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Intersubband transitions in quantum well mid-infrared photodetectors

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HIGHLIGHTS

- An infrared detector based on (CdS)/ZnSe)/BeTe quantum wells is modeled.
- The intersubband absorption, the dark current and the quantum efficiency are reported.
- The low dark current at 300 K reveals the good performance of the QWIP.
- The detectivity curves confirm its good quality at 3.3 μm wavelength.

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ABSTRACT

A study of intersubband transitions in quantum well infrared detectors working at high temperatures has been reported. This study allows a greater tunability in the device designs, with the ability to control the peak wavelength, the absorption coefficient, the dark current, the quantum efficiency and the detectivity of the modeled structure operating around 3.3 μm wavelength. The detection energy and absorption coefficient dependences with an applied electric field are given. Then, the electro-optic performances of the modeled mid-infrared detector are estimated, the dark current dependence with the applied voltage and temperature as well as the quantum efficiency and the detectivity are investigated and discussed. High detectivities were found at high temperatures revealing the good performances of the designed photodetector, especially at 3.3 μm wavelength.

1. Introduction

Several research groups [1–3] have reported studies on intersubband transitions (ISBTs) in quantum wells (QWs). Intensive research has been done on the double-well [4] and stepped-well [5] structures. In the other hand, photodetectors operating in the infrared region [6–9] and in particular the spectral region 3–5 μm have wide range applications including thermal imaging, remote gas sensing, medical imaging etc. These photodetectors have been generally based on the inter-band transitions. Superlattice infrared photodetectors using InAs/GaSb heterostructures have been proposed thanks to several theoretical advantages induced by its type II band alignment [10,11]. The effective band gap can be tailored by adjusting the layer thicknesses to cover a wide range of wavelengths including the mid-wavelength infrared range.

Later, photodetectors based on electron and hole ISBTs in single, multiple quantum wells and superlattices have been studied extensively [12,13]. Devices based on single QW have shown a weak overlap of the active region due to the limited thickness of the QW layer, but in multiple QWs, a strong optical absorption [14] has been observed experimentally. Such structures offer larger flexibility in the operating wavelength of the device compared to a photodetector based on the interband transition where the operating wavelength is determined by the energy gap and therefore can be varied only by using alloys such as $Cd_xHg_{1-x}Te$. In addition, the functioning wavelength of ISBT in multiple QWs, may be changed by using different quantum well-widths or by using different combinations of well and barrier materials.

As noted, the intersubband photodetectors have been designed based on transitions in the valence as well as in the conduction bands. However, in general, those based on electron transitions show improved detectivity compared to the hole-based photodetectors. One of the reasons for this advantage is their lower effective mass.

We notice that, even if the ISBTs in semiconductor QWs are of great interest for applications in optoelectronic devices [15,16], the studies of the ISBT in QWs have been mainly concentrated on III–V semiconductor devices. Nevertheless, the progress in growth technology makes possible the development of low-dimension structures based on II–VI semiconductors. The II–VI-based QWs are promising candidates for ultrafast devices in the mid- or near-infrared regions [17,18]. And specially, CdS/ZnSe /BeTe is a family technologically little controlled, less than GaAs [19,20] and even

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than GaSb/InAs [21], but have attracted a great interest in last years for 1.55 μm photoconduction and also for higher wavelengths.

The purpose of this work is to model and study the performances of quantum well infrared photodetector (QWIP) based on intersubband transitions in a CdS/ZnSe/BeTe system. We have previously analyzed the ISBT with 1.55 μm in a single QW [22]. We have developed an approach to achieve CdS/ZnSe/BeTe based ISBT waveguide devices. The absorption coefficient and its dependence with an applied electric field have been investigated [23]. In the present work, we propose and model an electron-based QWIP operating at 3.3 μm in a CdS/ZnSe/BeTe system. In order to optimize the modeled structure, the QWs and barriers are carefully

