. Zhang, Z. Liu, Y. Lin, Z. Zhu, X. Hu, W. Li, D. Zhang, X. Li, L. Wang, H. He, W. Yang, F. Gao, S. Chen, High-Responsivity SiC/TiO₂ Photoelectrochemical Ultraviolet Photodetector: Heterojunctions with Fast Response Times and Excellent pH Tolerance, *Small* **21**(33) (2025) 2504669. <https://doi.org/10.1002/sml.202504669>
2. J.Y. Wei, L.P. Shen, Z.C. Zheng, Y.C. Xu, H. Wu, H. Zhou, H. Wang, The suppression of dark current for achieving high-performance Ga₂O₃ nanorod array ultraviolet photodetector. *Ceram. Int.* **48**(9), 12112–12117 (2022). <https://doi.org/10.1016/j.ceramint.2022.01.071>
3. J.W. Min, T. Samanta, A.Y. Lee, Y.K. Jung, N.S.M. Viswanath, Y.R. Kim, H.B. Cho, J.Y. Moon, S.H. Jang, J.H. Kim, W.B. Im, Highly Emissive Lanthanide-Based 0D Metal Halide Nanocrystals for Efficient Ultraviolet Photodetector. *Small*. **20**(43), 2402951 (2024). <https://doi.org/10.1002/sml.202402951>
4. N. Episcopo, D. Das, C. Bowers, K. Mahalingam, P.R. Stevenson, C.V. Ramana, Highly Textured Sn-Doped Ga₂O₃ Epilayers for Economically Viable Solar-Blind Ultraviolet Photodetectors with High Responsivity. *Adv. Opt. Mater.* **13**(20), 2500325 (2025). <https://doi.org/10.1002/adom.202500325>
5. J.X. Chen, W.X. Ouyang, W. Yang, J.H. He, X.S. Fang, Recent Progress of Heterojunction Ultraviolet Photodetectors: Materials, Integrations, and Applications. *Adv. Funct. Mater.* **30**(16), 1909909 (2020). <https://doi.org/10.1002/adfm.201909909>
6. J. Ma, J. Zhu, C. Dun, H. Wang, B. Yang, M. Zhang, L. Li, H. Ji, Y. Han, Y. Liu, D. Wu, X. Li, C. Shan, Z. Shi, Hot-Pressing Annealing-Induced Light Utilization Enhancement and Crystallinity Optimization Enable High-Performance Narrowband Ultraviolet Photodetectors for Real-Time Ultraviolet Radiation Monitors. *Adv. Sci.* **12**(48), e13795 (2025). <https://doi.org/10.1002/advs.202513795>
7. B. Zou, C. Chen, L. Sun, Y. Lin, Z. Liu, W. Li, L. Wang, F. Gao, H. He, W. Yang, D. Zhang, S. Chen, Self-Powered High-Responsivity Self-Supporting SiC/SnO₂ Nanoarray Photoelectrochemical Ultraviolet

- Photodetector: Toward All-Scenario Harsh Underwater Applications. *Adv. Funct. Mater.* **35**(15), 2421819 (2025). <https://doi.org/10.1002/adfm.202421819>
8. R. Dong, H. Wang, J. Zhang, H. Yin, G. Liu, B. Orwat, B. Luszczynska, W. Li, D. Zhang, H. He, Z. Du, S. Chen, W. Yang, Self-Powered SiC-Based Photoelectrochemical Ultraviolet Photodetectors for Robust Underwater Optical Communication Against Full Aquatic Environments. *Adv. Sci.* **13**(2), e13939 (2026). <https://doi.org/10.1002/advs.202513939>
 9. H. Xu, Y. Weng, K. Chen, C. Wu, H. Hu, D. Guo, Ultra-Low BER Encrypted Communication Based on Self-Powered Bipolar Photoresponse Ultraviolet Photodetector. *Adv. Opt. Mater.* **13**(4), 2402238 (2025). <https://doi.org/10.1002/adom.202402238>
 10. M.Y. Li, M. Yu, D. Su, J. Zhang, S. Jiang, J. Wu, Q. Wang, S. Liu, Ultrahigh Responsivity UV Photodetector Based on Cu Nanostructure/ZnO QD Hybrid Architectures. *Small.* **15**(28), 1901606 (2019). <https://doi.org/10.1002/sml.201901606>
 11. Y. Wang, J. Chen, T. Hu, Y. Huang, W. Zhu, W. Li, Y. Hu, Z. Wei, Z. Fan, L. Zhao, K. Wang, High-Performance Ultraviolet Photodetector Based on the Vertical GaSe/GaN Heterojunction, *Small* **21**(8) (2025) 2407473. <https://doi.org/10.1002/sml.202407473>
 12. A. Rajan, K. Arora, B. Vidhani, J. Dalal, P. Kumar, Au-modified ZnO thin films for higher-performance ultraviolet photodetectors. *RSC Adv.* **15**(58), 49728–49738 (2025). <https://doi.org/10.1039/d5ra08186f>
 13. J. Kazmi, A. Abbas, D.J. Young, J.H. Shah, W. Ahmad, S.S.A. Shah, S.R.A. Raza, M.A. Mohamed, A.O. Govorov, Z. Wang, ZnO nanowire UV photodetectors: At the intersection of flexibility, biocompatibility, and visible blindness. *Mater. Today.* **82**, 139–180 (2025). <https://doi.org/10.1016/j.mattod.2024.11.004>
 14. H. Zhang, T. Abdiryim, R. Jamal, J. Li, H. Liu, A. Kadir, D. Zou, Y. Che, N. Serkjan, Self-powered TiO₂ NRs UV photodetectors: Heterojunction with PTTh and enhanced responsivity by Au nanoparticles. *J. Alloys Compd.* **899**, 163279 (2022). <https://doi.org/10.1016/j.jallcom.2021.163279>
 15. Q. Qiao, T. Zhao, J. Zheng, H. Yin, Y. Zhang, J. Zang, X. Yang, H. Li, T. Rao, X. Yu, X.M. Yu, Self-powered poly(3-hexylthiophene)/ZnO heterojunction ultraviolet photodetectors decorated by silver nanoparticles. *Opt. Mater.* **153**, 115615 (2024). <https://doi.org/10.1016/j.optmat.2024.115615>
 16. Z. Lyu, Y. Zhao, R. Duan, M. Liu, X. Yao, S. Liu, S. Li, Enhancing the performance of self-powered heterojunctional ZnO/Cs₃Bi₂I₉ photodetectors through pyroelectric-photovoltaic coupling effect. *Nano Energy.* **131**, 110205 (2024). <https://doi.org/10.1016/j.nanoen.2024.110205>
 17. Y.C. Wang, C.H. Chiang, C.M. Chang, H. Maeda, N. Fukui, I. Wang, C.Y. Wen, K.C. Lu, S.K. Huang, W.B. Jian, C.W. Chen, K. Tsukagoshi, H. Nishihara, Two-Dimensional Bis(dithiolene)iron(II) Self-Powered UV Photodetectors with Ultrahigh Air Stability. *Adv. Sci.* **8**(14), 2100564 (2021). <https://doi.org/10.1002/advs.202100564>
 18. X. Chen, B.P. Veettil, N. Nasiri, Morphology-driven UV photodetection in self-powered Pt/ZnO Schottky devices. *Nano Today.* **63**, 102754 (2025). <https://doi.org/10.1016/j.nantod.2025.102754>

