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Band to band optical absorption in LPE-growth $InAs_{0.94}Sb_{0.06}$ film

Y.F. Lv [a], S.H. Hu [a,*], W. Zhou [a], Y.G. Xu [a], Y. Wang [a], R. Wang [b], G.L. Yu [a], N. Dai [a,*]

[a] National Laboratory for Infrared Physics, Shanghai Institute of Technical Physics, Chinese Academy of Sciences, Shanghai 200083, PR China
[b] Key Laboratory of Infrared Imaging Materials and Detectors, Shanghai Institute of Technical Physics, Chinese Academy of Sciences, Shanghai 200083, PR China

HIGHLIGHTS

- InAsSb films with different carrier concentration were obtained by LPE.
- The complete optical absorption spectra of InAsSb films were obtained.
- The E_g of InAsSb film was obtained by fitting the intrinsic absorption region.
- The E_o value decreases with decrease of film carrier concentration.

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ABSTRACT

$InAs_{1-x}Sb_x$ films with $x = 0.06$ were grown on InAs (100) substrates by liquid phase epitaxy (LPE). Different purification procedures were applied to get InAsSb samples with different carrier concentration. The complete optical absorption spectra including absorption edge and intrinsic absorption region of InAsSb samples were extracted from the room temperature transmission spectra. The energy band gaps of InAsSb samples were obtained by fitting the intrinsic absorption spectra, giving rise to the values of 303.4–305.1 meV. The reciprocal slope (E_o) of the absorption edge related to the carrier concentration was also determined. The E_o value decreases with decrease of InAsSb epilayer carrier concentration.

1. Introduction

InAsSb material is very suitable for the fabrication of efficient and reliable mid-infrared photodetectors due to its stability, high electron mobility and small Auger recombination [1,2]. The band-to-band optical absorption is important for understanding the infrared optical absorption of InAsSb thin film, and it also plays an important role in optimizing the absorber layer thickness of the multilayer device architecture [3,4]. However, there are few reports on the research of the complete absorption spectra for InAsSb material. The determination of band gap from the transmission spectra is an acceptable method for narrow band gap materials reported by Chu et al. [5] since it is not easy to get bandgap data at or near room temperature by photoluminescence. In this paper, we report on this method to get the complete absorption spectra including absorption edge and intrinsic absorption region for narrow bandgap InAsSb material.

In this work, InAsSb films with different carrier concentrations were obtained by different purification procedures. InAsSb epilayers glued on sapphire substrates were used for electrical and optical characterization after the conductive InAs substrates were removed completely using chemical mechanical polishing (CMP). The film thicknesses were obtained from the interference fringes at the transparent region of Fourier transform infrared transmission spectra (FTIR). The room temperature optical absorption spectra were extracted from FTIR. The band to band energy gap and the characteristic energy of Urbach edge were also determined by fitting the intrinsic absorption region and absorption edge of the InAsSb sample, respectively.

2. Experimental details

InAsSb epilayers were grown on InAs (100) substrates using the conventional horizontal graphite boat system in ultrapure hydrogen ambient. The source materials were 7 N pure indium metal, undoped crystalline InAs wafers and 7 N pure antimony (Sb). Prior to the epitaxial growth, the source materials were baked at 650 °C for 3 h (for Sample A) and 8 h (for Samples B and C) to reduce the concentration of residual impurities. Excessive weighting for the melt composition is necessary in order to make up for the loss to component due to the element volatilization resulting from a long time baking. In particular, 2×10^{-5} mole fraction

* Corresponding authors. Tel.: +86 2125051870, +86 2165169633.
E-mail addresses: hush@mail.sitp.ac.cn (S.H. Hu), ndai@mail.sitp.ac.cn (N. Dai).

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rare-earth element Gd was added to the growth solution for Sample C to purify it further. Growth was initiated at 550 °C using the supercooling technique with a 12 °C supersaturation and the cooling rate was 0.2 °C/min.

The structural properties of InAsSb epilayers were investigated by high-resolution X-ray diffraction (HRXRD) (Bruker, Germany, D8/Discover 2000) measurements. Only Cu Kα_1 line (λ = 1.5406 Å) was provided by the Ge (220) monochromator. The InAs substrate was removed by CMP method to eliminate its influences on the electrical and optical properties of InAsSb film, which was glued on sapphire substrate. The complete removal of the substrate was identified by the HRXRD measurement and the interfero-microscope observation (Olympus, Japan, STM6). Electrical properties of InAsSb samples were examined by Hall measurements. The FTIR transmission spectra (Bruker, Germany, VERTEX80 FTIR) measurements were carried out to characterize the infrared optical properties of InAsSb samples at room temperature with a spectral resolution of 2 cm^{-1}.

3. Results and discussion

From Hall measurements, the carrier concentration of InAsSb sample ranges from 2.9 × 10^{16} cm^{-3} to 9.5 × 10^{15} cm^{-3}. The purification procedure, epilayer thickness, carrier concentration, energy band gap and characteristic energy of Urbach edge for each InAsSb sample are summarized in Table 1.

