EXTENDED ABSTRACT

Modeling and Simulation of Terahertz Detectors Based on Mercury Cadmium Telluride

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Extended Abstract

The research activity in the terahertz region (THz) received a significant boost with the advancement in materials research that is suitable for the development of detectors. Over the last six decades, mercury cadmium telluride (MCT) material technology has been successfully used for the development of detectors in the infrared region. Although MCT can be used for the development of the detectors in some part of the terahertz region, it is unexplored. Exploiting the unique properties of the mercury cadmium telluride material, this thesis is entirely focused on the development of detectors based on mercury cadmium telluride to operate at an absorption wavelength of 30 µm in the THz region. Since the experimental costs involved in development of photodetectors at the terahertz frequencies are very high, the theoretical and simulation studies presented in this thesis may be considered by design engineers. These devices will suffer from larger dark currents if operated at room temperature. The thermal energy of the charge carriers become comparable to the bandgap of the mercury cadmium telluride. The thermally generated carriers may become comparable to that of optically generated carriers. To reduce the effect of thermally generated carriers the devices are cooled down to cryogenic temperatures. Keeping in view of this factor, devices designed in this thesis have been operated at liquid nitrogen temperature of 77 K.

This thesis introduces the history of research in the terahertz region in Chapter 1. A brief discussion on the development of devices in the THz region over different decades has been presented. As there are no specific boundaries provided in defining the THz region, we have defined the terahertz spectral region with a broad prospective and used it throughout the thesis. Also, it discusses the unique properties of the THz radiation. The applications of the THz radiation in various multidisciplinary areas have been discussed elaborately.

Chapter 2 provides a brief overview on the review of the THz detectors. It discusses the existing detector technologies, their disadvantages and possible solution. This chapter provides the sate-of-the-art MCT material technology. It discusses the importance of the unique material properties that makes it suitable for the development of the detectors in the THz region.

In Chapter 3, we have designed a single heterojunction n-i-p photodetector based on MCT employing CdTe as a window material for an operating wavelength of 30 µm. CdTe material has been chosen as a window since it is a wide bandgap material and has less mismatch with the MCT material. The device has been analytically modeled for electrical and optical characteristics for an operating wavelength of 30 µm and a reverse bias voltage of 0.5 V. The device has been operated at a cryogenic temperature of 77 K. The results obtained are compared and contrasted with the results obtained from the numerical simulator ATLAS Silvaco tool. The single heterojunction n-i-p photodetector exhibited a dark current of $4.6 \text{ x } 10^{-9} A$. The optical characteristics such as quantum efficiency, responsivity, specific detectivity, and noise equivalent power have been computed. They are found to be 73.93%, 17.9 A/W, $1.44 \text{ x } 10^{9}\ mHz^{\frac{1}{2}}W^{-1}$, and $0.3 \text{ x } 10^{-16}\ WHz^{-1/2}$ respectively. The results obtained from the analytical modeling are in good agreement with the results obtained from numerical simulation.

In Chapter 4, we have designed a double heterojunction n-i-p photodetector based on MCT for an operating wavelength of 30 µm. The device has been analytically modeled for electrical and optical characteristics. The results obtained on the basis of analytical modeling have been compared and contrasted with the results obtained from numerical simulator ATLAS Silvaco tool which are in good agreement. The double heterojunction designed showed a substantial reduction in the dark current and superior performance in the optical characteristics in comparison to the single heterojunction. It is shown to exhibit a dark current of $2.42 \text{ x } 10^{-10} A$. The device designed showed a quantum efficiency of 75.35%, responsivity of 18.21 A/W, specific detectivity of $1.99 \times 10^{9} mHz^{\frac{1}{2}}W^{-1}$, and noise equivalent power of $0.21 \times 10^{-16}\, WHz^{-1/2}$. The double heterojunction photodetector exhibited enhanced optoelectronic characteristics in comparison to the single heterojunction.

In Chapter 5, a Schottky diode detector for the THz regime has been designed for an operating wavelength of 30 µm. The device has been simulated in the commercially available numerical simulator ATLAS Silvaco tool. This structure uses graphene as a semi-transparent material (metal contact) that allows THz radiation to reach the semiconductor. This graphene layer forms a Schottky contact with the MCT material. As the graphene layer is very thin, the depletion region on its side has been ignored. Therefore, the depletion region of the MCT is the depletion region of the Schottky diode. Owing to its structural advantage and since it is a majority carrier device, the Schottky diode detector exhibited a lower dark current in comparison to the other n-i-p photodetectors discussed in this thesis. It is shown to exhibit a dark current of $5.4 \times 10^{-11} A$. The optical characteristics such as quantum efficiency, responsivity, specific detectivity, and noise equivalent power have been obtained through the simulation in the numerical simulator ATLAS, Silvaco tool. They are found to be 77.88%, 18.6 A/W, $1.41 \times 10^{11} mHz^{\frac{1}{2}}W^{-1}$, and $0.71 \times 10^{-17}\, WHz^{-1/2}$ respectively. The Schottky diode detector designed outperformed the single and double heterojunctions due to its structural advantage.

In Chapter 6 a graphene-gated semiconductor THz detector has been designed. Graphene is a semi-metal and is used as a gate contact. Its thickness is so low that it allows most of the incident THz radiation to reach the semiconducting channel. Under the influence of illumination, two effects namely photoconductive and photovoltaic cause a change in the current flowing in the channel. The effect of higher optical power densities on the carrier lifetime and its limitations on the channel voltage developed in the device have been discussed.

In the proposed graphene-gated semiconductor field effect transistor (GSFET) device, the channel current is controlled entirely by the incidence of THz radiation. It exhibited a very low dark current of the order of 4.52 mA. The device operates at an optical power density of the order of 0.88 x 10^4 W/m^2. Under this optical power density, a current of 127.07 mA is found to flow in the channel. Therefore, it found to exhibit an optical gain of 27.11. The model presented in this chapter opens a new possibility of exploring the potential of a graphene-based MESFET built with a narrow bandgap material as a promising candidate for the development of future generation THz detectors.

The last chapter (Chapter-7) presents a summary of the outcomes of the detectors designed in this thesis. The possibility of using MCT material for the development of THz detectors has been explored. The performance of the detectors designed have been compared. The outlines for other possibilities to carry out the work as part of future scope has also been provided in this chapter.