19. X. Zhao, Q. Li, L. Xu, Z. Zhang, Z. Kang, Q. Liao, Y. Zhang, Interface Engineering in 1D ZnO-Based Heterostructures for Photoelectrical Devices. *Adv. Funct. Mater.* **32**(11), 2106887 (2022). <https://doi.org/10.1002/adfm.202106887>
20. Y.F. Zhan, J. Poisson, X.T. Meng, Z.B. Wang, L.Z. Chen, T.-H. Wu, R. Koehler, K. Zhang, Electrospun Lignin/ZnO Nanofibrous Membranes for Self-Powered Ultrasensitive Flexible Airflow Sensor and Wearable Device. *Adv. Mater.* **37**(37), 2502211 (2025). <https://doi.org/10.1002/adma.202502211>
21. F. Cao, L. Jin, Y. Wu, X.H. Ji, High-performance, self-powered UV photodetector based on Au nanoparticles decorated ZnO/CuI heterostructure. *J. Alloys Compd.* **859**, 158383 (2021). <https://doi.org/10.1016/j.jallcom.2020.158383>
22. Q. Li, J. Meng, J. Huang, Z. Li, Pyro-Phototronic Effect Enhancement in Self-Powered UV–Vis Detection with a ZnO/CuO p–n Junction Device. *Adv. Funct. Mater.* **32**(7), 2108903 (2022). <https://doi.org/10.1002/adfm.202108903>
23. X. Zheng, M. Dong, Q. Li, Y. Liu, X. Di, X. Lu, J. Meng, Z. Li, High-Performance UV Photodetector via Energy Band Engineering and LSPR-Enhanced Pyro-Phototronic Effect in Au Decorated 2D-PbI₂/1D-ZnO Heterojunction. *Adv. Opt. Mater.* **12**(17), 2303177 (2024). <https://doi.org/10.1002/adom.202303177>
24. X. Wang, S. Gao, Z. Han, X. Zhang, H. Chen, K. Xiang, M. Ye, J. Qiu, C. Wu, X. Yang, T. Zhang, Q. Gao, K. Xing, High Performance Self-Powered p-GaN/n⁺⁺-ZnO/Au UV Heterojunction Phototransistor with 3D Interconnected ZnO Nanowire Network for Solar-Blind Imaging and Optical Communication. *Adv. Opt. Mater.* **13**(1), 2401869 (2024). <https://doi.org/10.1002/adom.202401869>
25. M. Banari, N. Memarian, P. Kumar, S.J. You, A. Vomiero, I. Concina, CeO₂:ZnO hybrid nanorods for self-powered UV-photodetectors. *Ceram. Int.* **51**(1), 9–16 (2025). <https://doi.org/10.1016/j.ceramint.2024.10.254>
26. L.L. Chu, C. Xu, Z.P. Li, C. Nie, High-performance self-powered ultraviolet photodetector based on a ZnO/CuPc inorganic/organic heterojunction. *RSC Adv.* **14**(19), 13361–13366 (2024). <https://doi.org/10.1039/d4ra01773k>
27. S. Nandi, N.K. Das, S. Ghosal, D. Sahu, M. Meyyappan, P.K. Giri, 2D Bi₂Se₃-ZnO nanoparticle heterojunction based ultrafast photodetectors for enhanced detection in the UV to telecommunication wavelength, *J. Mater. Chem. C* **13**(31) (2025) 16183–16194. <https://doi.org/10.1039/D5TC01430A>
28. Y.X. Ji, X.Y. Zhao, Y.N. Pan, Z.H. Su, J.H. Lin, E.M. Akinoglu, Y. Xu, H.Y. Zhang, P.J. Zhao, Y. Dong, X.Z. Wei, F.Y. Liu, P. Mulvaney, *Adv. Funct. Mater.* **33**(11), 2211421 (2023). CuSCN Modified Back Contacts for High Performance CZTSSe Solar Cells <https://doi.org/10.1002/adfm.202211421>
29. S.M. Hatch, J. Briscoe, S. Dunn, A self-powered ZnO-nanorod/CuSCN UV photodetector exhibiting rapid response. *Adv. Mater.* **25**(6), 867–871 (2013). <https://doi.org/10.1002/adma.201204488>
30. J. Garnier, R. Parize, E. Appert, O. Chaix-Pluchery, A. Kaminski-Cachopo, V. Consonni, Physical properties of annealed ZnO nanowire/CuSCN heterojunctions for self-powered UV photodetectors. *ACS Appl. Mater. Interfaces.* **7**(10), 5820–5829 (2015). <https://doi.org/10.1021/am5089605>

