

Device structure-dependent field-effect and photoresponse performances of p-type ZnTe:Sb nanoribbons

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Sb-doped ZnTe nanoribbons (NRs) with enhanced p-type conductivity were successfully synthesized by a simple thermal co-evaporation method. Nanodevices, including nano-field-effect transistors (FETs) and nano-photodetectors (nanoPDs), were constructed based on the ZnTe:Sb NRs and their structure dependent device performances were systemically investigated. It is found that the transport properties of the ZnTe nanostructures as well as the device structures play a critical role in determining the device performances. In contrast to the nano-metal-oxide-semiconductor FETs (nanoMOSFETs) with back-gate structure, the top-gate nano-metal-insulator-semiconductor FETs (nanoMISFETs) show much enhanced performances in all aspects. On the other hand, owing to the appropriate p-type doping, nano-photodetectors (nanoPDs) based on the ZnTe:Sb NRs exhibit excellent device performances, such as high responsivity and photoconductive gain, fast response speed, large detectivity and so on. Moreover, the response time could be effectively shortened by using nano-heterojunction photodetectors (nanoHPDs). It is expected that knowledge gained from this work could be readily extended to nanodevices based on other nanostructures.

I. Introduction

In the past decades, tremendous efforts have been devoted to exploiting the potential applications of semiconductor nanostructures in new-generation nanoelectronic and nano-optoelectronic devices. Among the various nanodevices, nano-field-effect transistors (nanoFETs) and nano-photodetectors (nanoPDs) have attracted special attention since they are the basic elements of modern optoelectronics. Although nanoFETs and nanoPDs have been constructed from a variety of nanostructures, such as ZnO, GaN, In₂O₃, and CdS nanowires (NWs)/nanoribbons (NRs),^{1–6} it remains a major challenge to realize devices with robust stability and performances for practical applications. Recent progress demonstrates that both device structure and transport properties of the nanostructures play an important role in determining the device performances. For instance, performances of the nanoFETs could be substantially improved by enhancing the gate/channel coupling with a high- κ gate dielectric or by using top-gate and surrounding-gate structures.^{7–10} Schottky junction photodetectors (SPDs) and

heterojunction photodetectors (HPDs) exhibit much improved performances in terms of high sensitivity and fast response speed as compared with conventional Ohmic photodetectors (OPDs).^{11,12} High gain nanoPDs were also realized by tuning the electrical transport properties of ZnS and CdS NRs with appropriate doping.^{13–15}

As an important II–VI group semiconductor, zinc telluride (ZnTe) is a promising optoelectronic material for a host of optoelectronic applications because of its wide direct band gap (2.26 eV) and p-type doping capability.^{16–18} To date, ZnTe NWs/NRs have been synthesized *via* various methods, such as electrochemical deposition,¹⁹ molecular beam epitaxy,²⁰ and vapor phase transport.¹⁷ In spite of this progress, high-performance nanoFETs and nanoPDs based on ZnTe nanostructures are rarely studied and reported.^{21,22} Another concern is that the optoelectronic properties of the intrinsic ZnTe nanostructures are rather poor; thus, ZnTe nanostructures with tunable transport properties are highly desirable for their future device applications. So far, Cu and N doping have been utilized to enhance the p-type conductivity of the ZnTe nanostructures.^{23,24} However, Cu doping was conducted in a solution and needed a post-annealing process to allow the diffusion of the Cu ions into the ZnTe NWs.^{24,25} Also, the use of toxic ammonia (NH₃) gas for the N doping will inevitably increase the complexity of the synthesis process and has thus limited its application. Therefore, a more efficient doping method is much demanded to promote the applications of ZnTe nanostructures in further study.

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Herein, we report on the synthesis of ZnTe NRs with enhanced p-type conductivity *via* a simple co-thermal evaporation method by using an antimony (Sb) solid source as the dopant. Sb was selected in this work since it has been demonstrated to be a very efficient p-type dopant with a shallow acceptor level in ZnTe films.²⁶ High performance nanoFETs and nanoPDs were constructed based on the ZnTe:Sb NRs and their device structure-dependent performances were systemically investigated. Our results demonstrated that the ZnTe NRs with enhanced p-type conductivity may have important applications in nanoelectronics and nano-optoelectronics.