The structural properties of InAsSb films were characterized by HRXRD in a normal 2θ–ω mode. As shown in Fig. 1, the (400) peak of InAsSb epilayer is located at a lower angle than that of InAs substrate, indicating that the lattice constant of the InAsSb epilayer is larger than that of the InAs substrate. The lattice constant of InAsSb epilayer can be deduced from Bragg diffraction equation. Then, the lattice mismatch between the InAsSb epilayer and the InAs substrate is estimated to be around 0.4%. Assuming Vegard's law holds for InAs–InSb systems, the Sb content of the $InAs_{1-x}Sb_x$ epilayer is determined to be x = 0.06. The (400) rocking curve of $InAs_{0.94}Sb_{0.06}$ film is obtained to evaluate the film quality. As shown in the inset of Fig. 1, the experimental data is fitted well with a Gaussian function, and the full-width at half-maximum (FWHM) of the (400) rocking curve is extracted to be 226 arc sec, indicating high crystalline quality of the epilayers.

Fig. 2(a) shows the room temperature FTIR transmission spectra for $InAs_{0.94}Sb_{0.06}$ films glued on sapphire substrates. The transmission spectra consist of three parts: a flat transparent region at low energies where absorption coefficient is very small, a sharp absorption edge, and an intrinsic absorption region at high energies. Because the surfaces are relatively smooth, the transmission spectra show a number of sharp interference fringes in the transparent region. Fig. 2(b) shows the zoom-in interference fringes. We can see that there are two sets of interference waveforms in each transmission curve. The interference fringes with long period are attributed to the interference effects arising from InAsSb films, while the interference fringes with short period are from sapphire substrates. The thicknesses of three samples are calculated from the interference fringes at the transparent region by using the equation:

Table 1
Lists of the purification procedure (*pur.*), epilayer thickness (d),carrier concentration (n), energy band gap (E_g) and Urbach slope parameter (E_o) at 300 K for each InAsSb sample.

Sample	*pur.* (h)	d (μm)	n (cm^{-3})	E_g (meV)	E_0 (meV)
A	3	19	2.9 × 10^{16}	303.4 ± 0.1	5.7 ± 0.1
B	8	20	1.5 × 10^{16}	305.1 ± 0.1	5.1 ± 0.1
C	8 + Gd	18	9.5 × 10^{15}	304.9 ± 0.1	4.4 ± 0.1

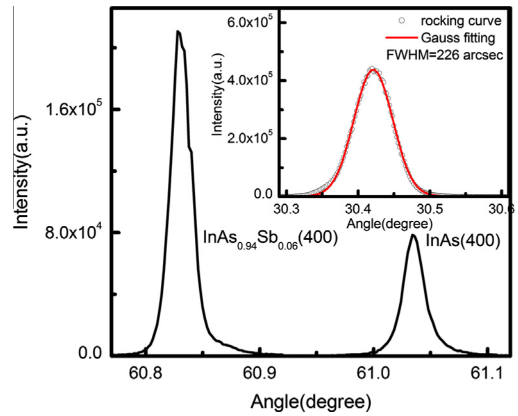

Fig. 1. Typical HRXRD (400) curve of $InAs_{0.94}Sb_{0.06}$ epilayer grown on the InAs substrate. The inset shows the (400) rocking curve (open circles) of the $InAs_{0.94}Sb_{0.06}$ epilayer, which is fitted with a Gaussian function (red solid line). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

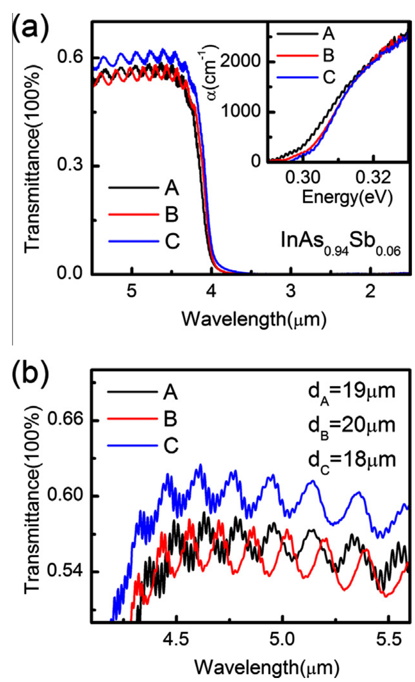

Fig. 2. (a) The room temperature FTIR transmission spectra for $InAs_{0.94}Sb_{0.06}$ films glued on sapphire substrates. The inset shows the corresponding absorption spectra derived from the transmission spectra. (b) Zoom in on interference fringes in the transparent region.

$$d = \frac{\lambda_1 \lambda_2}{2n(\lambda_1 - \lambda_2)}, \tag{1}$$

where d is the film thickness, λ_1 and λ_2 are wavelengths at two adjacent maxima (or minima), n is the refractive index of InAsSb film. The refractive index used here is n_{InAsSb} = 3.53, which is obtained from interpolation of the InAs and InSb binaries, where n_{InAs} = 3.50, n_{InSb} = 3.96 [6]. The values of d determined by Eq. (1) for different samples are listed in Table 1, which are close to the values obtained by interfero-microscope measurements. The absorption edge and the intrinsic absorption region of transmission spectra are used to extract the absorption coefficient of InAsSb, which is analyzed below.

The transmittance (T) can be rewritten according to Hougen's formula [7,8]: