ABSTRACT

Photodetector based on traditional semiconductor materials has stable performance, mature technology and wide application, but it also faces many problems. The doping concentration of impurities in the monoatomic semiconductor is limited by the solid solubility of the material itself; the control of the element types and contents in the multi-component semiconductor is complex; some semiconductors for photodetection are synthesized with toxic source materials. These disadvantages limit the application and development of traditional semiconductor materials. Graphene is a two-dimensional material composed of monolayer carbon atoms, which has excellent photoelectric properties such as wide spectral absorption and high carrier mobility. Graphene/silicon (Gr/Si) Schottky junction photodetector can be constructed by simply transferring graphene to silicon substrate. Compared with traditional semiconductor photodetectors, the fabrication process is simple. Due to the rectifying characteristics of Schottky junction, under reverse bias the dark current is small, which leads to high on-off ratio and detectivity. In this thesis, the graphene/silicon Schottky junction photodetectors were studied. The graphene oxide (GO) interface layer and gold nanoparticles (AuNPs) are used to improve the photoelectric performance of Gr/Si photodetector. Two-step hot-embossing method was proposed to directly transferr graphene and fabricate Gr/Si Schottky photodetector.

1) Single layer graphene films were grown by chemical vapor deposition (CVD) method and used to fabricate Gr/Si Schottky photodetector. The results of Raman spectroscopy, SEM and AFM indicated that the graphene was monolayer. After transferring by PMMA temporary support layer, graphene still had good integrity and continuity, while PMMA residue with thickness of about 5 nm existed on the surface. Gr/Si Schottky junction photodetector was fabricated by metal deposition, photolithography and lift-off. The responsivity of the detector was 0.23 A/W and the on-off ratio reached 3.7×10^3 under 633 nm illumination. The detector responded quickly and accurately to the periodic optical signals with different power density, and the response time was about 1 ms.

2) The performance of Gr/Si Schottky photodetectors was improved by inserting a graphene oxide film as interfacial layer. The interface between graphene and silicon normally contains a relatively high density of surface states, which leads to Fermi level

pinning and increases the leakage current noise, thus limits the overall performance of Gr/Si Schottky photodetector. The inserted GO interfacial layer can enhance the interface properties, the results show that the dark current of Gr/GO/Si photodetector was 26 times lower than that of the Gr/Si photodetector, and the photocurrent is 2.73 times higher than Gr/Si detector. Under 633 nm illumination the responsivity reached 0.65 A/W. After inserting GO interfacial layer, the series resistance of the device had no obvious change, while the Schottky barrier height and shunt resistance increased significantly. The dark current of graphene photodetector was reduced due to the suppression of reverse saturation current. The enhancement of photocurrent was attributed to multiple factors, including the increase of Schottky barrier height, the extra light absorption of GO film and the passivation of Schottky junction interface.

3) AuNPs obtained by two different methods, thin film annealing and electron beam lithography, were used to enhance the performance of Gr/Si Schottky junction photodetectors. By coupling gold nanoparticles to graphene surface, the optical near-field intensity of the photosensitive region can be enhanced by surface plasma resonance effect, which can effectively improve the photoelectric response of Gr/Si Schottky photodetector. AuNPs obtained by thin film annealing were disorderly distributed semi ellipsoidal gold nanoparticles, which significantly improved the responsivity of the detector in the visible light band. When the incident light wavelength was 500 nm, AuNPs/Gr/Si have the maximum enhancement, the responsivity increased by 48% (from 0.15 A/W to 0.22 A/W). The AuNPs fabricated by electron beam lithography are neat gold nanodisk arrays. When the incident light wavelength was 630 nm, the responsivity increased by 61% (from 0.23 A/W to 0.37 A/W). At the same time, the on-off ratio, detectivity, noise equivalent power and other performance indexes of the detector also significantly improved.

4) Two-step hot-embossing method was proposed to directly transfer of graphene and fabricate of Gr/Si Schottky photodetector. At present, the most commonly used graphene transfer method is using a temporary support layer like PMMA, but it requires experienced manual operation, which is not applicable for mass production, besides PMMA residue usually leads to degradation of device performance. Two-step hot-embossing method was carried out without the assistance of PMMA temporary support layer. Graphene was directly transferred to copolymers of cycloolefin (COC) film substrate by hot-embossing process, and then COC/graphene structure was embossed with prefabricated substrate by using hot-embossing process again to form Gr/Si Schottky photodetector. The Raman spectrums of graphene films before and after hot-

embossing showed that the structure of graphene remained intact after undergoing an intensity of pressure of 25 MPa. The photoelectric response showed that the responsivity reached 0.73 A/W under 633 nm illumination.