

Investigation of WO₃-doped Ga₂O₃ films as Deep-ultraviolet and Visible-light Photodetectors

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Deep-ultraviolet (DUV) and visible-light photodetectors have attracted considerable attention owing to their important applications in environmental monitoring, optical communication, image sensing, and intelligent sensing systems. However, most reported photodetectors are optimized for either the DUV or visible-light region, making broadband photodetection over 250–430 nm difficult. In this study, WO₃-doped Ga₂O₃ films were deposited on Si substrates by a simple electron-beam (E-beam) evaporation process, and interdigital aluminum electrodes were fabricated to construct broadband photodetectors. SEM observations revealed dense and uniform films with a thickness of approximately 131 nm, while energy dispersive spectrometry confirmed the successful incorporation of W into the Ga₂O₃ matrix. X-ray diffraction (XRD) analysis showed that the deposited films were amorphous, whereas UV–visible spectroscopy indicated a wide optical bandgap of 4.66 eV. The fabricated photodetectors exhibited characteristic photoresponse peaks at 250, 280, 360, and 430 nm and demonstrated stable current–voltage characteristics, excellent repeatability during five consecutive ON/OFF cycles, and stable response times over the wavelength range of 280–430 nm. The objective of this work is to investigate whether a simply fabricated WO₃-doped Ga₂O₃ thin-film photodetector can provide measurable photoresponse extending from the DUV toward the visible-light region.

1. Introduction

Deep-ultraviolet (DUV) photodetectors have become increasingly important because of their unique capability to detect ultraviolet radiation below 280 nm while remaining insensitive to most visible solar radiation. Owing to this solar-blind characteristic, DUV photodetectors have been extensively applied in flame detection, missile plume monitoring, environmental surveillance, sterilization process control, and astronomical observations.^(1,2) On the other hand, visible-light photodetectors play a critical role in optical communication systems, image sensing, machine vision, wearable electronics, and intelligent IoT platforms.^(3,4) With the rapid growth of

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smart sensing technologies and autonomous systems, there is an increasing demand for photodetectors capable of providing stable, high-sensitivity, and broadband optical detection. Therefore, the development of photodetectors that can simultaneously address the requirements of both DUV and visible-light sensing has emerged as an important research topic in modern optoelectronics. Numerous semiconductor materials and device architectures have been investigated for DUV and visible-light photodetection.

For DUV applications, wide-bandgap semiconductors such as β -Ga₂O₃, AlGaN, and ZnMgO have attracted significant attention because of their excellent solar-blind characteristics, high breakdown field, and high radiation resistance.^(5–7) In contrast, visible-light photodetectors commonly employ Si, perovskite semiconductors, and transition-metal dichalcogenides owing to their high optical absorption and carrier mobility in the visible spectral region.^(8–10) Although these materials have demonstrated excellent performance within their respective wavelength ranges, most reported devices are optimized for only a limited portion of the optical spectrum. Consequently, separate sensing platforms are often required for ultraviolet and visible-light detection, increasing device complexity, fabrication cost, and system integration difficulty. Despite considerable progress in photodetector technology, realizing efficient photoresponse across a broad spectral range from 250 to 430 nm remains challenging.⁽¹¹⁾

The primary difficulty originates from the intrinsic trade-off between ultraviolet selectivity and visible-light absorption. Materials exhibiting a sufficiently wide bandgap to achieve high DUV sensitivity generally exhibit limited absorption in the visible region, whereas materials optimized for visible-light detection often suffer from reduced ultraviolet responsivity and increased dark current. Furthermore, defect states, carrier recombination, interface trapping effects, and spectral mismatch frequently degrade overall device performance. As a result, achieving high responsivity, low dark current, high response speed, and stable operation simultaneously over both DUV and visible-light regions remains difficult. Therefore, developing a simple material system capable of extending spectral sensitivity while maintaining excellent optoelectronic properties is highly desirable for next-generation broadband photodetectors.

In this work, WO₃-doped Ga₂O₃ films are proposed as an effective active material for broadband photodetection spanning the DUV and visible-light regions.^(11,12) Compared with conventional heterojunction or multilayer structures, the proposed approach employs a simple electron-beam (E-beam) evaporation process to deposit WO₃-doped Ga₂O₃ films, offering advantages of low fabrication complexity, reduced processing cost, and excellent scalability. Interdigital-transducer (IDT) electrodes are subsequently fabricated to construct photodetector devices without requiring sophisticated device architectures. The incorporation of WO₃ is expected to modify the electronic structure and defect distribution of Ga₂O₃, thereby enhancing carrier transport and extending optical sensitivity toward longer wavelengths. The main novelty lies in combining WO₃-doped Ga₂O₃ films, a simple E-beam evaporation process, and an IDT electrode configuration to realize photoresponse spanning 250–430 nm without employing a complex heterojunction or multilayer device structure. However, the absence of an undoped Ga₂O₃ reference and the relatively modest photocurrent modulation remain limitations of the present work. Future studies will therefore focus on direct comparison with undoped Ga₂O₃ and the optimization of film composition and device performance.

