

All-carbon flexible photodetectors

Yujie Liu, Yuanda Liu, Shuchao Qin, Yongbing Xu, Rong Zhang, Fengqiu Wang*

School of Electronic Science and Engineering, Nanjing University, Nanjing 210093, China
E-mail address: fwang@nju.edu.cn

Abstract: We demonstrate a graphene-nanotube hybrid flexible photodetector with a high photoresponsivity (~ 51 A/W) and a fast response (~ 40 ms) over the visible range. The devices remain stable under severe bending conditions and repetitive bending cycles.

OCIS codes: (040.5160) Photodetectors; (160.1890) Detector materials; (310.6845) Thin film devices and applications

1. Introduction

One-dimensional carbon nanotubes (CNTs) and two-dimensional graphene exhibit advantageous electronic, optical and mechanical properties, the compatibility with large scale synthesis makes them highly applicable for photonic applications involving volume production. However, CNT networks typically exhibit lower mobility and operating speeds due to the existence of inter-tube Schottky barriers [1-3], whereas the low optical absorption and ultrafast photocarrier recombination of graphene severely limit its photoresponsivity [4].

By combining graphene and SWNTs into a van der Waals heterostructures, a high-performance photodetector with a balanced overall performance is recently achieved [5]. The interfacial charge transfer dynamics within such a hybrid nanostructure is also resolved through a combination of Raman and photocurrent spectroscopy [6]. Remarkably, graphene-SWNT assemblies have extraordinarily mechanical flexibility and stretchability, making it an ideal building block for flexible optoelectronics. Thus far, no investigation on the performance of flexible devices based on such an all-carbon composite material has been reported.

In this work, we demonstrate for the first time a fully flexible photodetector utilizing graphene-SWNT hybrid film as the light harvesting layer. The photodetector exhibits a high photoresponsivity of ~ 51 AW⁻¹ and a fast response speed of ~ 40 ms over the visible wavelength range. In addition, our devices remain stable under severe bending conditions and are free from pronounced degradation after a large number of repetitive bending cycles.

2. Flexible SWNT-graphene hybrid photodetector fabrication

The fabrication process of the SWNT-graphene hybrid photodetector on flexible polyethylene terephthalate (PET) substrate is as follows: homogeneous SWNT solutions with appropriate densities were spin-coated onto a PET substrate. Subsequently, monolayer CVD graphene was transferred atop the SWNTs networks. Asymmetric source/drain electrodes were patterned by standard photolithography, electron beam evaporation and lift-off. The SWNT-graphene channel was patterned by another photolithography and oxygen plasma etching. Fig. 1(a) schematically illustrates the architecture of the SWNTs-graphene hybrid films photodetector on PET substrate. The morphologies of the resulting SWNT-graphene hybrid films are examined by scanning electron microscopy (SEM) as shown in Fig. 1(b). The SWNTs are sparsely distributed on the PET substrate, covered by a large flake of graphene sheet. The resulted hybrid thin films exhibit a high transparency (inset of Fig. 1(c)). Typically, the transmittance of the resulted hybrid thin film on PET reaches up to $\sim 83\%$ at a wavelength of 532 nm, which is approximately 5% lower than that of the pure PET substrate (Fig. 1(c)).

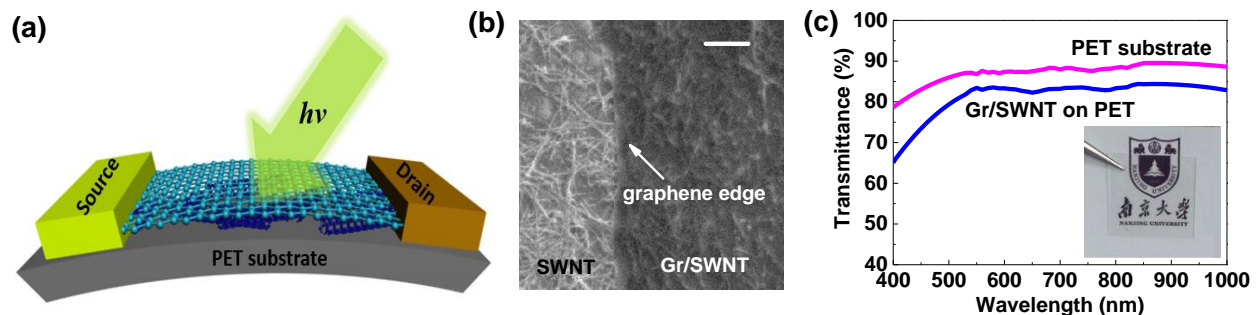


Fig.1 (a) Schematic illustration of the flexible SWNT-graphene hybrid films photodetector. (b) SEM image of the hybrid thin films (Scale bar, 1 μ m). (c) Vis-NIR transmittance spectra and the inset photograph shows a good visible transparency.

3. Results and discussion

Photoresponse of the flexible devices is carried out by using a laser diode operating at 532 nm under vacuum. As presented in Fig. 2(a), the photocurrent increases with increasing incident power, while the corresponding photoresponsivity decreases. The responsivity of the detectors reaches ~ 51 A/W under a low illumination power, which is on a par with that of a gold oxide-graphene heterojunction device (58 A/W at 500 nm) [7], the response time is estimated to be ~ 40 ms (Fig. 2(b)), which is faster compared with previously reported graphene flexible photodetectors (on the order of seconds) [8, 9]. To further verify the mechanical flexibility and durability under bending stress, the SWNTs-graphene hybrid devices are wrapped on cylindrical apparatus with three different radii of curvatures, and the photoresponse is measured while the devices are bent. The photocurrent is almost invariant compared with the original value. Significantly, the temporal photoresponse does not show degradation even under the maximum bending condition as illustrated in Fig. 2(c). The fatigue cycling performance of the flexible devices is schematically shown in the inset of Fig. 2(d). The devices exhibit no delamination or cracks after repeatedly bending tests. Compare with the initial state, the parameters of the flexible devices are only slightly degraded even when the devices go through 500 bending cycles, which demonstrates the electromechanically robust of the assembled flexible devices.

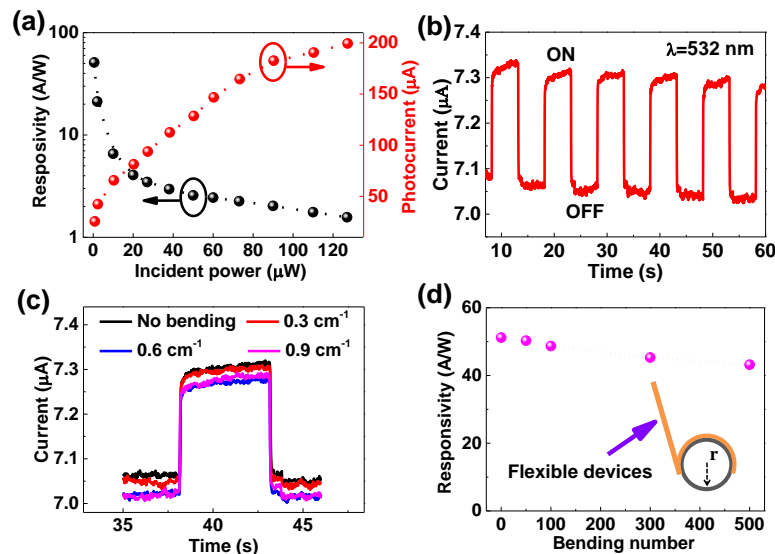


Fig.2 (a) Power-dependent responsivity and photocurrent. (b) Time-dependent photoresponse of the flexible devices. (c) Temporal photoresponse under different bending curvatures (k , $k=0.3, 0.6, 0.9 \text{ cm}^{-1}$). (d) Responsivity as a function of bending number at the radii (r) of 1.6 cm. The inset shows the schematic diagram of the bending process.

4. Conclusion

In summary, we have for the first time demonstrated a large-area, transparent and flexible SWNTs-graphene hybrid film photodetectors on PET substrates. The devices exhibit a high photoresponsivity (~ 51 A/W) and a fast response time (~ 40 ms) upon visible irradiation. Furthermore, the fabricated devices show superior flexibility, good folding strength under harsh strain and repeated bending tests. Such an all-carbon hybrid architecture would be fully compatible with graphene based flexible electronic components for practical applications in photosensors, flexible solar cells and facilitating large-scale optoelectronic functionality integration.

5. References

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