II. Experimental

Synthesis of the p-type ZnTe NRs was conducted in a horizontal tube furnace *via* a simple thermal co-evaporation method. Sb (purity 99.999%) and ZnTe powders (purity 99.99%) with a mass ratio of 1 : 8 were loaded onto two separated alumina boats and transferred to the upstream and center regions of the furnace, respectively. The distance between the two boats was 8 cm. Si substrates coated with 10 nm gold catalyst were then placed at the downstream position ~ 10 cm away from the ZnTe source. Before heating, the system was evacuated to a base pressure of 10^{-3} Torr, and back filled with an Ar and H₂ (5%) gas mixture with a constant flow rate of 100 sccm to a stable pressure of 150 Torr. Afterwards, the ZnTe source was heated up to 1050 °C and maintained at that temperature for 1 h. The temperature of the Sb source and the Si substrates were ~ 800 °C and ~ 700 °C, respectively, during the experiment. Morphologies and structures of the as-synthesized ZnTe:Sb NRs were characterized by X-ray diffraction (XRD, D/max- γ B), field-emission scanning electron microscopy (FESEM, SIRION 200 FEG), and high-resolution transmission electron microscopy (HRTEM, JEOL JEM-2010, at 200 kV). Compositions of the ZnTe:Sb NRs were analyzed by X-ray photoelectron spectroscopy (XPS, Thermo ESCALAB 250).

To assess the electrical transport properties of the ZnTe:Sb NRs, back-gate nano-metal-oxide-semiconductor FETs (nanoMOSFETs) were constructed based on individual ZnTe NRs (inset in Fig. 2a). First, the ZnTe:Sb NRs were parallel dispersed on SiO₂ (300 nm)/p⁺-Si substrate by the contact printing technique,²⁷ and then photolithography, followed by a lift-off process were used to define Au (100 nm) source/drain electrodes on the NRs. The heavily doped Si substrate served as the back-gate in the nanoMOSFETs. To study the impact of the device structure on device performance, top-gate nano-metal-insulator-semiconductor FETs (nanoMISFETs) were also fabricated (Fig. 2c and d). On the basis of the nanoMOSFETs, Si₃N₄ (100 nm), a high- κ gate dielectric layer was deposited on the ZnTe:Sb NRs by magnetron sputtering, and then an Au (20 nm) gate electrode was defined by additional photolithography and lift-off processes. ZnTe:Sb NR based nanoOPDs were fabricated according to the same process described for the nanoMOSFETs due to their similar structures. As for the nanoHPDs shown in Fig. 5a, photolithography and subsequently wet etching of SiO₂ (300 nm)/n⁺-Si substrates were first performed to define SiO₂ insulating pads (size 200 μ m \times 200 μ m) on the n⁺-Si substrate. Then, the ZnTe:Sb NRs were dispersed on the substrate uniformly, and p-n heterojunctions were formed at the contact

regions of the p-ZnTe NRs with the n⁺-Si substrate. After that, Au (100 nm) electrodes were fabricated on the ZnTe NRs by photolithography and lift-off processes. Electrical measurements on the nanoFETs and nanoPDs were conducted at room temperature by using a semiconductor characterization system (Keithley 4200-SCS). The photoresponse characteristics of the nanoPDs were detected by using a system that combines a monochromatic light source, an oscilloscope (Tektronix, TDS2012B), and an optical chopper (SRS, SR540), as shown in Fig. 4a.⁴

III. Results and discussion

Fig. 1a shows a typical FESEM image of the as-synthesized ZnTe:Sb NRs. It is seen that the NRs are clear and smooth with a uniform geometry and widths in the range of 0.5–2 μ m, thicknesses of 50–200 nm and lengths of several tens of micrometers. The HRTEM image and the corresponding selected-area electron diffraction (SAED) pattern also reveal that the NRs have a single-crystal zinc blende structure with a growth orientation of [11-1] (Fig. 1b). In the XRD patterns (Fig. 1c), all the diffraction peaks can be assigned to zinc blende ZnTe (JCPDS No. 15-0746) and no impurity phases are detected, suggesting a high phase purity of the product. In addition, two peaks at 537 eV and 528 eV corresponding to Sb 3d_{3/2} and Sb 3d_{5/2} core level emissions, respectively, are present in the XPS spectrum (Fig. 1d), implying that Sb might be successfully doped into the ZnTe NRs.