31. S. Li, J. Xu, S. Shi, X. Shi, X. Wang, C. Wang, X. Zhang, Z. Liu, L. Li, UVphotoresponse properties of ZnO nanorods arrays deposited with CuSCN by SILAR method. *Chem. Phys. Lett.* **620**, 50–55 (2015). <https://doi.org/10.1016/j.cplett.2014.12.026>
32. S. Shi, S. Li, Y. Su, K. Zhu, L. Jiao, J. Xu, L. Li, Optimized electrodeposition of CuSCN on ZnO nanorods arrays for high-performance self-powered ultraviolet photodetectors. *J. Lumin.* **286**, 121395 (2025). <https://doi.org/10.1016/j.jlumin.2025.121395>
33. G. Luo, Z. Zhang, J. Jiang, Y. Liu, W. Li, J. Zhang, X. Hao, W. Wang, Enhanced performance of ZnO nanorod array/CuSCN ultraviolet photodetectors with functionalized graphene layers, *RSC. Adv.* **11**(13), 7682–7692 (2021). <https://doi.org/10.1039/d0ra10420e>
34. N. Xu, Z. Yuan, F. Nie, J. He, X. Wang, S. You, Hydrothermal growth and ultraviolet sensing performance of well-aligned Ga-doped ZnO nanowire arrays. *Opt. Mater.* **133**, 112995 (2022). <https://doi.org/10.1016/j.optmat.2022.112995>
35. W. Dai, X. Pan, S. Chen, C. Chen, Z. Wen, H. Zhang, Z. Ye, Honeycomb-like NiO/ZnO heterostructured nanorods: photochemical synthesis, characterization, and enhanced UV detection performance. *J. Mater. Chem. C* **2**(23), 4606–4614 (2014). <https://doi.org/10.1039/C4TC00157E>
36. J.N. Tan, S. Jiang, B.H. Ge, B.J. Xu, B.B. Cao, Synthesis and characterization of high-purity $\text{SnO}_2(\text{ZnO}:\text{Sn})_m$ superlattice nanowire arrays with broad-spectrum emissions. *CrystEngComm.* **22**(32), 5355–5362 (2020). <https://doi.org/10.1039/D0CE00889C>
37. Q. Zhu, C.S. Xie, H.Y. Li, C.Q. Yang, S.P. Zhang, D.W. Zeng, Selectively enhanced UV and NIR photoluminescence from a degenerate ZnO nanorod array film. *J. Mater. Chem. C* **2**(23), 4566–4580 (2014). <https://doi.org/10.1039/C4TC00011K>
38. J. Rodrigues, M. Hoppe, N.B. Sedrine, N. Wolff, V. Duppel, L. Kienle, R. Adelung, Y.K. Mishra, M.R. Correia, T. Monteiro, ZnAl_2O_4 decorated Al-doped ZnO tetrapodal 3D networks: microstructure, Raman and detailed temperature dependent photoluminescence analysis. *Nanoscale Adv.* **2**(5), 2114–2126 (2020). <https://doi.org/10.1039/C9NA00730J>
39. A. Das, M. Patra, M. Kumar, P.M. Bhagavathiachari, R.G. Nair, Role of type II heterojunction in ZnO- In_2O_3 nanodiscs for enhanced visible-light photocatalysis through the synergy of effective charge carrier separation and charge transport. *Mater. Chem. Phys.* **263**, 124431 (2021). <https://doi.org/10.1016/j.matchemphys.2021.124431>
40. M. Huang, Y. Wang, H. Zhang, M. Mao, B. Cen, T. Wang, Z. Zhang, Q. Li, K. Liu, P. Kong, J. Zhang, S. Luo, G. Luo, O, N co-doped CuCrO_2 as efficient hole transport layer for high-performance ultraviolet photodetectors. *J. Alloys Compd.* **971**, 172743 (2024). <https://doi.org/10.1016/j.jallcom.2023.172743>
41. D. Wang, P. Shi, R. Xing, Z. Wu, L. Wei, Y. Chen, H. Ren, C. Yu, F. Li, Self-powered ZnO/ SrCoO_x flexible ultraviolet detectors processed at room temperature. *Mater. Des.* **203**, 109616 (2021). <https://doi.org/10.1016/j.matdes.2021.109616>
42. X. Qi, J. Yue, X. Ji, Z. Liu, S. Li, Z. Yan, M. Zhang, L. Yang, P. Li, D. Guo, Y. Guo, W. Tang, A deep-ultraviolet photodetector of a $\beta\text{-Ga}_2\text{O}_3/\text{CuBiI}_4$ heterojunction highlighting ultra-high sensitivity and