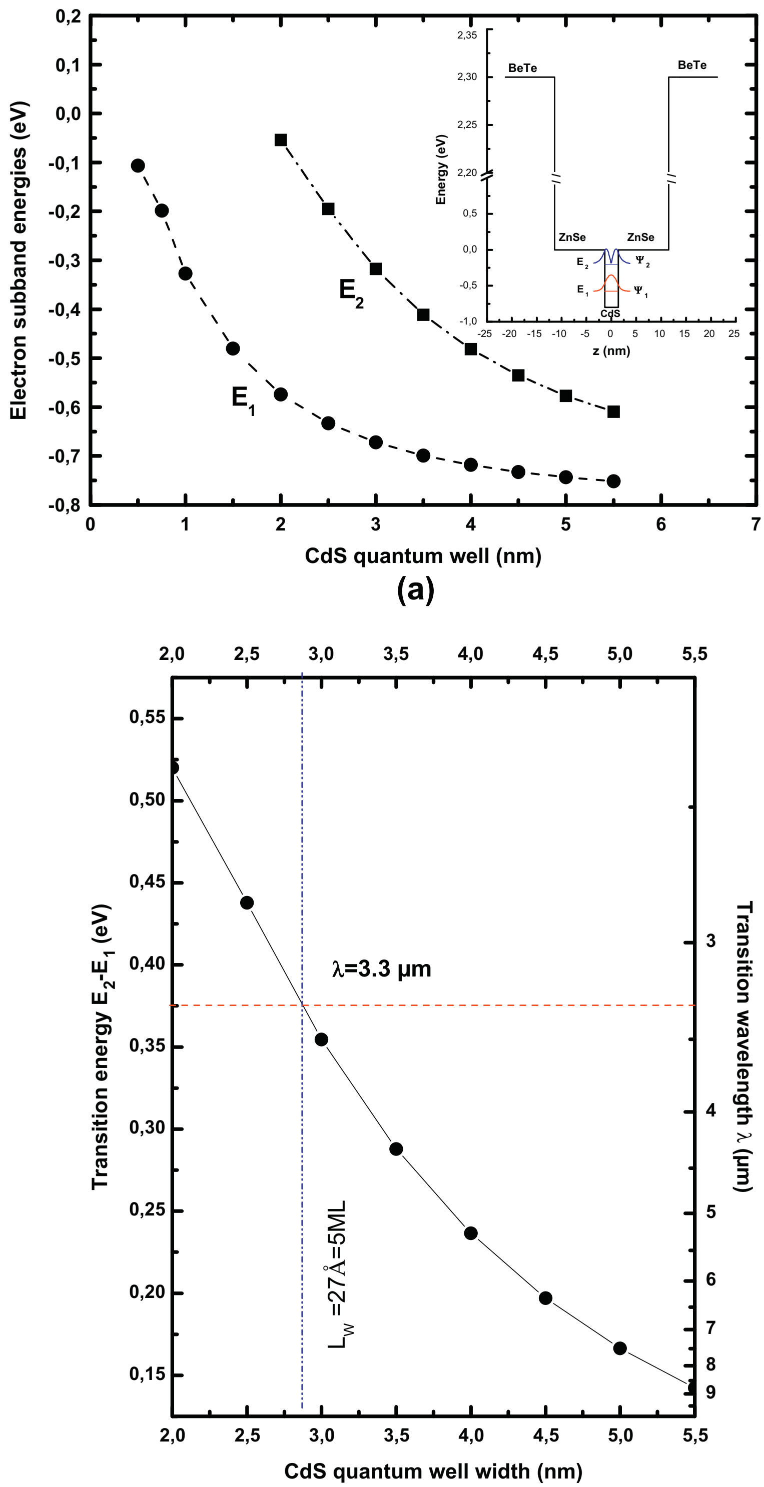

Fig. 1. (a) Confinement energies of the first E_1 and second E_2 electron levels in a ZnSe/CdS/ZnSe quantum well as a function of CdS width for a 20 nm BeTe contacts and a 10 nm thick ZnSe; (E_2 is not confined below 1.9 nm). (b) Energy and wavelength for intersubband transition E_2–E_1 versus CdS well width. The 3.3 μm (0.375 eV) required wavelength is achieved with 2.7 nm well width. The conduction band profile for one quantum well is shown in insert of Fig. 1a).