Enhanced Graphene Photodetector with Fractal Metasurface

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Abstract: We designed and fabricated a broadband, polarization-independent photodetector by integrating graphene with a fractal Cayley tree metasurface. Our measurements show an almost uniform, tenfold enhancement in photocurrent generation due to the fractal metasurface structure.

OCIS codes: (040.5160) Photodetectors; (130.3120) Integrated optics devices; (250.5403) Plasmonics;

1. Introduction

Graphene has been known as a promising photo-detection material for its ultra-broadband absorption, dynamic tunability, and high carrier mobility. There are multiple known mechanisms of photo-detection in graphene including photovoltaic, photo-thermoelectric, bolometric, and photo-gating effects [1]. Among these, photovoltaic effects have the fastest response time, making them one of the most competitive candidates for ultrafast photodetectors [2]. Specifically, a strong photo response near metal/graphene interfaces has been demonstrated in recent graphene photo-detection experiments. However, the responsivity (sensitivity) in photovoltaic graphene photodetectors is relatively low and there have been numerous efforts to enhance the responsivity in such detectors using plasmonic structures [3,4]. Such enhancements are mostly narrowband and polarization dependent. In order to achieve the desired broadband and polarization insensitive properties, self-similar fractal structures have been suggested to engineer the multi-band resonance response for realizing spectrum-spanning optical effects [5,6]. Furthermore, these fractal structures could benefit photo-detection as an efficient photocurrent collection electrode with maximized metal/graphene interfaces. In this work, we present our numerical and experimental studies on enhancing graphene photocurrent with a fractal Cayley tree metasurface structure.

2. Results and Discussion

The graphene photodetector consists of source/drain contacts, graphene, and a Cayley tree fractal structure, and is fabricated by transferring chemical vapor deposited (CVD) graphene onto SiO_2/Si (highly p doped) substrate, electron beam lithography (EBL), Ti(3 nm)/Au(40 nm) metallization, and liftoff. The fabricated device is shown in Fig. 1(a). We design a fractal Cayley tree structure which has a relatively flat optical absorption in the visible part of the spectrum, and integrate it with the drain contact of our graphene photodetector. Furthermore, we investigate the near field property of the gold fractal metasurface through the FDTD method [7]. We employ a dispersive model for gold, which is defined as the sum of a Drude term and two critical point terms and is implemented through a Generalized Dispersion Material model [8]. The parameters of the model are adapted from an online database [9]. We show one full-wave simulated in-plane electric field distribution just underneath the gold fractal metasurface when it is illuminated at the wavelength of 568 nm (Fig. 1(b)). The high intensity regions (hot spots) are tightly localized around the branches and edges of the fractal structures. In reality, these induced multiple hot spots will further enhance and contribute to generating electron-hole pairs in graphene. A portion of the generated electron-hole pairs are then separated and harvested by the built-in electric field due to the potential gradient at the metal-graphene interface before they recombine, giving rise to a detectable photocurrent.

The light source used in our experiment is an Ar-Kr continuous wave laser with a beam spot diameter of ~7 um and is chopped at 1.1 kHz. The photocurrent is recorded by a lock-in amplifier synchronized with the chopper. The enhancement due to the fractal structure is defined as the ratio of photocurrent generations between two different incident spots: one on the fractal structure (spot A in Fig. 1(a)) and the other on the bare graphene/gold edge (spot B in Fig. 1(a)). Our measurement shows a ten-time enhancement of photocurrent generation due to the fractal structure across the spectral range of 488 nm to 647 nm, as shown in Fig. 1(c). Because of the highly symmetric geometry of the fractal structure, we expect the photocurrent generation to be independent of the polarization of the incident beam. To illustrate, we measure the photocurrent generation by shining a linearly polarized beam on the fractal structure. The beam is at the wavelength of 568 nm with a power of 0.574 mW. By rotating our sample with respect to the incident beam polarization, we observe that the generated photocurrent is almost at the same magnitude, as shown in Fig. 1(d).

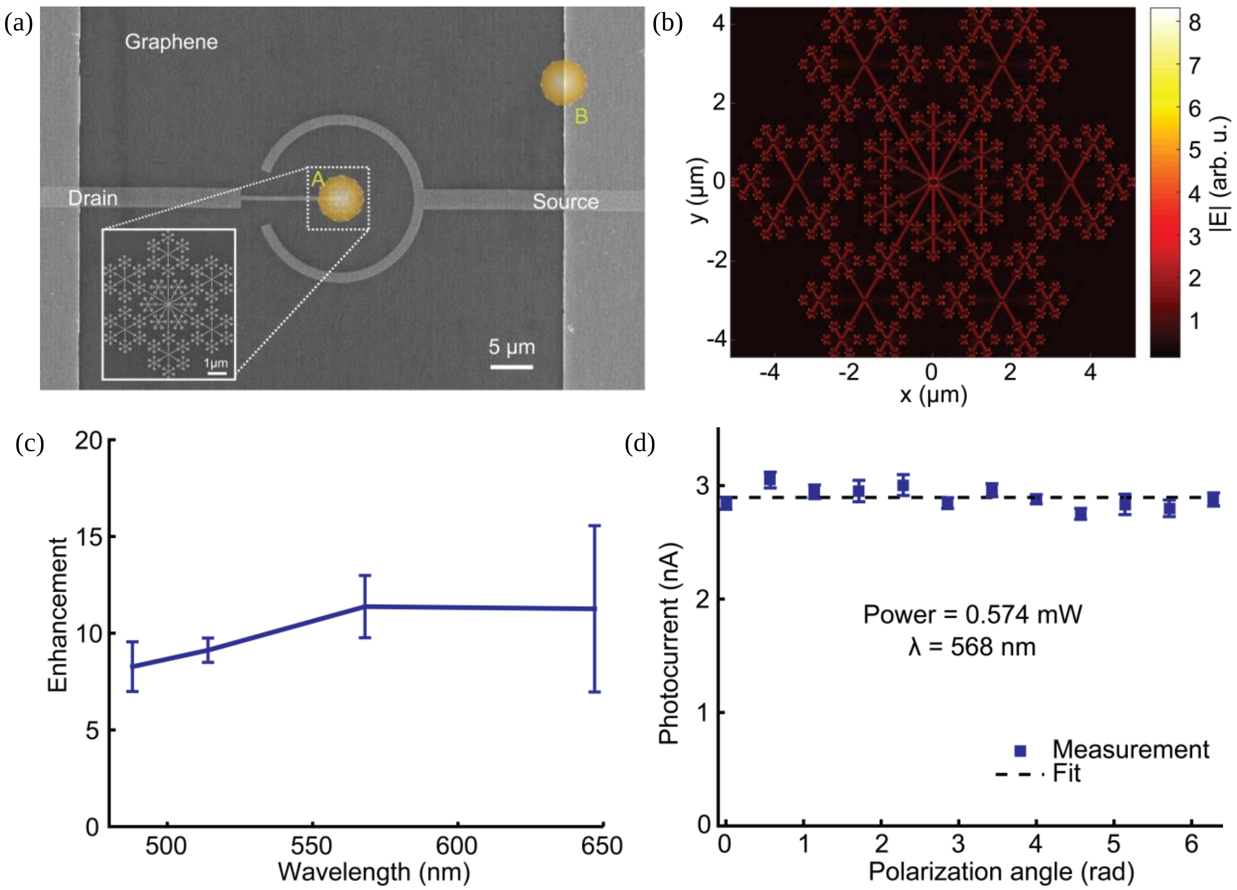

Fig. 1. (a) SEM image of the graphene photodetector with the fractal Cayley tree metasurface (the white scale bar is 5 μm); inset image shows the zoomed-in view of gold fractal Cayley tree metasurface (the white scale bar is 1 μm). (b) FDTD simulated in-plane electric field (resulted from incident EM wave) distribution just underneath the gold fractal Cayley tree metasurface at a wavelength of 568 nm. (c) Measured enhancement of photocurrent generation over wavelength range of 488 nm to 647 nm. (d) Photocurrent measurements at a wavelength of 568nm of varied polarization angles, with a beam power of 0.574 mW.

To conclude, we designed and fabricated a broadband, polarization-independent photo detector by taking advantage of the intrinsic nature of fractals. We believe our fractal design could further extend to numerous optoelectronic applications, such as transparent conducting electrodes, photovoltaic devices, biological and chemical sensing.

The authors acknowledge financial support by the NSF Materials Research Science and Engineering Center (MRSEC) program (DMR 1120923), US Army Research Office grant 63133-PH (W911NF-13-1-0226), and the Air Force Office of Scientific Research MURI grant (FA9550-12-1-0389).

3. References

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