- responsivity. *Thin Solid Films*. **757**, 139397 (2022). <https://doi.org/10.1016/j.tsf.2022.139397>
43. H. Guan, G. Mao, T. Zhong, T. Zhao, S. Liang, L. Xing, X. Xue, A self-powered UV photodetector based on the hydrovoltaic and photoelectric coupling properties of ZnO nanowire arrays. *J. Alloys Compd.* **867**, 159073 (2021). <https://doi.org/10.1016/j.jallcom.2021.159073>
 44. Y. Ji, L. Wu, Y. Liu, Y. Yang, Chemo-phototronic effect induced electricity for enhanced self-powered photodetector system based on ZnO nanowires. *Nano Energy*. **89**, 106449 (2021). <https://doi.org/10.1016/j.nanoen.2021.106449>
 45. W.X. Ouyang, J.X. Chen, J.H. He, X.S. Fang, Improved Photoelectric Performance of UV Photodetector Based on ZnO Nanoparticle-Decorated BiOCl Nanosheet Arrays onto PDMS Substrate: The Heterojunction and $\text{Ti}_3\text{C}_2\text{T}_x$ MXene Conduction Layer. *Adv. Electron. Mater.* **6**(6), 2000168 (2020). <https://doi.org/10.1002/aelm.202000168>
 46. A.P. Thilakan, P.-L. Hung, J.-B. Yang, D.-L. Lin, S.-D. Tzeng, Y.-K. Hsu, C.-H. Tsai, Y.-H. Pai, A. Yabushita, C.-W. Luo, M.-H. Chen, Investigating Dopant Effects in ZnO as an Electron Transport Layer for Enhanced Efficiency in Organic Photovoltaics. *Adv. Mater. Interfaces*. **12**(11), 2400923 (2025). <https://doi.org/10.1002/admi.202400923>
 47. L.X. Qian, H.F. Zhang, P.T. Lai, Z.H. Wu, X.Z. Liu, Photodetector on high- temperature pretreated c-plane sapphire substrate. *Opt. Mater. Express*. **7**(10), 3643–3653 (2017). <https://doi.org/10.1364/OME.7.003643>
 48. Y. Zhao, D. Jiang, M. Zhao, A spectrally selective self-powered photodetector utilizing a ZnO/Cu₂O heterojunction. *Appl. Surf. Sci.* **636**, 157800 (2023). <https://doi.org/10.1016/j.apsusc.2023.157800>
 49. C.Y. Tsay, I.P. Hsiao, F.Y. Chang, C.L. Hsu, Improving the photoelectrical characteristics of self-powered p-GaN film/n-ZnO nanowires heterojunction ultraviolet photodetectors through gallium and indium co-doping. *Mater. Sci. Semicond. Process.* **121**, 105295 (2021). <https://doi.org/10.1016/j.mssp.2020.105295>