2. Materials and Methods

P-type Si (100) wafers were employed as substrates for the fabrication of WO_3 -doped Ga_2O_3 photodetectors. A WO_3 -doped Ga_2O_3 evaporation target was prepared by mixing high-purity Ga_2O_3 and WO_3 powders with a nominal precursor W:Ga ratio of 6:100. This ratio represents the precursor composition used for target preparation rather than the measured atomic composition of the deposited film. The mixed powders were thoroughly homogenized and subsequently used as the evaporation source. WO_3 -doped Ga_2O_3 films were deposited onto the Si substrates using an E-beam evaporation system. Prior to deposition, the vacuum chamber was evacuated to a base pressure of approximately 7.5×10^{-6} torr to minimize contamination and ensure film quality. The WO_3 -doped Ga_2O_3 films were deposited using an E-beam evaporation system (Sizigi, Taiwan) equipped with a vacuum chamber. The films were deposited on cleaned p-type Si (100) substrates under the deposition conditions described above. The deposition process was conducted under controlled conditions to obtain uniform thin films suitable for photodetector applications. After film deposition, interdigitated aluminum (Al) electrodes were fabricated on the film surface by thermal evaporation to form the photodetector devices. The IDT electrode structure was adopted to enhance carrier collection efficiency and improve photoresponse performance. A schematic of the fabricated WO_3 -doped Ga_2O_3 photodetector is shown in Fig. 1(a) and a schematic of the fabrication process is shown in Fig. 1(b).

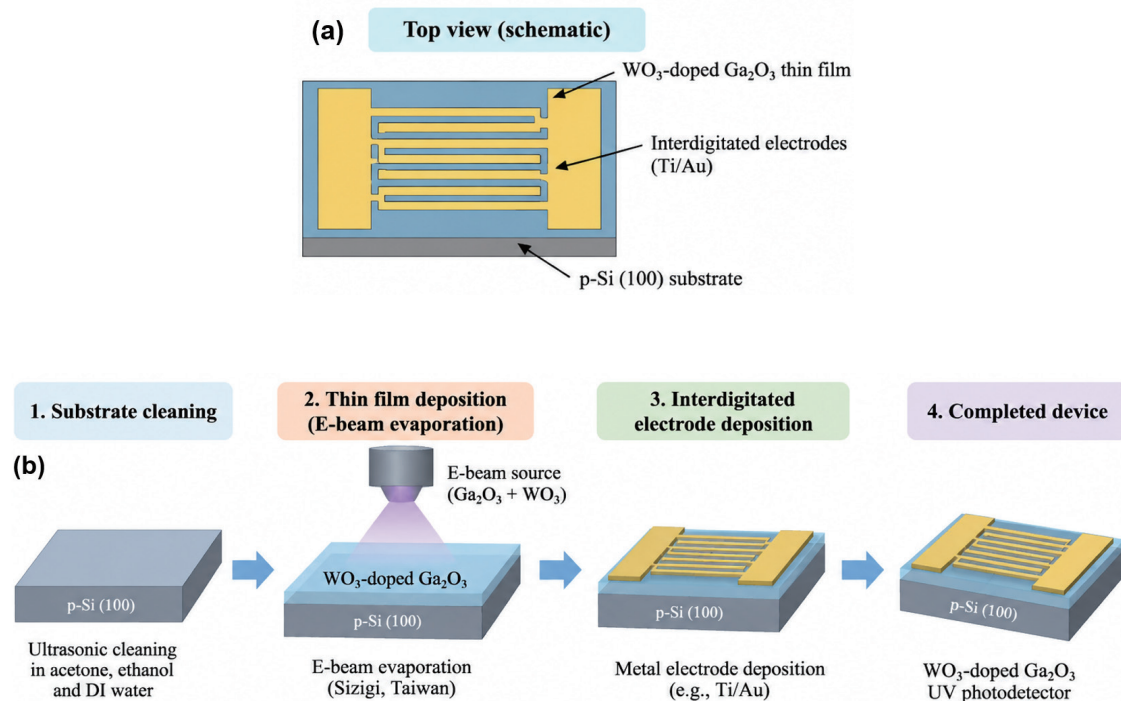


Fig. 1. (Color online) (a) Schematic of the fabricated WO_3 -doped Ga_2O_3 photodetector and (b) schematic of the fabrication process.

The surface morphology and cross-sectional thickness of the deposited films were examined by field-emission scanning electron microscopy (FE-SEM, S-4800, Hitachi, Japan), and the elemental composition was analyzed using the associated energy-dispersive X-ray spectroscopy (EDS) system. The structural characteristics of the films were investigated using an X-ray diffractometer (D8, Bruker, Germany). The elemental composition and distribution of Ga, O, and W within the films were analyzed by EDS to verify successful WO₃ incorporation. The crystalline structure and phase evolution of the deposited films were investigated by X-ray diffraction (XRD). Optical properties were evaluated by UV–visible spectroscopy over a broad wavelength range. The optical transmittance and absorption spectra were analyzed to determine the optical bandgap energy (E_g) of the films, providing insight into the effects of WO₃ doping on the electronic structure and optical absorption characteristics of Ga₂O₃. The optoelectronic performance of the fabricated photodetectors was evaluated using a semiconductor parameter analyzer integrated with a monochromator-coupled light source. Spectral photoresponse measurements were performed over the wavelength range of 200–600 nm at a fixed bias voltage of 5 V to investigate the detection capability from the DUV to the visible-light region. The same 5 V bias voltage was maintained for the wavelength-dependent photoresponsivity, cyclic ON/OFF photoresponse, and response-time measurements to ensure a consistent comparison of the device characteristics.