Fig. 2a depicts the typical *I*-*V* curves of an individual ZnTe:Sb NR measured before and after annealing at 500 °C for 5 min in Ar atmosphere, respectively. The linear curves indicate the good Ohmic contact between the Au electrodes and the ZnTe:Sb NR. Notably, the NR's conductivity is dramatically improved from 1.9×10^{-3} S cm⁻¹ to 6.7×10^{-2} S cm⁻¹ after annealing. This result is consistent with our previous investigation on Bi-doped p-type ZnSe NWs and could be attributed to the activation of Sb

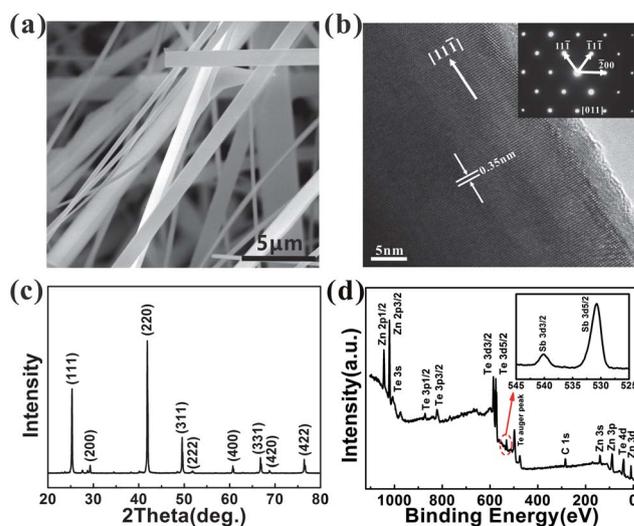


Fig. 1 (a) FESEM image, (b) HRTEM image, (c) XRD pattern, and (d) XPS spectrum of the as-synthesized ZnTe:Sb NRs. Insets in (b) and (d) show the corresponding SAED pattern and the enlarged Sb peaks, respectively.

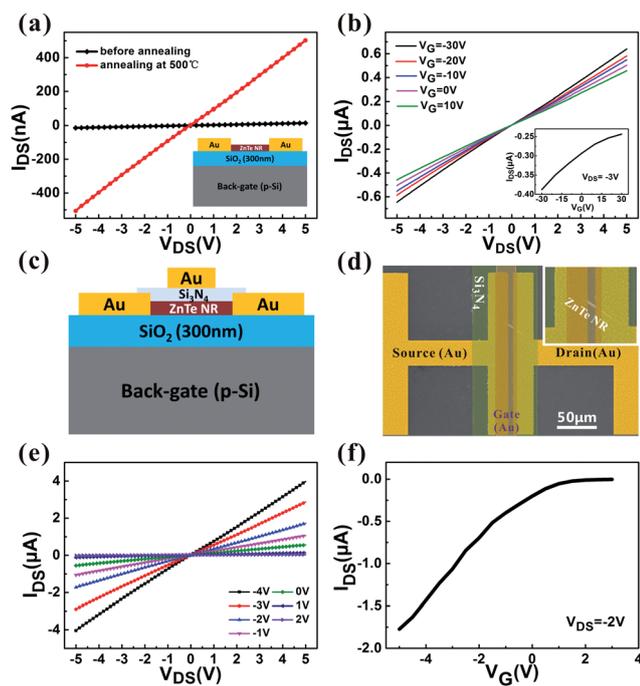


Fig. 2 (a) I - V curves of the ZnTe:Sb NR before and after annealing. Inset shows the schematic illustration of the nanoMOSFET based on a single ZnTe:Sb NR. (b) Electrical transport characteristics of the nanoMOSFET. (c) Schematic illustration and (d) SEM image of the nanoMISFET based on a single ZnTe:Sb NR. Inset shows the enlarged SEM image. (e) I_{DS} - V_{DS} curves of the nanoMISFET measured by varying V_G from -4 to $+2$ V in steps of $+1$ V. (f) I_{DS} - V_G curve at $V_{DS} = -2$ V.