Figures

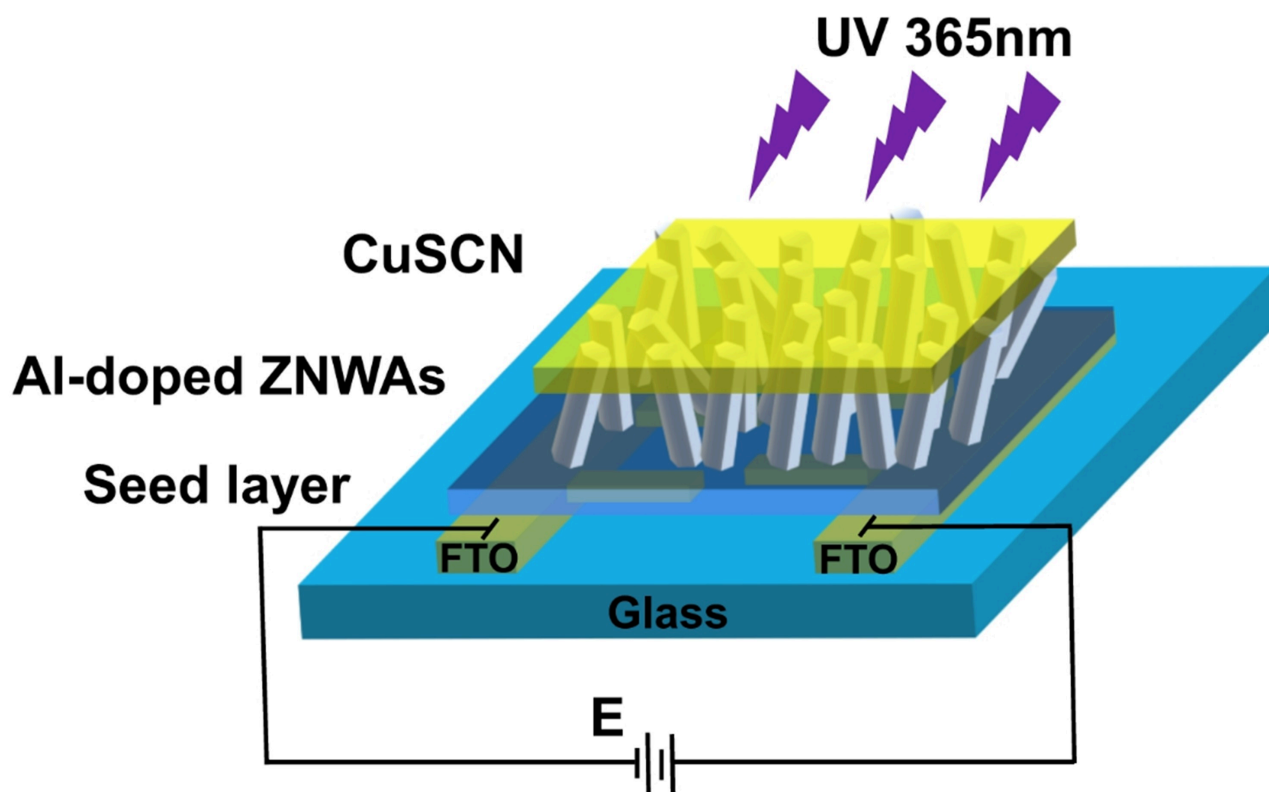


Figure 1

Schematic illustration of Al-doped ZNWAs/CuSCN UV PDs

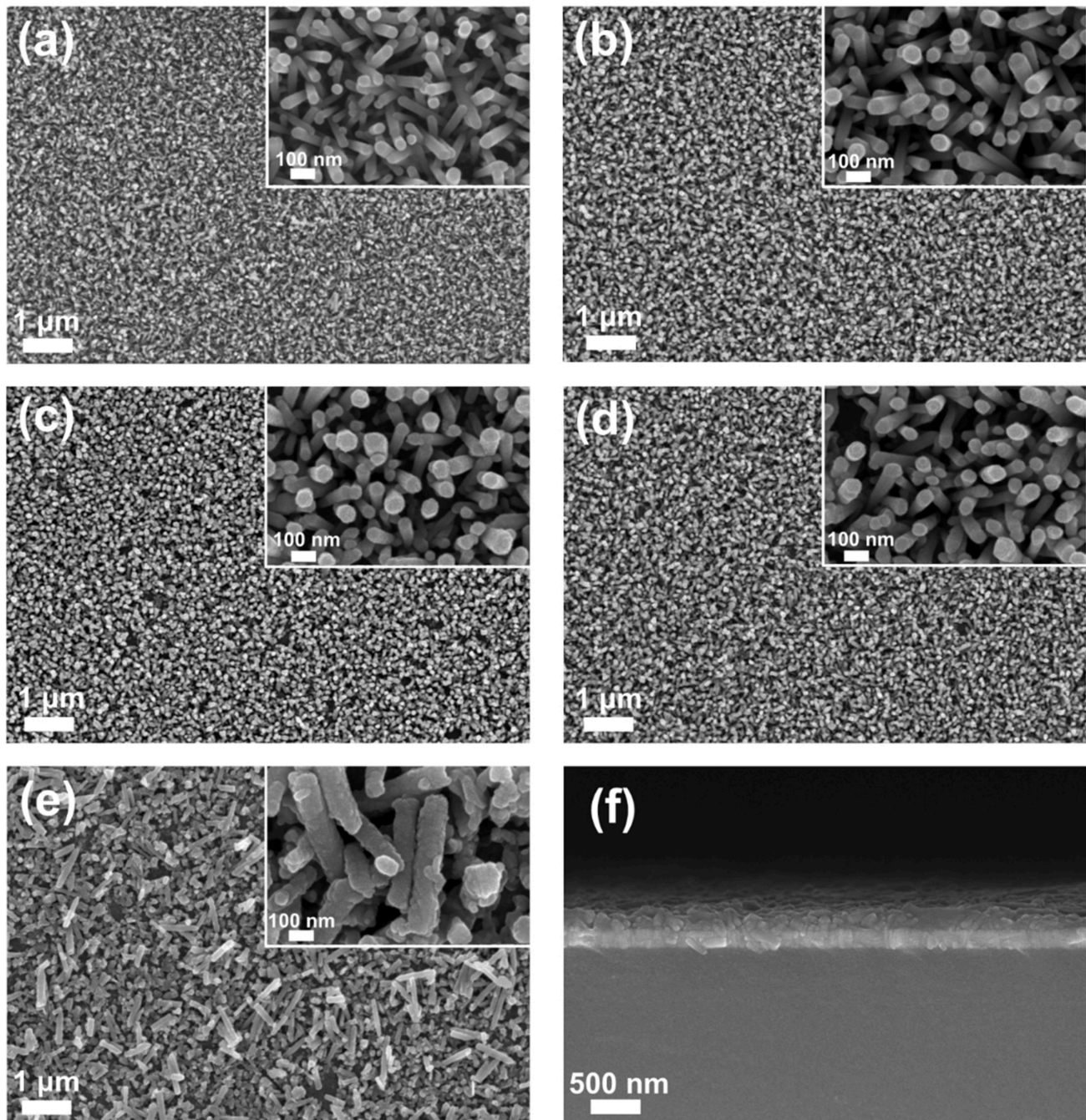


Figure 2

Typical top-view FE-SEM images of different Al-doped ZNWAs/CuSCN, (a) 0%, (b) 0.25%, (c) 0.5%, (d) 1%, (e) 2%, (f) Cross-sectional SEM image of 0.5% Al-doped ZNWAs/CuSCN, the insets show the corresponding high-magnification FE-SEM images.