The wavelength-dependent photocurrent was recorded and compared with the corresponding dark current characteristics. The specific detectivity (D^*) was estimated by assuming that the detector noise was dominated by the shot noise associated with the dark current. Accordingly, D^* was calculated as

$$D^* = R[A/(2qI_{dark})]^{1/2}, \quad (1)$$

where R is the photoresponsivity, A is the effective photosensitive area of the device, q is the elementary charge (1.602×10^{-19} C), and I_{dark} is the measured dark current at a bias voltage of 5 V. The effective photosensitive area of the IDT device was approximately 0.60 cm², and the gap between adjacent Al electrode fingers was 40 μ m. Thus, the reported D values represent shot-noise-limited estimates rather than values obtained from direct noise spectral-density measurements. The photocurrent and dark current of the fabricated photodetectors were measured using a Keithley 2450 SourceMeter under dark and illuminated conditions, respectively. The wavelength-dependent photoresponse and current–voltage characteristics were evaluated using the optical illumination and electrical measurement system. The same measurement setup was used to record the cyclic photoresponse and transient current characteristics under different illumination wavelengths.

To examine the dynamic response behavior and operational reliability of the devices, transient photoresponse measurements were carried out under illumination at different wavelengths. Transient photoresponse measurements were performed at a fixed bias voltage of 5 V under illumination at 250, 280, 360, and 430 nm. During the measurements, the incident light was periodically switched ON and OFF, and the corresponding photocurrent was continuously recorded using a Keithley 2450 SourceMeter. Five consecutive ON/OFF cycles were conducted

at each wavelength to evaluate the short-term switching repeatability and transient response characteristics of the device. The rise time (τ_r) and fall time (τ_f) were subsequently extracted from the transient photoresponse curves. The present five-cycle measurement was intended as a short-term repeatability test rather than a long-term operational stability test. A larger number of continuous switching cycles will be investigated in future work to further evaluate the long-term stability and reliability of the device. The combination of WO_3 -doped Ga_2O_3 films, a simple E-beam evaporation process, and an IDT electrode configuration provides a straightforward and cost-effective approach for realizing high-performance photodetectors capable of operating across both DUV and visible-light spectral regions.

3. Results and Discussion

Figure 2(a) shows the surface SEM image of the WO_3 -doped Ga_2O_3 film. No obvious pores, cracks, or surface defects can be observed, indicating that the film was successfully deposited with good structural integrity. In addition, the surface morphology appears highly uniform and the grain distribution is relatively homogeneous over the observed area. The smooth and dense

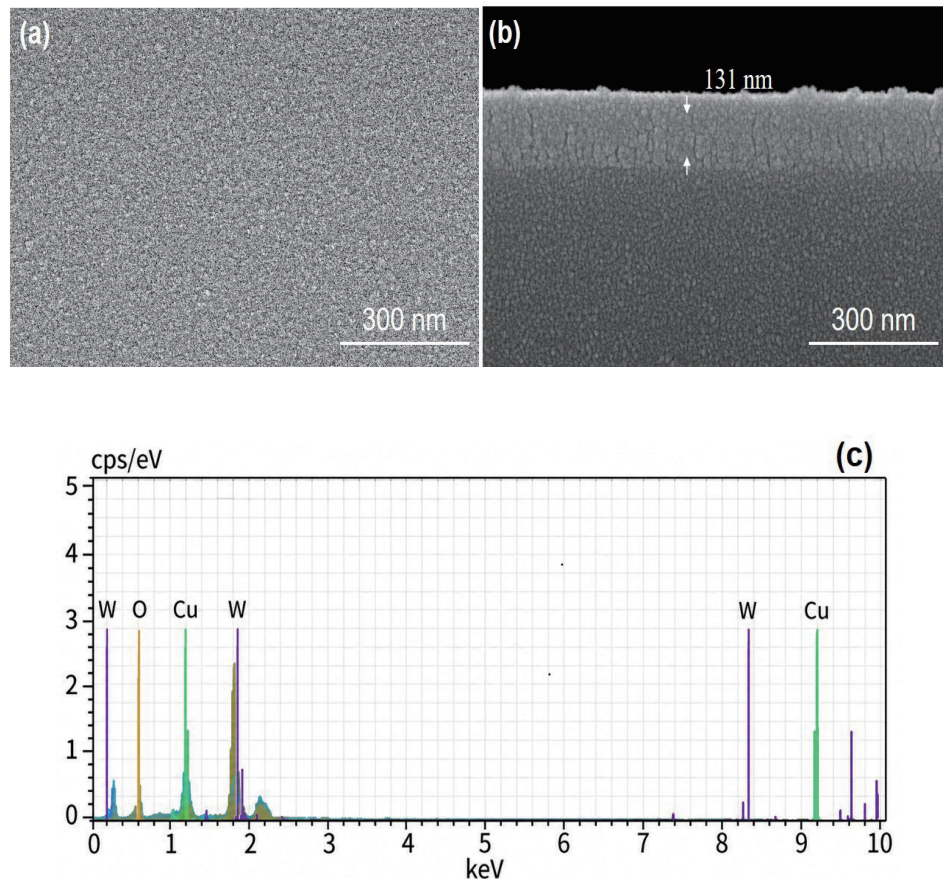


Fig. 2. (Color online) (a) Surface and (b) cross-sectional SEM images, and (c) elemental composition of the deposited WO_3 -doped Ga_2O_3 films analyzed by EDS.

surface suggests that the E-beam evaporation process provides favorable film growth conditions and contributes to the formation of high-quality WO_3 -doped Ga_2O_3 films. Such a compact morphology is beneficial for reducing carrier scattering and defect-related recombination, which can improve the electrical and photoresponse characteristics of the photodetector. Figure 2(b) presents the cross-sectional SEM image of the WO_3 -doped Ga_2O_3 film. A clear and continuous film layer can be observed on the substrate surface without notable delamination or structural discontinuities. The film thickness is approximately 131 nm and remains relatively uniform across the cross section, demonstrating good thickness controllability during the deposition process. The absence of significant voids or interfacial defects further confirms the good adhesion between the deposited film and the substrate. A uniform film thickness is advantageous for achieving consistent optical absorption and carrier transport throughout the active region of the photodetector. The elemental composition of the WO_3 -doped Ga_2O_3 film was analyzed by EDS, as shown in Fig. 2(c). The presence of Ga, W, and O peaks confirms the incorporation of W-containing species into the deposited Ga_2O_3 -based film.

