Modeling of HgCdTe photoconductive infrared detector with metallic nanostructures

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Abstract

An HgCdTe photoconductive infrared detector with metallic nanostructures has been numerically studied. The plasmonic resonant absorption and the photo current response spectra of the detector are investigated by using a combination of the FDTD method and FEM method. The simulated results show the dependence between the geometric design and the performance of the detector. A higher photo response can be achieved in comparison to common HgCdTe photoconductive infrared detector.

I. INTRODUCTION

Conventional HgCdTe photoconductive infrared detector has a rather thick HgCdTe layer (several microns) to absorb the incident light. Nowadays, metal-semiconductor-metal (MSM) configuration and metallic nanostructure for high absorption efficiency is widely studied [1-3]. Benefited from surface plasmon and gap plasmon resonance [4-5], this configuration can achieve high quantum efficiency (QE) while largely reducing the volume of semiconductor so that dark currents and single/noise ratios can be improved [6].

In this paper, the MSM configuration is applied in HgCdTe photoconductive infrared detector. Based on subwavelength metallic grating, the semiconductor layer of HgCdTe can be several hundred nanometers. The detector is numerically investigated by using a combination of the FDTD method [7] and FEM method [8], which can simulate and analyze both the optical and electrical characteristics of the device.

II. SIMULATION MODELS

First, Maxwell equations are solved in EMLAB (from Synopsys Inc.) by FDTD to explore the optical propagation and distribution. The distribution of photon-generated electrical field E in the whole device can be obtained. Then the optical generation rate can be calculated by the two equations as follows [9],

$$W = -\nabla \cdot S_{AV} = \frac{1}{2}\sigma |E|^2 \quad (1)$$

$$G_{opt} = \eta \frac{W}{E_{ph}} \quad (2)$$

where S_{AV} is the time-averaged Poynting vector, σ is the conductivity, E_{ph} is the energy per photon, and η is the quantum yield.

Then, the optical generation rate is included into the continuity equation, which is to be used in Sentaurus-DEVICE to simulate the electrical process. For plain drift-diffusion simulation the well-known Poisson and continuity equations are used.

The basic Poisson equation and drift-diffusion current continuity equations for electrons and holes are included in the simulator to calculate the electrical characteristics of the device. Meanwhile, generation–recombination (g-r) current which is caused by g-r centers, diffusion current which is due to diffusion of thermally generated minority carriers, and other two tunneling currents known as trap-assisted tunneling current and band-to-band tunneling current are all introduced in our simulation for dark current models [10].

The structure discussed in this study is illustrated in Fig.1. The size value is referred to Ref[2].And Fig.1 here is a 2D side view for clear numeric captions and the simulated model is 3D device with 2D periodic square metallic grating (as Fig.2 shows). The composition of HgCdTe is x=0.211 and doping densities is 2.5×10^{11}cm^{-3}. The contacts are placed at two sides of the detector on HgCdTe layer. The light is 10W/m^2 from front side and the temperature is fixed at 77K.

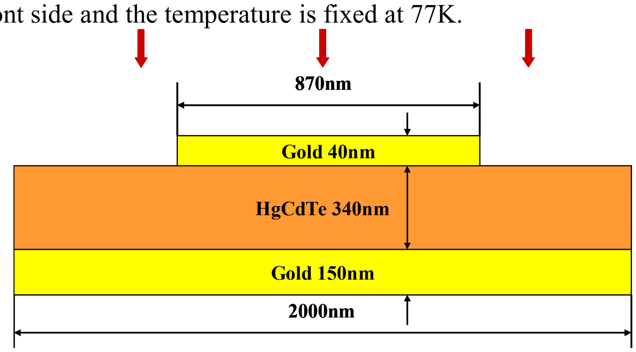

Fig.1. 2D side view of HgCdTe photoconductive infrared detector with metallic nanostructures

III. RESULT AND DISCUSSION

By 3D numerical simulation, Fig 2 shows the distribution of photon-generated electrical field when the incident light is set as 8μm. And there are two x-normal cut views in Fig.2 to illustrate the electrical field within the materials. The trapping and enhancement of light is resulted from surface plasmon and gap plasmon resonance [4-5]. So the HgCdTe regions which are closely below or near the edge of gold can achieve quite high absorption [11-12]. Since this is a local effect, the thin

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layer of HgCdTe is able to utilize most light and further study indicate that (not list here) the photo absorption spectra can be tunable by the size, thickness, shape and periodicity of the nanostructure.

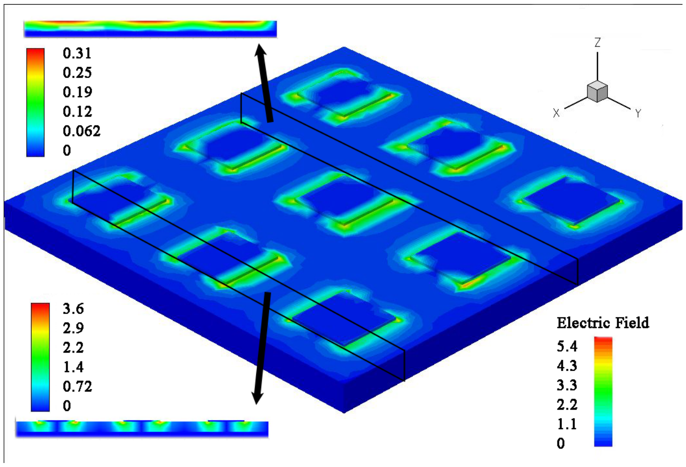

Fig.2. Distribution of photon-generated electrical field at 8μm light. The unit of electric field is V/cm.

We also vary the wavelength of the incident light to investigate the photo response spectra as Fig.3 shows. It is noted that for our long-wavelength HgCdTe infrared detector, a certain geometrical size (refers to Fig.1) can design for a range of detected wavelength. Since the light enhancement is stem from plasmonic resonance, either the thickness of HgCdTe, or the width and the period of gold grating, can affects the peak resonant wavelength. As a result, the photo response is can be optimized by carefully designing and adjusting the configuration of the HgCdTe photoconductive infrared detector with metallic nanostructures.

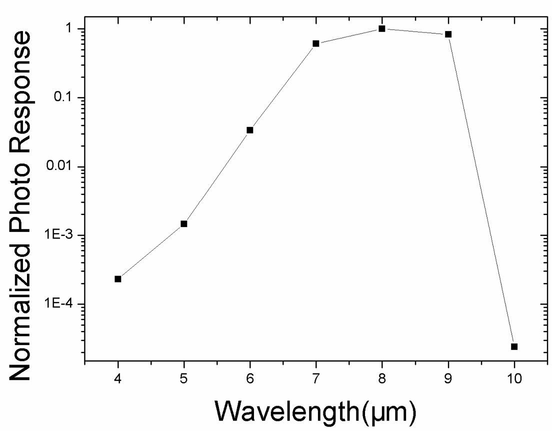

Fig.3. Photo response spectra of the detector. The unit of photo response is normalized.

IV. Conclusion

The distribution of photon-generated electrical field and photo response of HgCdTe photoconductive infrared detector with metallic nanostructures have been numerically simulated with a combination of the FDTD method and FEM method. The calculated results show the dependence between the geometric design and the performance of the detector. A higher photo response can be achieved in comparison to common HgCdTe photoconductive infrared detector.

Acknowledgements

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