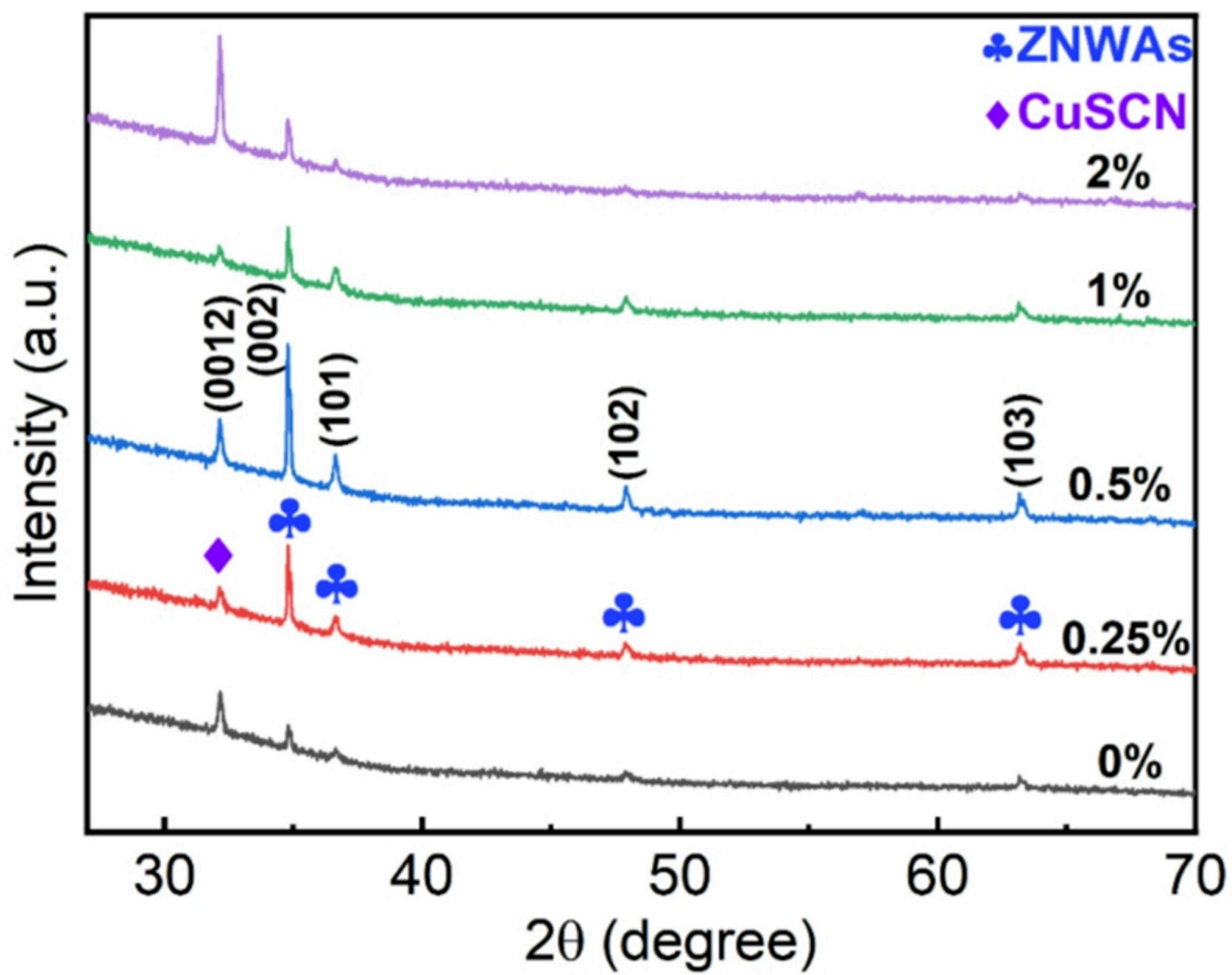


Figure 3

XRD patterns of different Al-doped ZNWAs/CuSCN

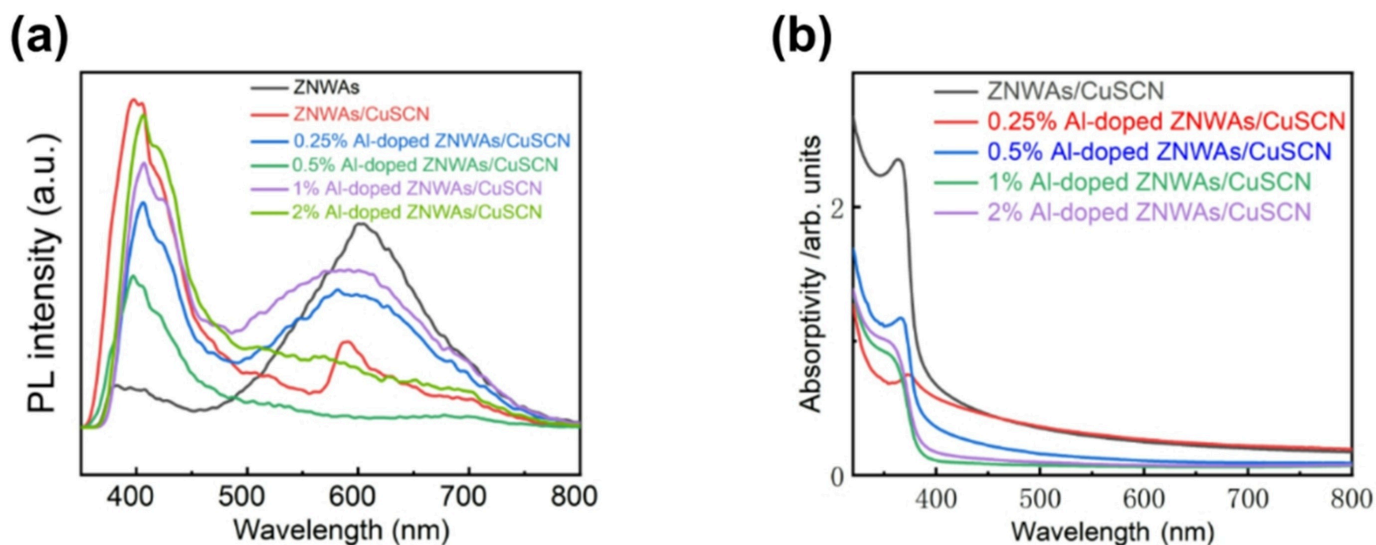


Figure 4

Optical properties of different Al-doped ZNWAs/CuSCN, (a) Room temperature