Quantitative EDS analysis gives an apparent Ga:W:O atomic ratio of 24.81:21.93:53.27, which differs substantially from the nominal precursor W:Ga ratio of 6:100 used for target preparation. This large discrepancy cannot be attributed solely to normal EDS measurement uncertainty. In addition to the semi-quantitative nature of EDS for a thin film of approximately 131 nm, composition transfer during E-beam evaporation may be non-stoichiometric because Ga- and W-containing species can exhibit different evaporation behavior, transport, and incorporation efficiencies. Consequently, the precursor mixing ratio should not be interpreted as the final film composition. In the present work, EDS is therefore used primarily to confirm the incorporation of W into the deposited Ga_2O_3 film rather than to establish its precise bulk stoichiometry. Since an independent quantitative compositional analysis such as XPS was not performed, the exact W concentration in the deposited film remains to be confirmed in future work. The interaction volume of the incident electron beam may partially penetrate into the underlying layers, affecting the calculated elemental concentrations. Second, the evaporation rates and sticking coefficients of Ga_2O_3 and WO_3 species during the E-beam deposition process may differ, resulting in the preferential incorporation of tungsten-containing species in the deposited film. Third, the overlap of characteristic X-ray signals, matrix effects, and differences in elemental sensitivity factors may further affect the accuracy of quantitative EDS analysis. Therefore, while EDS confirms the successful incorporation of W into the Ga_2O_3 film, the absolute elemental ratios obtained from EDS should be regarded as approximate values rather than precise stoichiometric compositions. The SEM and EDS results demonstrate that dense and uniform WO_3 -doped Ga_2O_3 films were successfully fabricated by E-beam evaporation. The smooth surface morphology, uniform thickness, and confirmed tungsten incorporation provide a solid foundation for the subsequent investigation of the optical and photodetection properties of the fabricated devices.

The crystallographic properties of the deposited WO_3 -doped Ga_2O_3 films were investigated by XRD, and the corresponding diffraction patterns are presented in Fig. 3(a). It can be observed that no obvious diffraction peaks associated with crystalline WO_3 or Ga_2O_3 phases are detected throughout the scanned diffraction range. Instead, only a broad diffraction background is

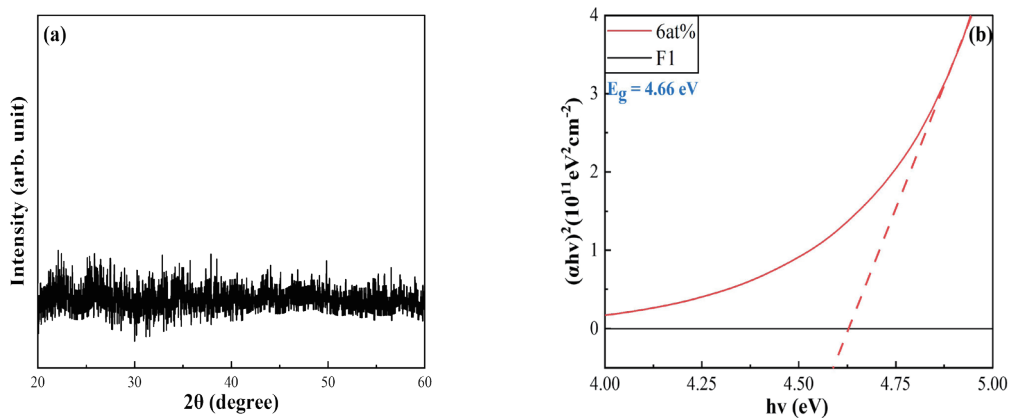


Fig. 3. (Color online) (a) XRD pattern and (b) Tauc plot of $(\alpha h\nu)^2$ versus $h\nu$ of the WO_3 -doped Ga_2O_3 film.

observed, indicating that the deposited films exhibit an amorphous structure. The amorphous nature of the films can be attributed to the room-temperature E-beam evaporation process, which provides insufficient thermal energy for atoms to rearrange into a long-range ordered crystalline structure during film growth. Similar amorphous characteristics have also been reported in oxide semiconductor thin films deposited at relatively low substrate temperatures. Although the absence of crystallinity may reduce carrier mobility compared with highly crystalline films, amorphous oxide semiconductors often exhibit advantages such as smoother surfaces, higher thickness uniformity, lower processing temperatures, and compatibility with large-area device fabrication.

Moreover, the uniform distribution of W dopants within the amorphous Ga_2O_3 matrix may contribute to the formation of localized electronic states, which can affect optical absorption and photocarrier generation behavior. Therefore, despite the lack of long-range crystal ordering, the amorphous WO_3 -doped Ga_2O_3 films may still be suitable for photodetector applications. To further evaluate the suitability of the WO_3 -doped Ga_2O_3 films for DUV and visible-light photodetection, their optical properties were investigated by UV–visible spectroscopy. E_g was determined from the Tauc plot of $(\alpha h\nu)^2$ versus photon energy ($h\nu$), as shown in Fig. 3(b). By extrapolating the linear region of the absorption edge to the photon-energy axis, the optical bandgap of the deposited film was estimated to be approximately 4.66 eV. Note that the WO_3 -doped Ga_2O_3 film exhibits a relatively large bandgap despite its amorphous structure. In general, amorphous materials often contain structural disorder and defect states that may narrow the effective optical bandgap.

However, Ga_2O_3 is an ultrawide-bandgap semiconductor, and the incorporation of WO_3 does not significantly deteriorate its intrinsic wide-bandgap characteristics. The measured E_g value of 4.66 eV remains within the typical range reported for Ga_2O_3 -based materials and is sufficiently high to enable high absorption in the DUV region while maintaining low visible-light absorption. Such a wide bandgap is advantageous for suppressing dark current, improving signal-to-noise

ratio, and enhancing ultraviolet selectivity. Furthermore, the large bandgap energy indicates that the WO_3 -doped Ga_2O_3 films exhibit considerable potential for solar-blind and DUV photodetection applications. At the same time, the introduction of W-related defect levels and impurity states may facilitate sub-bandgap optical transitions, extending the photoresponse toward the near-ultraviolet and visible-light regions. This characteristic is particularly beneficial for realizing broadband photodetectors capable of operating across both DUV and visible-light wavelengths. Therefore, the combination of an amorphous structure and a wide optical bandgap provides a promising foundation for the development of high-performance WO_3 -doped Ga_2O_3 photodetectors.

The wavelength-dependent photoresponsivity of the fabricated WO_3 -doped Ga_2O_3 photodetectors is presented in Fig. 4(a). As shown in the figure, the photoresponsivity gradually decreases with increasing incident wavelength, indicating that the device exhibits a higher sensitivity in the DUV region than in the visible-light region. This behavior is consistent with the wide-bandgap nature of WO_3 -doped Ga_2O_3 , which favors the absorption of high-energy photons. Nevertheless, several distinguishable photoresponse peaks can still be observed at wavelengths of 250, 280, 360, and 430 nm. These characteristic wavelengths are likely associated with the intrinsic absorption of the WO_3 -doped Ga_2O_3 films as well as W-induced defect or impurity states, which may introduce additional optical transitions and broaden the spectral response toward longer wavelengths. Note that an undoped Ga_2O_3 reference film fabricated under identical conditions was not included in the present experimental batch, because the primary focus was to evaluate the broadband photoresponse characteristics of the WO_3 -doped Ga_2O_3 photodetector. Therefore, although the measurable responses at 360 and 430 nm suggest that W-related defect or impurity states may contribute to sub-bandgap optical transitions, the extended visible-light response cannot be attributed exclusively to WO_3 doping without a direct undoped control. A systematic comparison of undoped and WO_3 -doped Ga_2O_3 films prepared and measured under identical conditions will be conducted in future work to clarify the

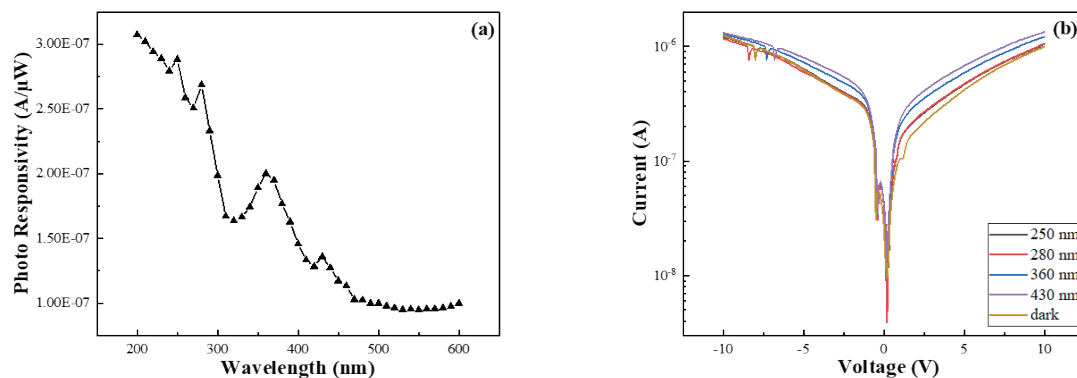


Fig. 4. (Color online) (a) Wavelength-dependent photoresponsivity of the WO_3 -doped Ga_2O_3 photodetector measured at a bias voltage of 5 V and (b) I - V characteristics measured under dark conditions and illumination at 250, 280, 360, and 430 nm.

contribution of WO_3 incorporation. Therefore, these four representative wavelengths were selected for the subsequent photoresponse measurements and device performance evaluation.

