Infrared Physics & Technology 54 (2011) 247–251

Contents lists available at ScienceDirect

Infrared Physics & Technology

journal homepage: www.elsevier.com/locate/infrared

InAs/GaSb superlattice based long-wavelength infrared detectors: Growth, processing, and characterization

Alexander Soibel, Jean Nguyen, Linda Höglund, Cory J. Hill, David Z. Ting *, Sam A. Keo, Jason M. Mumolo, Mike C. Lee, Sarath D. Gunapala

Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA

ARTICLE INFO

Article history:
Available online 25 December 2010

Keywords:
Infrared detector
InAs
GaSb
Antimonide
Superlattice

ABSTRACT

We report growth, processing, and characterization of antimonide superlattice long-wavelength infrared photodetectors based on the complementary barrier infrared detector (CBIRD) design. We used photoluminescence measurements for evaluating detector material and studied the influence of the material quality on the intensity of the photoluminescence. We performed direct noise measurements of the superlattice detectors and demonstrated that while intrinsic $1/f$ noise is absent in superlattice heterodiode, side-wall leakage current can become a source of strong frequency-dependent noise. We developed an effective dry etching process for these complex antimonide-based superlattices that enabled us to fabricate single pixel devices as well as large format focal plane arrays.

1. Introduction

The type-II InAs/GaSb superlattice (SL) and InAs/GaInSb strained layer superlattice (SLS) promise absorption coefficients comparable to HgCdTe (MCT), uniformity, reduced tunneling currents, suppressed Auger recombination, and normal incidence operation [1,2]. Owing to the flexibility of the nearly lattice-matched InAs/GaSb/AlSb material systems, many SL infrared detectors with advanced heterostructure architecture have been fabricated, including the nBn [3], the double heterostructure (DH) [4,5], the graded-gap W-superlattice based DH structure [6], the pMp structure [7], and the complementary barrier infrared detector (CBIRD) [8] and related structure [9]. Many of these detectors have exhibited very good performance [10] despite the short lifetimes in SL absorbers [11–13]. The growth and processing of these device structures present special challenges due to the complexity of these advanced heterostructures. In this paper, we focus on the development of CBIRD and present some aspects of material growth and characterization, device processing, and device characterization.

2. The complementary barrier infrared detector device structure

The basic CBIRD device structure consists of a LWIR InAs/GaSb absorber SL sandwiched between an InAs/AlSb hole-barrier (hB) SL, and a MWIR InAs/GaSb electron-barrier (eB) SL. The hB SL and the eB SL are respectively designed to have approximately zero conduction and valence subband offset with respect to the absorber SL, i.e., they acts as a pair of complementary unipolar barriers [8] with respect to the absorber SL. A heavily doped n-type $InAs_{0.91}Sb_{0.09}$ adjacent to the eB SL acts as the bottom contact layer. Detailed results and discussion on this particular CBIRD device have been reported earlier [8,14]. In short, a CBIRD device with a 9.9 μm cutoff reached 300 K background limited infrared photodetection (BLIP) operation at 87 K, with a black-body BLIP D^* value of 1.1×10^{11} cm Hz$^{1/2}$/W for $f/2$ optics under 0.2 V bias. Furthermore, CBIRD-based LWIR imaging focal plane array (FPA) have been recently demonstrated and results of this development were presented at a recent SPIE conference [15], as well as in an article by Gunapala et al. appearing elsewhere in this issue.

3. Material growth and characterization

In growing CBIRD material for focal plane array applications, material quality and uniformity are important considerations. Photoluminescence (PL) measurements in combination with X-ray diffraction (XRD) and atomic force microscopy (AFM) are used for evaluation of the CBIRD detector material directly after growth. The PL peak wavelength serves as a good estimate of the cut-off wavelength of the detector (Fig. 1) and from the PL intensity and the full-width-half-maximum (FWHM) of the PL spectrum, information about the material quality is obtained [16–18]. An important aspect for FPA fabrication is the uniformity of the epi-material. PL intensity mapping generates valuable information about material uniformity across wafer.

* Corresponding author. Address: Jet Propulsion Laboratory, M/S 302-231, 4800 Oak Grove Drive, Pasadena, CA 91109-8099, USA. Tel.: +1 818 354 1549; fax: +1 818 393 4663.

E-mail address: David.Z.Ting@jpl.nasa.gov (D.Z. Ting).

1350-4495/$ - see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.infrared.2010.12.023

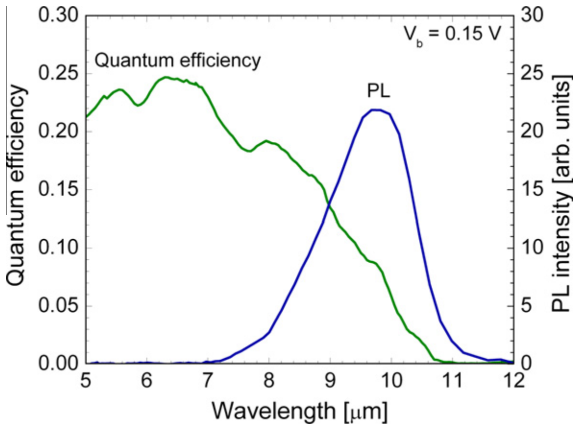

Fig. 1. Comparison of the QE at an applied bias of 0.15 V (left axis) and the PL spectrum of the same sample (right axis) showing a good correlation between the PL-peak and the cut-off wavelength of the detector.

