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1D/2D material-based photodetectors driven by ferroelectrics

Feng-Xia Liang, and Lin-Bao Luo*

School of Electronic Science and Applied Physics, Hefei University of Technology, Hefei 230009, China

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One-dimensional (1D) and two-dimensional (2D) materials, such as nanowires, graphene, and transition metal dichalcogenides (TMDs), have received emerging research study in the past ten years [1-3]. They have demonstrated to be idea building blocks for fabricating high-performance photodetector devices owing to their unique electrical and optical properties [4-6]. However, the photoresponsivity, detectivity, and response time of the 1D/2D material-based photodetectors, are far away from the demands of practical application. To achieve the high-performance photodetector, an additional gate bias or a large drain-source bias was usually applied in the device. These factors will to some extent increase the device performance at the sacrifice of reliability. What is more, they will seriously increase the power dissipation as well.

Ferroelectric material has a spontaneous electric polarization, which has been widely used in various nano-electronic devices, such as nonvolatile memories and ferroelectric tunnel junctions [7]. Additionally, the polarization of ferroelectric materials has also been employed to tune the transport property of the semiconducting channel in field effect transistors (FETs) [8,9]. Recently, ferroelectric FETs have been used for improving the performance of 1D/2D material-based photodetectors. For example, the researchers [10-13] from Shanghai Institute of Technical Physics, Chinese Academy of Sciences, have successfully combined several ferroelectric materials with 1D/2D materials to form field effect transistor-based photodetectors. Among these photodetectors, the poly(vinylidene fluoride-trifluoroethylene) (PVDF) was employed as the gate dielectric materials because of its excellent ferroelectricity and light transmission properties. The stable remnant polarization of PVDF after polarization, can provide an ultrahigh local electrostatic field (≈10^9 V/m) onto the semiconducting channel which is much stronger than that produced by additional gate bias in FETs [10-13]. With the positive or negative direction of remnant polarization electrostatic field in PVDF, the 1D/2D materials channel can be maintained in fully depleted or accumulated state. While the 1D/2D materials channel is fully depleted, the photodetector obtains an ultralow dark current which leads to the high photoconductive gain and detectivity. Additionally, the photoresponse wavelengths of the PVDF-driven 2D material-based photodetectors are extended beyond the bandgap width of 2D material, because of the tunable band structure of 2D materials by the ultrahigh local electrostatic field [12]. In the case of MoS_2 photodetector, a high detectivity of 2.2×10^{12} Jones and photoresponsivity up to 2570 A/W at λ = 635 nm have been achieved [12]. During the process of photodetection study, no external gate voltage is required and only a small drain-source bias is needed to read the current of 1D/2D materials channel. In this regard, the power consumption of this device geometry is ultralow because of the polarized electrostatic field in PVDF which can function as an external gate bias.

In addition to photodetectors made of 2D materials, the deposition of ferroelectric materials is beneficial for improving the device performance of 1D semiconductor nanostructures as well [10,11]. For instance, Hu et al. assemble highly sensitive side-gated phototransistors. In such single InP nanowire photodetector, when covered with ferroelectric polymer (VDF-TrFE), the dark current is substantially reduced by the inherent electric field from ferroelectric polarization and as

*Corresponding author (email: luolb@hfut.edu.cn)

a result, the sensitivity is increased even without the gate voltage. The photoconductive gain, responsivity specific detectivity were estimated to be 4.2×10^5, 2.8×10^5 A/W, and 9.1×10^{15} Jones at $\lambda = 830$ nm, respectively, which are much better than that without ferroelectric material.

In summary, the modification of ferroelectric material has proved to be highly efficient to suppress the dark-current by full carrier depletion, as a result of inherent electric field from polarization of the ferroelectric materials. It was found that the as-optimized device based on 1D/2D materials displayed considerable increase in sensitivity, detectivity as well as photo-conductive gain. In addition, these structure-based photodetectors enjoy relatively low power consumption, which makes them highly promising for future applications in optoelectronic device.

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1 J. Mao, K. Ding, and J. S. Jie, Sci. China-Phys. Mech. Astron. **60**, 017031 (2017).
2 B. Nie, L. B. Luo, J. J. Chen, J. G. Hu, C. Y. Wu, L. Wang, Y. Q. Yu, Z. F. Zhu, and J. S. Jie, Nanotechnology **24**, 095603 (2013).
3 W. C. Qiu, and W. D. Hu, Sci. China-Phys. Mech. Astron. **58**, 027001 (2015).
4 J. Miao, W. Hu, Y. Jing, W. Luo, L. Liao, A. Pan, S. Wu, J. Cheng, X. Chen, and W. Lu, Small **11**, 2392 (2015).
5 P. Wang, S. S. Liu, W. J. Luo, H. H. Fang, F. Gong, N. Guo, Z. G. Chen, J. Zou, Y. Huang, X. H. Zhou, J. L. Wang, X. S. Chen, W. Lu, F. X. Xiu, and W. D. Hu, Adv. Mater., doi: 10.1002/adma.201604439 (2017).
6 B. Nie, J. G. Hu, L. B. Luo, C. Xie, L. H. Zeng, P. Lv, F. Z. Li, J. S. Jie, M. Feng, C. Y. Wu, Y. Q. Yu, and S. H. Yu, Small **9**, 2872 (2013).
7 B. B. Tian, J. L. Wang, S. Fusil, Y. Liu, X. L. Zhao, S. Sun, H. Shen, T. Lin, J. L. Sun, C. G. Duan, M. Bibes, A. Barthélémy, B. Dkhil, V. Garcia, X. J. Meng, and J. H. Chu, Nat. Commun. **7**, 11502 (2016).
8 R. C. G. Naber, C. Tanase, P. W. M. Blom, G. H. Gelinck, A. W. Marsman, F. J. Touwslager, S. Setayesh, and D. M. de Leeuw, Nat. Mater. **4**, 243 (2005).
9 Y. Zheng, G. X. Ni, C. T. Toh, C. Y. Tan, K. Yao, and B. Özyilmaz, Phys. Rev. Lett. **105**, 166602 (2010), arXiv: 1009.0076.
10 D. Zheng, J. Wang, W. Hu, L. Liao, H. Fang, N. Guo, P. Wang, F. Gong, X. Wang, Z. Fan, X. Wu, X. Meng, X. Chen, and W. Lu, Nano Lett. **16**, 2548 (2016).
11 D. Zheng, H. Fang, P. Wang, W. Luo, F. Gong, J. C. Ho, X. Chen, W. Lu, L. Liao, J. Wang, and W. Hu, Adv. Funct. Mater. **26**, 7690 (2016).
12 X. Wang, P. Wang, J. Wang, W. Hu, X. Zhou, N. Guo, H. Huang, S. Sun, H. Shen, T. Lin, M. Tang, L. Liao, A. Jiang, J. Sun, X. Meng, X. Chen, W. Lu, and J. Chu, Adv. Mater. **27**, 6575 (2015).
13 Y. Chen, X. D. Wang, P. Wang, H. Huang, G. J. Wu, B. B. Tian, Z. C. Hong, Y. T. Wang, S. Sun, S. Shen, J. L. Wang, W. D. Hu, J. L. Sun, X. J. Meng, and J. H. Chu, ACS Appl. Mater. Interfaces, doi: 10.1021/acsami.6b10206 (2016).