Figure 4(b) shows the current–voltage (I – V) characteristics measured under dark conditions and illumination at wavelengths of 250, 280, 360, and 430 nm. As the applied bias voltage increases, both the dark current and photocurrent increase gradually, exhibiting typical semiconductor conduction behavior. The photocurrent measured under illumination is consistently higher than the corresponding dark current throughout the investigated bias-voltage range, confirming that the WO_3 -doped Ga_2O_3 films are photoresponsive over both the DUV and visible-light regions. Although the difference between the dark current and the photocurrent is relatively small, a distinguishable increase in current can still be observed under illumination, indicating that photogenerated carriers are successfully generated and collected within the device. To quantitatively evaluate the photocurrent modulation, the ON/OFF current ratio was calculated as $I_{\text{light}}/I_{\text{dark}}$ at a bias voltage of 5 V. The obtained ratios were approximately 1.117, 1.131, 1.413, and 1.628 under illumination at 250, 280, 360, and 430 nm, respectively. These values confirm measurable but relatively modest photocurrent modulation under optical illumination. Note that the ON/OFF current ratio and specific detectivity (D) characterize different aspects of detector performance. The former represents the relative change in current upon illumination, whereas D is a noise-normalized figure of merit describing the capability of the photodetector to detect weak optical signals. Therefore, the modest ON/OFF current ratios do not necessarily preclude relatively high D^* values.

The relatively limited photocurrent enhancement may be attributed to the amorphous nature of the deposited films, where localized defect states and carrier trapping centers can increase carrier recombination and reduce carrier collection efficiency. In addition, the relatively thin active layer may also limit optical absorption, thereby restricting the generation of photocurrent. Overall, these results demonstrate that the fabricated WO_3 -doped Ga_2O_3 photodetectors exhibit broadband photoresponse characteristics extending from the DUV to the visible-light region. Although the photocurrent enhancement is modest under steady-state illumination, the measurable photoresponse confirms the photoactive nature of the deposited films and validates the feasibility of employing WO_3 -doped Ga_2O_3 as the active layer for broadband photodetection. A more detailed evaluation of the transient photoresponse, including repeated light ON/OFF switching characteristics and detectivity analysis, is presented in the following sections to further assess the performance and stability of the proposed photodetectors.

The cyclic photoresponse characteristics of the WO_3 -doped Ga_2O_3 photodetectors are presented in Fig. 5. On the basis of the photoresponsivity spectra shown in Fig. 4(a), four representative wavelengths (250, 280, 360, and 430 nm) were selected because relatively distinguishable photoresponse peaks were observed at these wavelengths. Therefore, the transient photoresponse under repeated illumination at these four wavelengths was investigated to evaluate the operational stability and repeatability of the fabricated photodetectors. Several important observations can be made from Fig. 5. First, all WO_3 -doped Ga_2O_3 photodetectors exhibit excellent repeatability during five consecutive light ON/OFF cycles. For the WO_3 -doped Ga_2O_3 films, both the maximum photocurrent under illumination and the minimum dark current remain nearly unchanged throughout the repeated cycles at all four wavelengths. This result

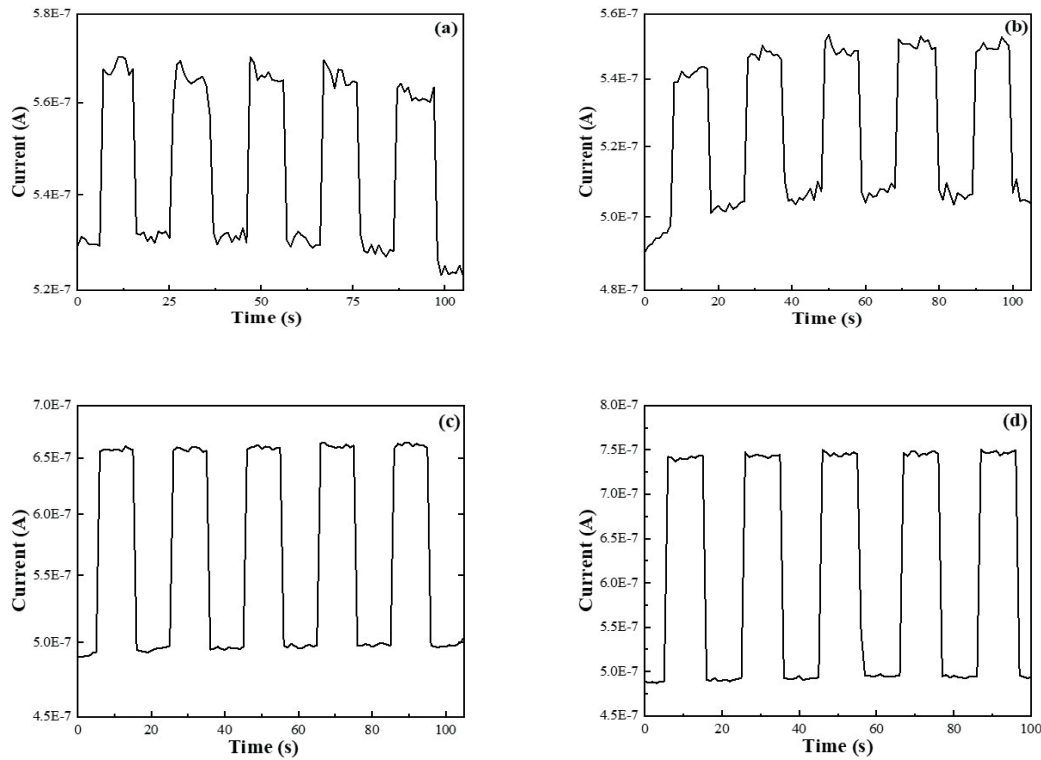


Fig. 5. Cyclic ON/OFF photoresponse measurements of the WO_3 -doped Ga_2O_3 photodetector at a bias voltage of 5 V under different illumination wavelengths: (a) 250, (b) 280, (c) 360, and (d) 430 nm.

indicates that the fabricated devices exhibit good operational stability, reliable switching behavior, and excellent reproducibility under repeated optical excitation.