acceptors in the NRs after annealing.²⁸ By applying a gate voltage (V_G) on the p⁺-Si back gate of the nanoMOSFET, the gate-dependent source-drain current (I_{DS}) versus source-drain voltage (V_{DS}) curves are detected. From Fig. 2b, it is shown that the conductance of the ZnTe:Sb NR decreases (increases) consistently with the increasing (decreasing) of the gate voltage, revealing the p-type nature of the ZnTe:Sb NR. The enhanced p-type conductivity of the ZnTe:Sb NRs is a result of the substitutional doping of Sb³⁺ ions by replacing Te²⁻ ions in the NRs. In this situation, Sb has five outermost electrons which is one less than that of the Te atom. When Sb atoms replace Te atoms in the ZnTe compounds, holes will be generated which enhance the p-type conductivity. Moreover, the field-effect hole mobility (μ_h) of the ZnTe:Sb NR can be estimated to be ~ 0.94 cm² V⁻¹ s⁻¹ based on the following equation:

$$\mu_h = \frac{g_m L}{Z C_0 V_{DS}} \quad (1)$$

where $g_m = 8.1$ nS at $V_{ds} = -3$ V represents the transconductance of the nanoMOSFET and is deduced from the slope of the I_{DS} - V_G curve in the linear part according to the relationship of $g_m = dI_{DS}/dV_G$ (inset in Fig. 2b), $Z/L = 2 \mu\text{m} : 8 \mu\text{m}$ is the width-to-length ratio of the NR channel, C_0 is the capacitance per unit area and is given by $C_0 = \epsilon\epsilon_0/h$, where ϵ is the dielectric constant of SiO₂ (3.9), ϵ_0 is vacuum permittivity, and h (300 nm) is the thickness of the SiO₂ gate dielectric layer. In addition, the threshold voltage (V_{th}) of the device is estimated to be about 29 V

from the I_{DS} - V_G curve and a small I_{on}/I_{off} ratio of ~ 1.6 can be obtained as well. We note that the device cannot be fully depleted even at a large gate voltage in excess of $+30$ V. On the other hand, the subthreshold swing (S), which reflects the switching capability of a FET, is determined to be 2.94×10^2 V dec⁻¹ according to the following equation:⁷

$$S = \ln(10) \frac{dV_G}{d \ln I_{DS}} \quad (2)$$

It is clear that the nanoMOSFET with back-gate structure has exhibited relatively poor device performances, such as a large operation voltage, small I_{on}/I_{off} ratio, large subthreshold swing, and low hole mobility. The weak gate coupling caused by the SiO₂ dielectric and the back-gate device configuration is an important reason for its poor performance.^{7,15}

To further study the influence of the device structure on the performance, a nanoMISFET with top-gate configuration and a high- κ gate dielectric was constructed based on the ZnTe:Sb NR. Fig. 2c and d display the schematic illustration as well as the FESEM image of the nanoMISFET. From the typical electrical transfer characteristics (Fig. 2e and f), it is found that the device exhibits a substantial improvement in performance by adopting the new device structure. In contrast to the nanoMOSFET, the I_{on}/I_{off} ratio, g_m , and μ_h have significantly increased to $\sim 7 \times 10^2$, 372 nS at $V_{DS} = -2$ V, 11.2 cm² V⁻¹ s⁻¹, respectively, while V_{th} and S have reduced to $+1$ V and ~ 1.5 V dec⁻¹, respectively. We note that a small gate voltage range of ± 4 V is already enough to switch the device between accumulation state and full depletion state. Therefore, the above results undoubtedly demonstrate that the device structure plays an important role in determining the device performance of the nanoFETs. Table 1 summarizes the key device parameters of the nanoFETs, along with the previous work for comparison. It is clear that the ZnTe:Sb NR with a nanoMISFET structure has exhibited the best performance obtained so far. It is suggested that the high- κ dielectric can afford high channel capacitance without relying on ultrathin dielectrics, thus leading to the large ON current, high I_{on}/I_{off} ratio, low operation voltage, and small subthreshold swing. On the other hand, with the top-gate configuration, the conduction channel is fully encapsulated by the dielectric; as a result, the gate coverage to the channel is higher, allowing enhanced charge coupling between the gate and the channel, which also contributes to the performance improvement.^{7,8}

