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NEWS AND VIEWS

Photodetectors based on 2D material/Si heterostructure

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In recent years, low-dimensional materials especially 2D materials have attracted wide attention due to their novel proprieties. Plenty of devices with excellent performance have been made for different applications basing on 2D materials. In order to further explore the advantages of 2D materials and integrating them into semiconductor fabrication lines, the 2D material/Si heterostructure-based photodetectors played important roles in many different domains due to their price advantage, mature manufacturing craft and good compatibility to integrated circuits.

Graphene is a single 2D sheet of carbon atoms, it has good properties such as zero bandgap, ultrahigh carrier mobility, high conductivity[1]. Graphene is an appealing material for photonics devices, and a lot of photodetectors which were made by graphene/Si heterostructure had been finished. For example, the IBM group designed a graphene-based photodetector with an ultra-broadband photoresponse from 514 to 2400 nm in 2010[2]. Recently, THz graphene-based detector went into scientists' sight for its potential application in outer space[3]. On the other hand, the light absorption of graphene is low, hence, many efforts were focused to reduce the dark current. Fang *et al.* reported a design that introduce an interfacial oxide layer between the graphene and silicon, this kind of structure could effectively improve the performance of graphene/Si heterostructure photodetector[4]. What's more, in some photodetectors, graphene could be an excellent electrode material because of its high conductivity.

Black phosphorus (BP) is another typical 2D material. It has wide direct bandgap (0.3–2 eV) which is thickness-dependent, strong linear dichroism and high carrier mobility[5]. Owing to these novel features, the BP/Si heterostructure based photodetectors had outstanding performances. The responsivity of the photodetectors could be as high as 6.7×10^5 A/W, the spectrum range was wide (from 0.475 to 3.39 μm), and even at the illumination of 3.39 μm light, the responsivity and detectivity could achieve as high as 82 A/W, 10^{12} J, respectively[6]. Meanwhile, polarization-sensitivity is another important feature for BP/Si based photodetectors. It makes them promising candidates for infrared polarization detection.

Transitional metal dichalcogenides (TMDCs) is a big family in 2D materials. Most of TMDCs have similar characteristics such as good mechanical properties, high mobility, etc. Moreover, the indirect gap bulk material will become direct gap for some TMDCs when their thickness reduce to single layer[7]. Recently, large-scale preparations for TMDCs/Si heterostructure based devices had been realized. Das *et al.* successfully fabricated an excellent photodetector which was made by large-area MoS_2/Si heterostructure. This device had high responsivity (up to 8.75 A/W), high detectivity (about 1.4×10^{12} J) and fast response time (about 15 μs)[8]. The schematic diagram of the device is shown in Fig. 1.

Photodetectors based on 2D materials mentioned above had satisfying performances. However, devices of larger responsivity, higher detectivity, faster response time are still pursued by researchers. Some researchers designed the van der Waals (vdW) heterostructures made by different kinds of 2D materials. In this way, advantages of different 2D materials could be combined in one device and the lattice mismatch requirements were waived. For example, Ye *et al.* constructed a BP/MoS_2/Si based detector and its detection range was from 532 to 1550 nm, responsivity achieved 22.3 A/W[9]. It could be seen that the performances of BP/MoS_2/Si based detector were greatly improved compared with the MoS_2/Si based detectors. Hence, vdW heterostructures provided a promising stage to design good photodetectors.

Owing to their outstanding performances, scientists and entrepreneurs have been working on the commercialization of 2D materials. And the best way is to integrate the 2D materials into conventional silicon-based lines. However, there are many difficulties in this process. Four critical steps: growth, transfer, encapsulation, and electric contacts are the most difficult challenges to achieve our goal. To date, graphene is one of the most commercialized product among the 2D materials. Scientists could synthesis large-scale graphene thin film with high quality on a wafer scale[10], and the electric contacts were preliminarily solved by Wang's group[11]. However, the transfer processes would lead to contamination and degrade device performance, and high-quality encapsulation for wafer-scale graphene thin film was not yet available. Other 2D materials faced similar situation. And the absence of industry standard is another hindrance. In the process to com-

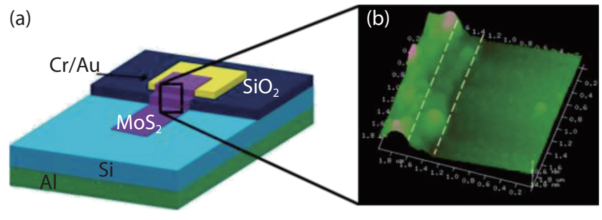

Fig. 1. (Color online) (a) Schematic representations of the Si/MoS_2 p–n heterojunction photodetector. (b) AFM image of MoS_2 layer at metal contact and heterojunction interface[8]. Copyright © 2017, Springer Nature.

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mercialization, these problems need to be solved urgently.

Tremendous advances have been made in the design of two-dimensional material/Si heterostructure detectors, but many challenges still exist and need to be resolved in the future. There are some fields requiring additional improvement: (1) Processability and practical application, most of reports works are manipulated by manual system, it causes a hindrance for the industrialization. (2) Further improvement of the key parameters, most of present devices can only enhance one or two aspects of the key parameters. More efforts need to be cast to improve full aspects of the devices. And it is a long-term process for all researchers.

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