Second, the photocurrent generally exhibits a slight increase as the illumination wavelength increases from 250 to 430 nm. This behavior may be associated with W-related defect or impurity states, which could contribute to the extended photoresponse toward the visible-light region. However, the confirmation of this mechanism requires a direct comparison with an undoped Ga_2O_3 reference prepared under identical conditions. More importantly, the transient photoresponse becomes progressively more stable with increasing illumination wavelength. Compared with the photoresponses at shorter wavelengths, the photocurrent measured at 360 and 430 nm shows smoother switching characteristics and a more stable current plateau during illumination. This suggests that carrier generation and transport become more stable under longer-wavelength illumination, resulting in improved photoresponse stability. Overall, the excellent repeatability, stable ON/OFF switching characteristics, and broadband photoresponse demonstrate that the proposed WO_3 -doped Ga_2O_3 photodetectors fabricated by a simple E-beam evaporation process have good potential for DUV and visible-light photodetection. The response speed and detectivity of the devices are further discussed in the following section.

The photoresponse time is an important parameter for evaluating the dynamic performance of photodetectors under optical illumination. In this study, the response time is characterized by

the rise time (τ_r) and fall time (τ_f). The rise time is defined as the time required for the photocurrent to increase from 10 to 90% of its maximum after light illumination, whereas the fall time is defined as the time required for the photocurrent to decrease from 90 to 10% of its maximum after the light source is turned off. Fast response characteristics are essential for many practical applications, including optical communication, environmental monitoring, and real-time sensing. In IDT-structured photodetectors, the response speed is mainly affected by carrier generation, carrier transport, recombination processes, and defect-related carrier trapping within the active layer. The measured rise and fall times of the WO_3 -doped Ga_2O_3 photodetectors under different illumination wavelengths are summarized in Fig. 6. As the illumination wavelength increases from 250 to 280 nm, the rise time decreases significantly from 1.62 to 0.81 s, while the fall time decreases from 1.62 to 0.87 s. This result indicates that the photogenerated carriers can be generated and transported more efficiently under 280 nm illumination, leading to a faster photoresponse. One possible explanation is that the carrier trapping effect is reduced at this wavelength, allowing photogenerated electrons and holes to be collected more rapidly.

Interestingly, when the illumination wavelength exceeds 280 nm, both the rise and fall times remain nearly unchanged. This suggests that the carrier transport and recombination processes reach a relatively stable state over the wavelength range of 280–430 nm. In addition, the nearly

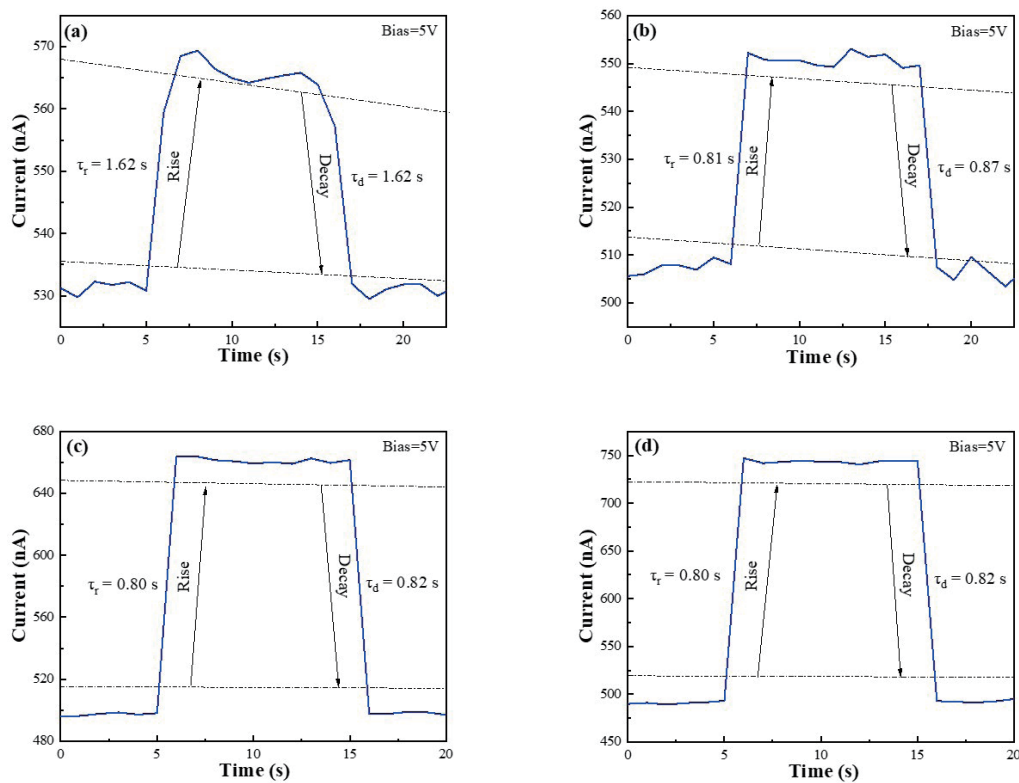


Fig. 6. (Color online) Response-time measurements of the WO_3 -doped Ga_2O_3 photodetector at a bias voltage of 5 V under different illumination wavelengths: (a) 250, (b) 280, (c) 360, and (d) 430 nm.

identical rise and fall times indicate that the trapping and detrapping processes become less wavelength-dependent within this spectral region. These results are consistent with the stable transient photoresponse observed in Fig. 5, where the photocurrent exhibits repeatable ON/OFF switching characteristics under repeated illumination cycles. The WO₃-doped Ga₂O₃ photodetectors exhibit relatively stable response times over a broad spectral range from 280 to 430 nm. The combination of stable response speed, excellent switching repeatability, and broadband photoresponse demonstrates that the proposed WO₃-doped Ga₂O₃ films fabricated by a simple E-beam evaporation process are promising candidates for DUV and visible-light photodetector applications.