PL spectra, (b) UV-visible absorption spectra

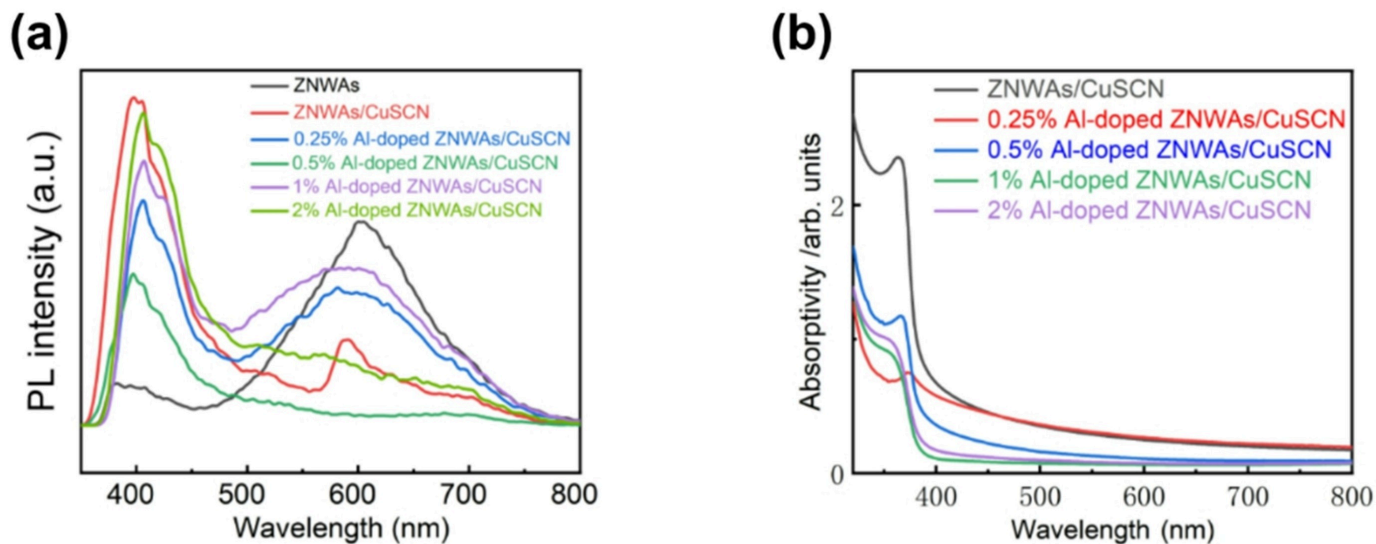


Figure 4

Optical properties of different Al-doped ZNWAs/CuSCN, (a) Room temperature PL spectra, (b) UV-visible absorption spectra