As we know, ZnTe is a promising material for green/UV light detection due to its primary band gap of 2.26 eV with superior sensitivity to Si and GaAs.^{21,22,29} Fig. 3a depicts the wavelength-dependent I - V curves of the ZnTe:Sb NR based nanoOPD obtained when the device was exposed to monochromatic light at a constant intensity of 1.1 mW cm⁻². The less linear of the I - V curves in Fig. 3 is due to the non-Ohmic contact, when the Au electrodes were connected to Ag wires *via* Ag paste for optoelectronic measurement. Notably, the nanoPD shows a pronounced photoresponse to the short wavelength light. The photoconductance is estimated to be 0.7 and 1.05 μS at 500 and 550 nm, respectively, while it is only 0.16 μS at 600 nm. From the spectral response (Fig. 3b), it is seen that sensitivity is highest around 550 nm and shows a steep decline in the long wavelength

Table 1 Summary of the performances of the ZnTe:Sb nanoFETs. Values from previous reports are also presented for comparison

	g_m/nS	$\mu_n/cm^2 V^{-1}s^{-1}$	$S/mV dec^{-1}$	V_{th}/V	I_{on}/I_{off}
MOSFET	8.1	0.94	2.94×10^5	~ 29	~ 1.59
MISFET	372	11.2	1.58×10^3	~ 1	$\sim 7 \times 10^2$
ZnTe ²³	0.4	0.0062	n.a.	~ 1	~ 8
ZnTe:N NR ²³	78.4	1.2	n.a.	4	~ 2.4
ZnTe:Cu NW ²⁴	1.7	1	n.a.	-13	~ 5

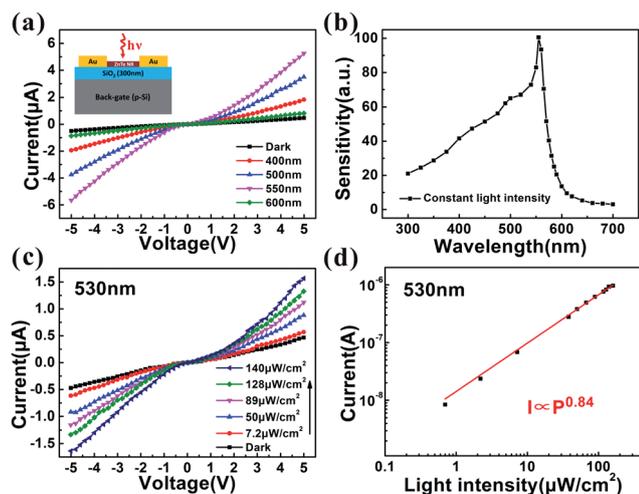


Fig. 3 (a) I - V curves of an individual ZnTe:Sb NR exposed to light of varied wavelength at a constant intensity of 1.1 mW cm^{-2} . Inset shows the configuration for the photocurrent measurement. (b) Spectral response of the ZnTe:Sb NR. (c) I - V curves of the ZnTe:Sb NR at varied light intensity (530 nm). (d) Logarithmic plot of the photocurrent light intensity. The curve is fitted well by the power law.

direction. The cut-off wavelength of 560 nm is consistent with the ZnTe bandgap, indicating that the electron-hole pairs excited by light with an energy larger than the band-gap of ZnTe should account for the photocurrent.

Light intensity is another factor that determines the photocurrent in the ZnTe:Sb NR.^{21,22} Fig. 3c plots the I - V curves of the nanoOPD irradiated by green light (530 nm) with varied light intensity. It is noted that the conductance of the ZnTe:Sb NR increases from 93 nS in dark to 314 nS at $140 \mu\text{W cm}^{-2}$. The dependence of photocurrent on the light intensity can be expressed by the power law:

$$I = AP^\theta \quad (3)$$

where A is a constant for a certain wavelength, and the exponent θ ($0.5 < \theta < 1$) determines the response of the photocurrent to light intensity. By fitting the curve in Fig. 3d with this equation, $\theta = 0.84$ is obtained. This fractional power dependence is likely to be related to the carrier traps in the NRs.²¹ In addition, responsivity (R) and photoconductivity gain (G) are key parameters for a PD and reflect the sensitivity of a PD to the incident light, which has the following relation:¹³