This work demonstrates that a simple IDT-structured photodetector based on WO₃-doped Ga₂O₃ films fabricated by E-beam evaporation can achieve broadband photodetection with good responsivity, stable operation, and fast photoresponse. The fabricated devices exhibited high specific detectivity (D^*), a widely used figure of merit that reflects the capability of a photodetector to detect weak optical signals while suppressing noise. Note that D is a noise-normalized performance metric and should not be directly interpreted as the magnitude of photocurrent modulation. Therefore, the relatively high D values can coexist with the modest ON/OFF current ratios observed in Fig. 4(b). The maximum D^* values reached 1.68×10^{11} , 1.56×10^{11} , 1.16×10^{11} , and 7.90×10^{10} Jones under illumination at representative wavelengths of 250, 280, 360, and 430 nm, respectively. These high detectivity values indicate that the proposed WO₃-doped Ga₂O₃ photodetectors exhibit excellent sensitivity over both the DUV and visible-light regions. Combined with their stable ON/OFF switching behavior, relatively fast response, and straightforward fabrication process, the proposed devices show considerable potential for broadband optoelectronic sensing and next-generation ultraviolet–visible photodetector applications.

The photoresponse characteristics obtained in this work can also be compared with those of representative Ga₂O₃-based DUV photodetectors reported recently. Zhang *et al.* developed an ϵ -Ga₂O₃ metal–semiconductor–metal photodetector with a responsivity exceeding 1300 A/W, a D above 10^{16} Jones, and a decay time of 0.123 s, demonstrating the high DUV detection capability of optimized Ga₂O₃ structures.⁽¹³⁾ Chen *et al.* reported a self-powered β -Ga₂O₃/GaN photodetector with a responsivity of 1.88 A/W, D of 2.7×10^{13} Jones, and rise/fall times of 0.15/0.14 s under 222 nm illumination.⁽¹⁴⁾ Yu *et al.* obtained D of 3.8×10^{13} Jones for a homoepitaxial Ga₂O₃ Schottky photodetector at zero bias, with its peak response located near 248 nm.⁽¹⁵⁾ More recently, a suspended Ga₂O₃ photodetector reported by Li *et al.* has achieved D of 6.01×10^{17} Jones and a rise time of 0.18 s under 250 nm illumination.⁽¹⁶⁾ Although these devices exhibit higher DUV performance for specific operating conditions, they are primarily designed for solar-blind or DUV detection. In comparison, the present WO₃-doped Ga₂O₃ device exhibits measurable photoresponse at 250, 280, 360, and 430 nm, with D values ranging from 7.90×10^{10} to 1.68×10^{11} Jones. Therefore, its notable characteristic is not the highest individual DUV performance metric, but the extension of the photoresponse from the DUV toward the visible-light region together with stable ON/OFF switching and a simple E-beam evaporation process.

4. Conclusions

In this study, broadband DUV and visible-light photodetectors were successfully fabricated using WO₃-doped Ga₂O₃ films deposited by a simple E-beam evaporation process. SEM observations confirmed that the deposited films exhibited a dense, smooth, and uniform surface morphology with a thickness of approximately 131 nm. XRD measurements revealed that the films exhibited an amorphous structure, and UV–visible spectroscopy showed a wide optical bandgap of 4.66 eV, indicating their suitability for DUV photodetection. The fabricated devices exhibited broadband photoresponse characteristics with distinguishable response peaks at 250, 280, 360, and 430 nm. Current–voltage measurements confirmed measurable photocurrent under optical illumination, while repeated ON/OFF switching tests demonstrated good short-term switching repeatability and reproducibility. The response-time analysis further showed that both the rise and fall times decreased significantly from 250 to 280 nm and remained nearly unchanged from 280 to 430 nm, indicating stable carrier transport and recombination processes over a broad spectral range. The maximum D reached 1.68×10^{11} , 1.56×10^{11} , 1.16×10^{11} , and 7.90×10^{10} Jones under illumination at 250, 280, 360, and 430 nm, respectively. These D values indicate favorable noise-normalized weak-signal detection capability across the investigated spectral range, although the absolute photocurrent modulation and ON/OFF current ratios remain relatively modest. Thus, the sensitivity discussed here specifically refers to the specific detectivity rather than to the magnitude of the absolute photocurrent change. The combination of a simple fabrication process, broadband photoresponse, stable switching behavior, and reliable photoresponse characteristics demonstrates that WO₃-doped Ga₂O₃ thin films are promising active materials for next-generation DUV and visible-light photodetectors. The present study is limited by the absence of an undoped Ga₂O₃ control fabricated under identical conditions and by the relatively modest photocurrent modulation, which restrict the definitive evaluation of the contribution of WO₃ incorporation. Future work will focus on optimizing the WO₃ doping concentration, improving film crystallinity, and enhancing device responsivity and detectivity to further expand the potential of this material system for practical optoelectronic sensing applications.

Acknowledgments

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