Efficient absorption by monolayer graphene in microring resonator

Ziyu Liu
Qian Xuesen Laboratory of Space Technology, China Academy of Space Technology, Beijing, China,
100094, Email: liuziyu@qxslab.cn

Abstract. We demonstrate a graphene photodetector based on a SOI microring resonator. The absorption of the graphene was enhanced by the resonating, so to improve the detection efficiency by 5 times. The impact of graphene’s position and length on the absorption rate was also been studied. The frequency selective effect shows the potential on spectrum detection and WDM photoelectric conversion.

1. Introduction
At present, photo detector based on the two-dimensional materials provides a promising way to realize the efficient detection of optical. Graphene has emerged as an attractive photocurrential material because of its ultra-broadband light absorption, high carrier mobility and gate-tunability of the optical absorption. However, there are still some basic scientific problems to be solved, such as dark current, limited bandwidth and low detection. Graphene-based photo detectors on Si waveguides [5-8] have been proposed to enhance the absorption of the graphene, however, the enhancement was determined by the effective length of detection.

In this paper, we demonstrate a graphene photodetector based on a SOI microring resonator. The optical wave was coupled to the ring through a bus waveguide and resonating in the ring, graphene was located on the looped optical waveguide. The absorption of the graphene was enhanced by the resonating, so to improve the detection efficiency.

2. The influence of graphene for micro ring
The schematic of the photo detector is shown in Fig. 1. The microring resonator with base width of 400nm was fabricated on a SOI substrate with 220-nm-thick silicon layer with a 3um buried oxide layer. The monolayer graphene was prepared by mechanical exfoliation on a stack of polymers on the ring resonater. The source and drain contacts on the graphene are prepared on both sides of the ring waveguide, doping for Photovoltaic effect. A gate was prepared to tuning the Fermi level of the graphene.

The transport characters of the graphene microring detector were calculated using three-dimensional (3D) FDTD method. Figure 2(a) shows an add-drop racetrack ring photo detector model with a radius of 3.1um, the coupling gap of the ring is 100 nm, a straight waveguide was defined in the racetrack ring with an 2D rectangle graphene on it. The TE mode incident into the straight waveguide from in port and coupled to the ring, then resonate in the ring then transmitted to the drop port. The incident field which didn’t conform to the resonance condition almost transmitted to the through port.
Fig. 1 The schematic of the graphene ring detector.

2.1. Comparison of graphene on the straight waveguide and on the ring

The optical parameters of monolayer graphene refer to the article [9]. In order to compare the graphene’s absorption rate between the ring resonator photodetector and traditional straight waveguide photodetector, ring resonators with graphene on the add port and pass port with the same length also being calculated as references as shown in Fig. 2(a). In order to characterize the graphene’s absorption rate, the sum of the transmittance of four ports (input, pass, drop and add) was shown in Fig. 2(b), which reflects the total absorption of the device. A valley at 1.542nm in micro ring without graphene represents the loss in the SOI micro ring. The ring with graphene on the add port represents a broadband absorption, while the ring with graphene on the pass port shows an enhanced absorption at resonance peak of the ring resonator, showing the absorption effect of graphene before and after the micro ring frequency selective filter.

Compared above, the micro ring with graphene on the racetrack looped waveguide represents obvious absorption at ring’s resonating wavelength than that with graphene on the drop port. With the ring resonator loss as reference, the absorption at the resonating wavelength was increased by about 5 times than the graphene on the straight waveguide.

Fig. 2 (a)The schematic of the photodetector in FDTD solution (b)The absorption of photodetector with graphene on the loop ring and straight waveguide.

2.2. Comparison of graphene on the different position of the ring

We also studied the impact of graphene’s position on the absorption rate. Graphene was located on the different position of the ring, seen in Fig.3 (a), covering a 20 um long straight part of the racetrack ring. The absorption rate was then calculated as shown in Fig.3 (b), indicating that the
absorption of graphene on the right side is higher than that on the left side. The intensity of the light field in the right part is stronger than that in the left part, which causes the difference on absorption.

![Graphene schematic and absorption diagram](image)

**Fig. 3** (a) The schematic of the photodetector with graphene at different position of the loop in FDTD solution. (b) The absorption of photodetector with graphene at different position of the loop.

2.3. *The impact of graphene’s length on the absorption rate*

The impact of graphene’s length on the absorption rate was also studied. A race track microring model with straight part of 20 μm on both sides was built for the calculation convenient of the graphene’s length, the graphene cover both straight parts with length of L, seen in Fig. 4(a). Fig. 4(b) shows the absorption rate of the ring resonator with different covering length of graphene, the covering length L varies from 0μm to 40μm. From the Fig. 4(b) we can see that with the increase of graphene cover length, the absorption first increases then decreases.

![Graphene length schematic and absorption diagram](image)

**Fig. 4** (a) The schematic of the photodetector with graphene at different position of the loop in FDTD solution. (b) The absorption of photodetector with graphene at different position of the loop.
We deduced that there is a trade-off relationship between the absorption of graphene and resonance of micro ring. When graphene cover length rise to more than 16 um, the resonance of light in the microring damping so violently that it cannot enhance the light field as the growth of the graphene coverage length, the decay of the resonating absorption leads to the absorption attenuation.

In conclusion, we presented a graphene photodetector based on microring resonator. The absorption enhancement was achieved through located the graphene on parts of light field resonance. As a result, graphene detection efficiency increased 5 times than traditional waveguide mode. Location is a factor that influence efficiency of graphene detection, the absorption is related to the optical field distribution of micro rings. There is a trade-off relationship between the absorption of graphene and resonance of micro ring when the cover length of graphene increases. The frequency selective effect shows the potential on spectrum detection and WDM photoelectric conversion.

Acknowledgment
This work is supported by the independent innovation foundation of the Qian Xuesen Laboratory of Space Technology and the independent innovation foundation of CASC.

References
[1] Lee E J, Balasubramanian K, Weitz R T, Burghard M and Kern K 2008 Nature nanotechnology 3 486-90
[2] Park J, Ahn Y H and Ruiz Vargas C 2009 Nano Lett. 9 1742–1746
[3] Xia F, Mueller T, Lin Y M, Valdes-Garcia A and Avouris P 2009 Nature nanotechnology 4 839-43
[4] Mueller T, Xia F and Avouris P 2010 Nature Photonics 4 297-301
[5] Gan X, Shiue R-J, Gao Y, Mert I, Heinz T F, Shepard K, Hone J, Assefa S and Englund D 2013 Nature Photonics 7 883-7
[6] Pospischil A, Humer M, Furchi M M, Bachmann D, Guider R, Fromherz T and Mueller T 2013 Nature Photonics 7 892-6
[7] Wang X, Cheng Z, Xu K, Tsang H K and Xu J-B 2013 Nature Photonics 7 888-91
[8] Youngblood N, Anugrah Y, Ma R, Koester S J and Li M 2014 Nano letters 14 2741-6
[9] Liu M, Yin X, Ulin-Avila E, Geng B, Zentgraf T, Ju L, Wang F and Zhang X 2011 Nature 474 64-7