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Terahertz absorption in AlGaAs films and detection using heterojunctions

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Abstract

HEterojunction Interfacial Workfunction Internal Photoemission (HEIWIP) detectors using AlGaAs as both the emitter and the barrier material with different Al fractions for the two layers are demonstrated. The extension of the HEIWIP concept to wavelengths longer than 110 μm in the GaAs/AlGaAs system requires the use of AlGaAs as the emitter material to reduce the barrier height. The p-type doping produces an offset in the valance band between doped and undoped material. The Al fraction difference then gives a valance band offset in the opposite direction, which reduces the total offset. The FIR absorption up to ~400 μm for AlGaAs films with different Al fractions and doping are presented. The absorption in the films with low Al fraction (1%) shows little variation from comparable GaAs films while for 20% Al, the absorption is reduced. The spectral results on a device with 12% Al emitters and 11% Al barriers have shown a response of 0.6 A/W at 30 μm with $D^* = 3 \times 10^{10}$ Jones measured at 5 K. The low responsivity is due to the reduced number (3) of emitters in the test device, and when scaled for the number of emitters this is comparable to results obtained from GaAs/AlGaAs HEIWIP detectors. Based on these results, a design for a 300 μm detector is presented and potential difficulties in growth and fabrication such as dopant migration are discussed.

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Keywords: Terahertz detectors; AlGaAs; Heterojunction; Absorption; Refractive index

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1. Introduction

Far InfraRed (FIR) or Terahertz (THz) detectors [1–6] have attracted increased attention for use in both astronomy and other applications. The astronomical interest stems from the many different objects which radiate in the far infrared: dust disks [7,8] and gas molecules such as CO and HD [9] being important examples. THz detectors will be important in studies of planet formation around nearby stars, and the outer planets and their moons. Also, there is a potential for use in early universe studies as the near and mid-infrared emissions of high red shift objects can end up in the THz.

In this paper, results are presented on a novel approach to the development of FIR/THz detectors based on using AlGaAs both as emitters and as barriers. The proposed design is a modification of the standard heterojunction interfacial workfunctions internal photoemission (HEIWIP) detectors [10]. In the standard HEIWIP detectors, doped GaAs emitter layers alternate with undoped $Al_xGa_{1-x}As$ barrier layers. The detection mechanism involves free-carrier absorption in the emitters, internal photoemission across the emitter/barrier interface and collection of the emitted carriers at the contacts. The threshold wavelength λ_0 is determined from the workfunction Δ by λ_0 (μm) = 1240/Δ (meV), where $\Delta = \Delta_x + \Delta_d + \Delta_b$, with Δ_x the contribution from the Al fraction, Δ_d the contribution from the doping, and Δ_b the contribution from the band bending in the barrier as shown in Fig. 1(a). In the standard HEIWIP design, $\Delta_b < 1$ meV (for 1×10^{15} cm^{-3} residual doping) and can be ignored, $\Delta_d \sim 9$–10 meV [11] (for $1-8 \times 10^{18}$ cm^{-3}), and $\Delta_x = 530x$ meV based on 35% offset in the valence band. As x is decreased λ_0 increases, however due to Δ_d there is a limit of $\lambda_0 \sim 110$ μm associated with the MBE growth limit for the lowest Al fraction ($x = 0.005$). At $x = 0$ a homojunction detector [12] will be realized. Although increasing the doping would reduce Δ_d, for homojunctions, the transitions between light and heavy holes will still limit λ_0 to 70–100 μm [13]. An alternate approach explored here is to use $Al_xGa_{1-x}As$ in both the emitters and the barriers as shown in Fig. 1(b). If x is larger in the emitter than in the barrier, $\Delta x < 0$, giving $\Delta_x = \Delta x \times 530$ meV < 0 and $\Delta < \Delta_d$, avoiding the limits for GaAs emitters.

2. Doped AlGaAs absorption

As a first step towards developing a HEIWIP detector using AlGaAs emitters, the absorption was studied in doped AlGaAs thin films. Four p-type $Al_xGa_{1-x}As$ thin films were grown by MBE on 520-μm-thick semi-insulating GaAs

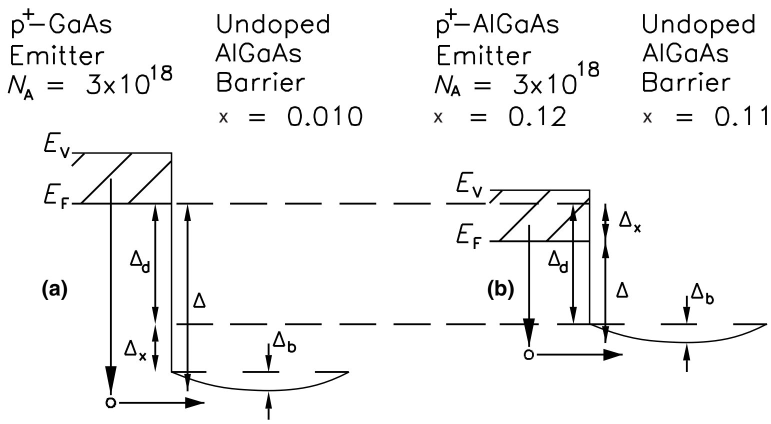

Fig. 1. (a) The band diagram for the standard HEIWIP design showing the contributions to Δ from doping (Δ_d), Al fraction (Δ_x) and the band bending due to residual doping (Δ_b). In the standard approach $\Delta > \Delta_d + \Delta_b$. (b) The modified design with AlGaAs emitter and barriers. Here, $\Delta_x < 0$ so Δ can be reduced to obtain $f_0 < 2.7$ THz ($\lambda_0 > 110$ μm).