$$R(A/W) = \frac{I_p}{P_{opt}} = \eta \left(\frac{q\lambda}{hc} \right) G \quad (4)$$

where I_p is the photocurrent, P_{opt} is the incident light power, η is the quantum efficiency, h is Planck's constant, λ is the light wavelength, and c is the light speed. Based on this equation, R and G are estimated to be $4.8 \times 10^4 \text{ A W}^{-1}$ and 1.2×10^5 , respectively, at +5 V for the ZnTe:Sb NR based nanoOPD. It is noted that these values are much higher than previous investigations,^{19,20} indicating the high performance of our devices. The main reasons for the high sensitivity of the ZnTe:Sb nanoPDs could be ascribed to (i) the high quality of the NRs and consequently the large photocurrent; (ii) surface energy bending caused by the surface states on the NR, resulting in the separation of the electrons and holes. Therefore the carrier lifetime is prolonged due to the reduced electron-hole recombination;³⁰ (iii) Sb acceptors in the NR may also serve as the trapping centers for the minority carriers, leading to a further prolongation of the lifetime.¹⁴

The response speed of a PD reflects its ability to follow a fast-varying optical signal. To record an optical signal faithfully, a PD must have a speed higher than the fastest temporal variations in the signal, or equivalently, a frequency response that has a bandwidth covering the entire bandwidth of the signal.^{11,12,31,32} In this work, the photoresponse characteristics of the ZnTe:Sb NR based nanoOPDs were further evaluated by modulating the incident light with a mechanical chopper (Fig. 4a), and an oscilloscope was used to monitor the variation of the photocurrent with time. Fig. 4b and c show the reversible switching of the nanoOPD between low and high conduction states when the light was turned on and off regularly (data are normalized according to the highest photocurrent). Significantly, the nanoOPD could operate with excellent stability and reproducibility in a wide frequency range from 1 to 400 Hz under light illumination of 5.3 mW cm^{-2} . Moreover, as shown in Fig. 4d, the relative balance $[(I_{max} - I_{min})/I_{max}]$ of the photocurrent only decreases by 25% at a high frequency of 400 Hz, implying that the ZnTe:Sb nanoOPDs can operate at much higher frequencies, in fact. In the time domain, the speed of a PD is often characterized by the rise time (τ_r) and the fall time (τ_f) of its response to an impulse signal or to a pulse signal. The τ_r is defined as the time interval for the response to rise from 10 to 90% of its peak value, whereas the τ_f is defined as the time interval for the response to decay from 90 to 10% of its peak value. Further analysis to the nanoOPD reveals a small τ_r of 5 ms, as well as a small τ_f of 12 ms (Fig. 4e), which are much shorter than those reported for ZnTe NWs.²¹ The 3 dB bandwidth (f_{3dB}) of a PD is defined as:

$$f_{3dB} = \frac{0.35}{\tau_r} = 0.886B \quad (5)$$

where B is the bandwidth. Therefore, f_{3dB} and B are estimated to be 70 Hz and 79 Hz, respectively, for the ZnTe:Sb nanoPD. On