In this study, the radial dependence of the PL intensity of three different wafers was investigated, all grown in the same growth run, symmetrically mounted at different positions on a three-wafer carrier. Samples were grown in a Veeco Gen III molecular beam epitaxy chamber. The sample holder is a molybdenum block with openings for three 50 mm wafers. Each wafer is isolated from the molybdenum block in the front by a pyrolytic boron nitride ring. The wafers are held in place with a tungsten snap ring. 50 mm clear sapphire wafers thermally isolate the GaSb wafers from the snap ring. The PL measurements were carried out at a temperature of 77 K using a Thermo-Fisher Fourier transform spectrometer, run in step-scan mode, with a liquid nitrogen cooled HgCdTe detector. A 658 nm laser diode (excitation power of 3.2 W/cm^2) was used as excitation source.

Two of the three wafers exhibited no or little variation in PL intensity across the 50 mm growth (Sb1995_W1 and Sb1995_W2 in Fig. 2a and b, respectively), while the third wafer exhibited a large variation (Sb1995_W3, Fig. 2c), with a continuous decrease in the intensity from the center towards the edge. Since the wafers are mounted symmetrically on the wafer carrier, the observed variations should not be related to non-uniformity of the flux. One possible explanation for the observed non-uniformity is in substrate mounting. Occasionally a substrate slips out of the thin lip which holds it in place during growth and a small thermal gradient occurs. A second possibility is that the sapphire wafers used for thermal isolation develop thermal non-uniformities as As and Sb compounds slowly accumulate on the backside. From the X-ray data of the InAsSb contact layer, it is apparent that during MBE growth there was a small temperature gradient across one of the wafers (Sb1995_W3 wafer which exhibited variation of PL intensity). Although this temperature gradient is not discernable in the X-ray pattern for the superlattice, we can use variation in InAsSb stoichiometry as a thermal mapper of the wafer temperature during growth (Fig. 3). The PL non-uniformity can then be attributed to the temperature gradient across the wafer. This theory is corroborated by previous PL studies, which show that superlattice PL strength is strongly influenced by the growth temperature [19–21]. For the particular CBIRD structures studied in this paper, a strong variation of the PL intensity is observed for growth temperatures in the range of 390–410 °C. These observations indicate that PL is a necessary tool for the evaluation of superlattice wafers designed for high performance detector application. PL is nondestructive, and provides critical information not available in standard materials analysis techniques such as XRD, surface scanning and AFM. The information contained in PL is useful not only for determining the quality of grown wafers, but also as a feedback mechanism for improving the quality control of the wafer growth process itself.

4. Leakage current and noise

We performed direct measurements of the noise spectra of high performance SL heterodiodes based on a variant CBIRD design [9] at different operational conditions to understand the effects of dark

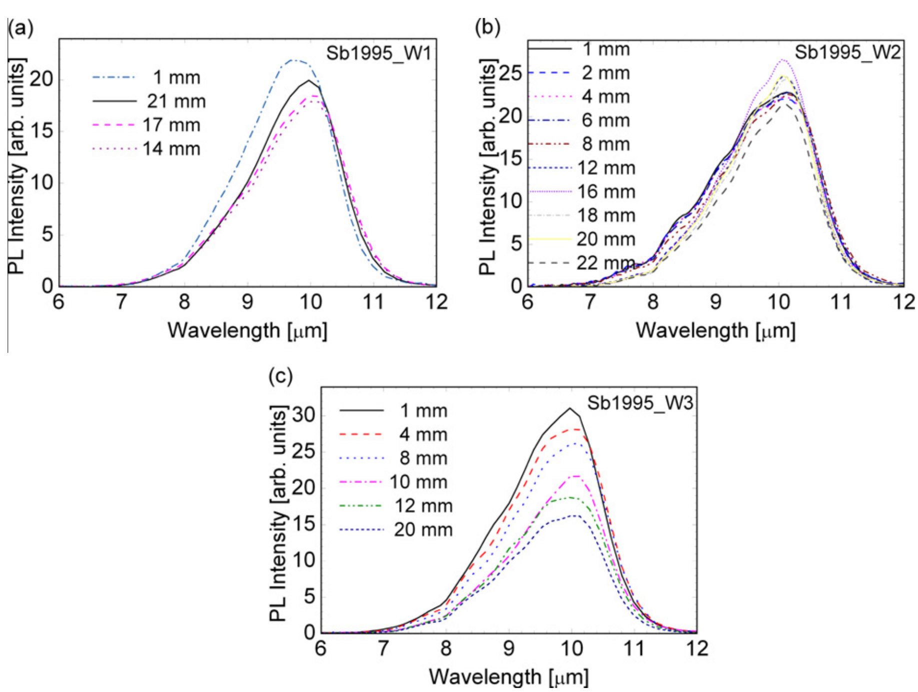

Fig. 2. PL spectra of CBIRD detector material measured along the radius of three different 2″ wafers showing: (a) and (b) small variation of the PL intensity indicating high uniformity (c) a strong radial decrease of the PL intensity indicating a less uniform wafer. Distances are given relative to the center of the wafer.