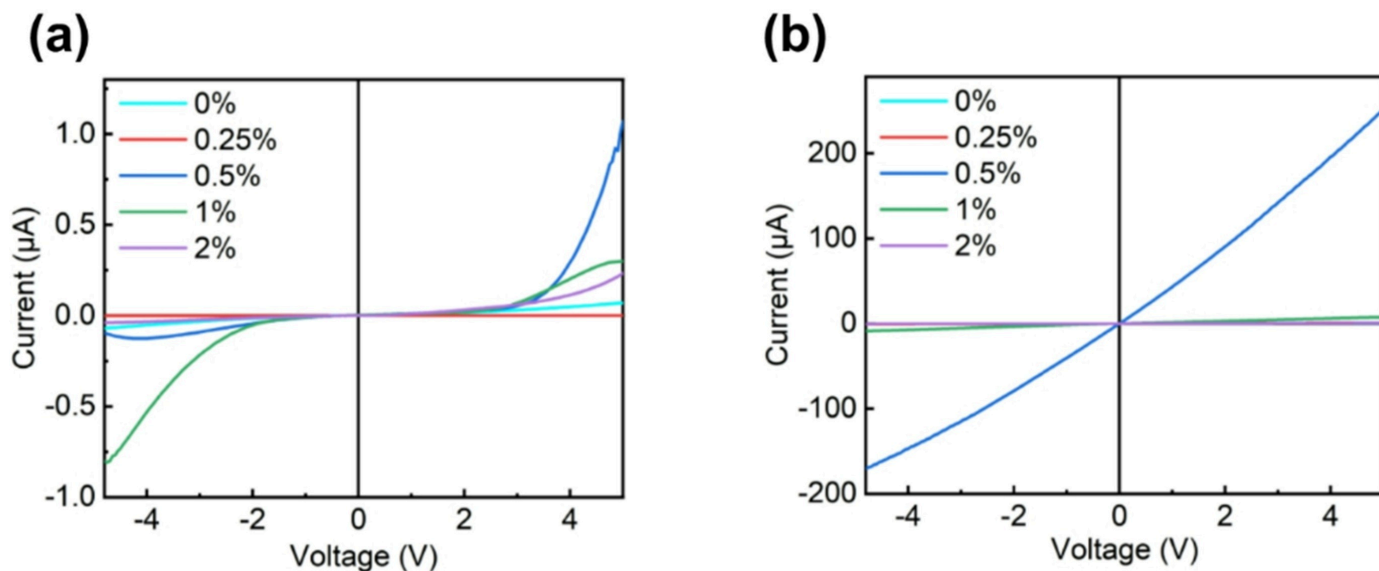


Figure 5

I-V characteristics of different Al-doped ZNWAs/CuSCN UV PDs in different conditions, (a) Dark, (b) UV light illumination (light power density = $190 \mu\text{W}\cdot\text{cm}^{-2}$, $\lambda = 365 \text{ nm}$)

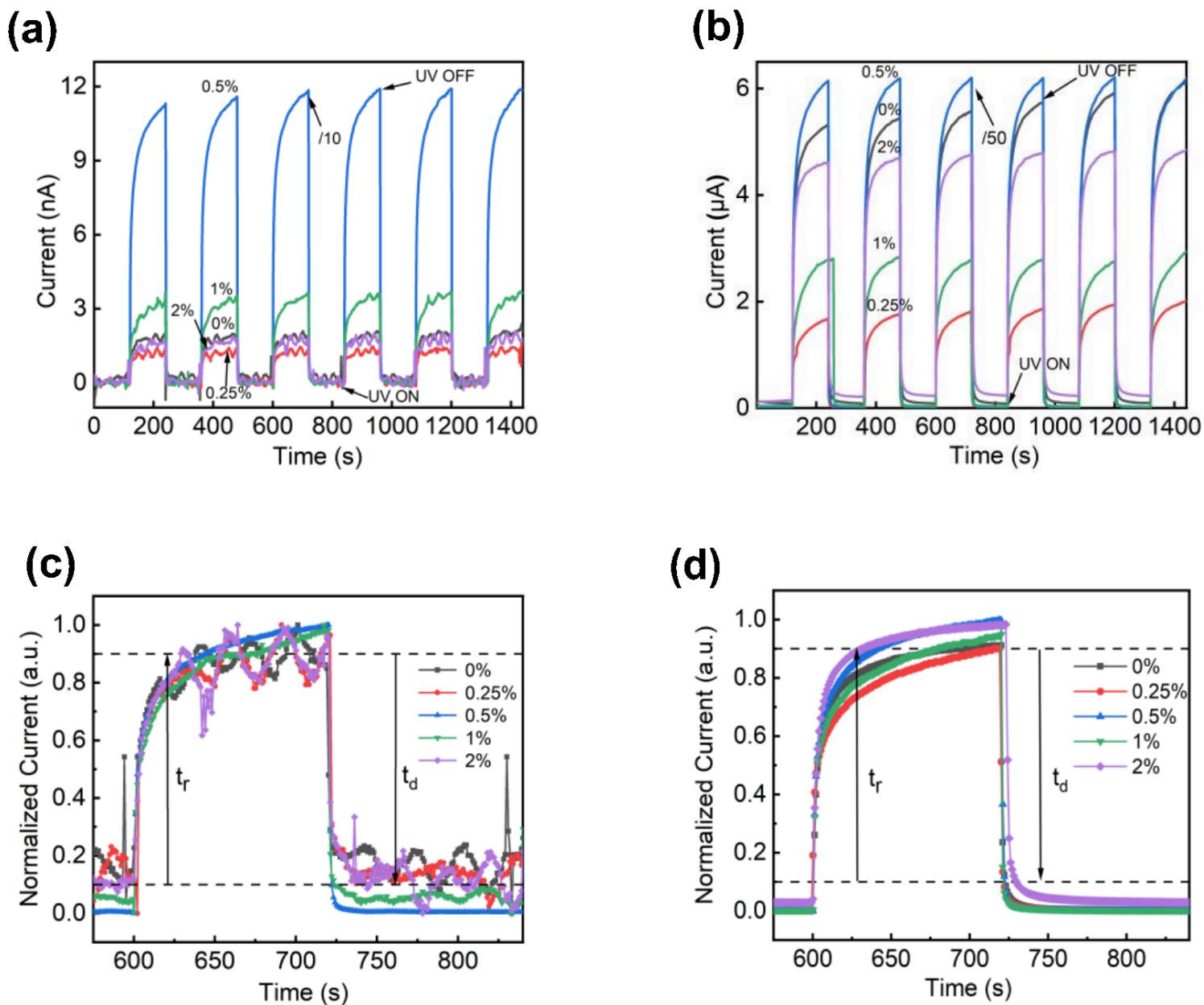


Figure 6

I-t characteristics of different Al-doped ZNWAs/CuSCN UV PDs at different bias (light power density = $190 \mu\text{W}\cdot\text{cm}^{-2}$, $\lambda = 365 \text{ nm}$), (a) 0 V, (b) 2 V, (c) Normalized responses of all the PDs at different bias, (c) 0 V, (d) 2 V