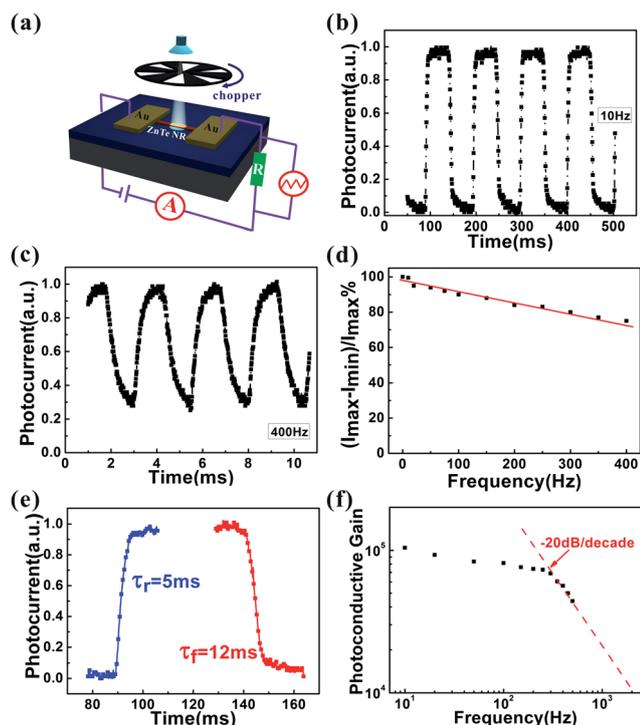


Fig. 4 (a) Schematic illustration of the measurement configuration for photoresponse detection. Photoresponse characteristics of the ZnTe:Sb NR based nanoPD to pulsed light irradiation at frequencies of (b) 50 Hz and (c) 400 Hz. (d) The relative balance $[(I_{\max} - I_{\min})/I_{\max}]$ versus switching frequency. (e) Rising and falling edges for estimating τ_r and τ_f . (f) Frequency dependence of the photoconductive gain.

the other hand, the dynamic gain as a function of frequency in the range from 10 to 500 Hz is depicted in Fig. 4f. It is shown that the gain values are consistently high even at high frequency. The gain is 4.4×10^4 at 500 Hz, leading to a large gain-bandwidth (GB) of 2.2 MHz.

The detectivity (D) characterizes the ability of a PD to detect a weak optical signal, and noise equivalent power (NEP) is a measure of the sensitivity of a PD and is defined as the signal power that gives a signal-to-noise ratio (SNR) of one, in a one Hertz output bandwidth. Specific detectivity (D^*) for a photo-detector is a figure of merit used to characterize performance, equal to the reciprocal of NEP, normalized per unit area and bandwidth. They are all important performance parameters for a PD. A smaller NEP is desirable for a detector with high sensitivity and is defined by the following equation:³²

$$\text{NEP} = \frac{\left(2eI_b + 2eI_d + \frac{4K_B T}{R_1}\right)^{\frac{1}{2}}}{R} B^{\frac{1}{2}} \quad (6)$$

D and D^* are expressed as follows:³²

$$D = \frac{1}{\text{NEP}} \quad (7)$$

$$D^* = \frac{(AB)^{\frac{1}{2}}}{\text{NEP}} \approx \frac{A^{\frac{1}{2}} R}{(2eI_d)^{\frac{1}{2}}} \quad (8)$$

Where, A is the PD area, and I_d is the dark current. Based on the equations, $D = 1.4 \times 10^{16} \text{ W}^{-1}$, $D^* = 4.8 \times 10^{13} \text{ cm Hz}^{1/2} \text{ W}^{-1}$, and $\text{NEP} = 7.5 \times 10^{-17} \text{ W}$ are obtained. These values for the ZnTe:Sb based nanoOPDs have increased by 4 orders of magnitude as compared with previous reports.^{33,34,38}

In OPDs, the response speed is usually limited by the transit time of carriers between electrodes, which means device dimension, carrier mobility, and the defects are all important factors in determining the response speed. Although the ZnTe:Sb NR based nanoOPDs have exhibited fast response speed (ms) due to the high quality of the NRs, this speed is still much lower than the commercial PDs with high speeds ranging from μs to ns or even higher. The underlying reason is that p-n or p-i-n device structures are often adopted in commercial PDs. The strong built-in electric field in the junction guarantees the high speed of the device. To examine this point, nanoHPDs based on ZnTe:Sb NR/Si p-n heterojunctions were fabricated and their device performances were further evaluated (Fig. 5a). Fig. 5b depicts the typical I - V characteristics of a nanoHPD measured in dark, revealing an excellent rectification behavior of the device with a rectification ratio $>10^3$ within $\pm 5 \text{ V}$. The ideality factor (n) for this device could be estimated to be 2.1 from the equation:

$$n = \frac{q}{K_B T} \frac{dV}{d \ln I} \quad (9)$$

Under light illumination ($\lambda = 530 \text{ nm}$ and $P_{\text{opt}} = 5.3 \text{ mW cm}^{-2}$), the device also exhibits a pronounced light response, and R , G , τ_r and τ_f can be estimated to be $1.8 \times 10^3 \text{ A W}^{-1}$, 4.2×10^3 , $790 \mu\text{s}$ and $960 \mu\text{s}$, respectively, from Fig. 5c and d at $V_{\text{bias}} = -2 \text{ V}$. The decrease of R and G is normal for the nanoHPD due to the smaller reverse current of the junction. In the meantime, the response time of the nanoHPD has decreased by nearly one order of magnitude compared to the nanoOPD. The fast response speed of the nanoHPD is a result of the high-quality p-n junction between the ZnTe:Sb NR and the Si substrate. The photo-generated electron-hole pairs could be quickly separated and transferred to the electrodes by the built-in electric field, leading

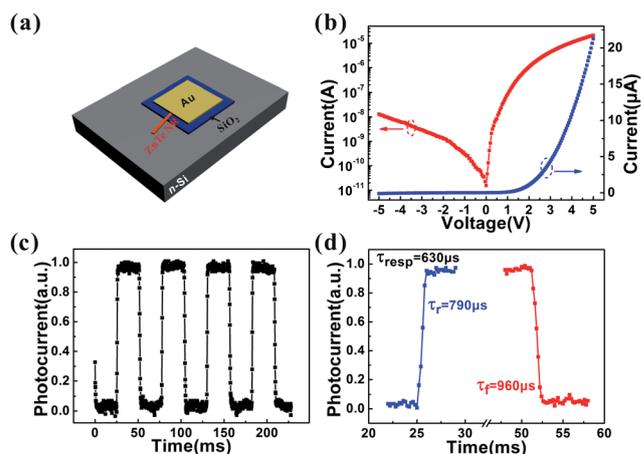


Fig. 5 (a) Schematic illustration of the nanoHPD based on a ZnTe/Si p-n heterojunction. (b) Rectification characteristics of the heterojunction measured in dark. (c) Time response of the nanoHPD measured at $V_{\text{bias}} = -2 \text{ V}$ with a fixed light intensity of 5.3 mW cm^{-2} . (d) Rising and falling edges for calculating τ_r and τ_f .

Table 2 Summary of the performances of the ZnTe:Sb NR nanoPDs. Values from previous reports are also presented for comparison

Materials	Rise time (τ_r)	Fall time (τ_f)	Responsivity (R)	Gain (G)		Detectivity (D)
ZnTe:Sb NR	5 ms	12 ms	4.8×10^4	1.2×10^5	ZnTe NR	1.4×10^{16}
ZnTe:Sb NR/Si	790 μ s	960 μ s	1.8×10^3	4.2×10^3	Polymer ³³	10^{12}
ZnTe NW ²¹	1300 ms	1300 ms	2.2×10^3	1.5×10^4	AlGaIn ³⁴	2.6×10^{12}
CdSe NW ³⁵	20 μ s	30 μ s	10-100	0.05	GaN/ZnO ³⁶	1.71×10^{11}
CdS NR ⁴	746 μ s	794 μ s	10^4	100	Organic ³⁷	3.4×10^{12}

to the high response speed.¹² Table 2 also summarizes the performances of the ZnTe:Sb NR nanoOPDs and nanoHPDs, along with the results for other nanoPDs for comparison, it is worth noting that the devices in this work show robust performances close or superior to the previous results. Our work demonstrates that the device performances of the nanoFETs and nanoPDs highly rely on the device structures as well as the transport properties of the nanostructures. The methods used for constructing high-performance ZnTe NR based nanodevices can hopefully be extended to other nanostructures.

Conclusions

In summary, Sb-doped ZnTe NRs with enhanced p-type conductivity were successfully synthesized by using the solid source Sb as the dopant *via* a simple thermal co-evaporation method. It is found that the improvement in the transport properties of the ZnTe nanostructures, together with the use of advanced device structures, leads to the substantial enhancement of the nanodevice performance. As compared with the back-gate nanoMOSFET, the top-gate nanoMISFETs based on ZnTe:Sb NRs show better performance in all aspects, including a larger I_{on}/I_{off} ratio and transconductance, higher hole mobility, lower operation voltage and smaller subthreshold swing. On the other hand, nanoOPDs based on the ZnTe:Sb NRs exhibit excellent device performances in terms of high responsivity and photoconductive gain, fast response speed, high detectivity, and low noise equivalent power. It is suggested that appropriate p-type doping of the ZnTe NRs by Sb acceptors is an important reason accounting for their high performance. Moreover, by introducing a heterojunction structure in the nanoPDs, the corresponding nanoHPDs show a much enhanced response speed compared to the nanoOPDs.

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