Characterization of InGaSb/GaSb p-n photodetectors in the 1.0- to 2.4-μm wavelength range

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Abstract. Optical and electrical characteristics of InGaSb p-n photodetectors are presented at different temperatures. The device structures were grown on GaSb substrates using organic metal vapor phase epitaxy. Spectral calibration indicates peak responsivity around 2 μm, equivalent to 58% quantum efficiency, with 2.3-μm cutoff at room temperature. Reducing the device temperature increases the responsivity and shifts the cutoff wavelength to a shorter value. Current voltage measurements at different temperatures indicate that tunneling is the primary leakage current mechanism. Assuming Johnson limited performance, detection calculations resulted in 4 × 10^10 cm^2 Hz^1/2/W indicating that InGaSb is a superior material for 2-μm detection applications. © 2004 Society of Photo-Optical Instrumentation Engineers. [DOI: 10.1117/1.1695566]

Subject terms: infrared; detectors; epitaxy; spectral response; detectivity.


Detectors for the 2-μm wavelength are important for several applications such as atmospheric remote sensing and fiber optic communication systems. InGaSb p-n photodiodes grown on intermediate buffer layers, show cutoff wavelengths near 2.5 μm. InGaSb bulk band gap with In content was reported in a study of InGaSb/GaSb strained-layer quantum well structures. Investigation of InGaSb/GaSb strained-layer superlattice structures exhibited a peak absorption wavelength that can be switched from 1.77 to 1.92 μm depending on the bias voltage. With suitable composition, InGaSb, grown on GaSb substrates, may provide the basis for photonic devices operating in the 2-μm range. In this letter the optical and electrical characteristics of InGaSb/GaSb p-n photodetectors are presented.

The p-n mesa-type junction photodiode reported here consists of p-type and n-type epitaxial layers of InxGa1-xSb (x = 20%), grown on a n-type GaSb substrate. The epitaxial films are grown using low-pressure organic metal vapor phase epitaxial reactor. Trimethylgallium, trimethylindium, and trimethylantimony were used as the precursors for Ga, In, and Sb respectively. Figure 1 shows the device geometry. The substrates were first degreased in organic solvents, and etched in HCl and immediately placed in a graphite susceptor that was heated by RF. The growth was done at 600°C. First, the 5-μm-thick n-type layer doped to 10^17 cm^-3 was grown followed by 0.6-μm-thick p-type InGaSb. Diethyltellurium was used as the n-type source and silane was used as the p-type source. The mesa device structures were fabricated by photolithography, and contacts were made by depositing 2000 Å gold followed by 1-μm-thick silver. Different area p-n junction diode and photodiode samples were fabricated and characterized on the same wafer. The diameters of the diode samples were 0.8, 1.2, and 2.9 mm, while the diameters of the sensitive area of the photodiode samples were 0.8 and 1.9 mm.

Figure 2 shows the spectral response of a 0.8-mm photodiode sample obtained at different temperatures with 0-V bias voltage. The spectral response was measured with the substitution method using a PbS reference detector in the 1- to 2.4-μm wavelength range. A quartz-halogen lamp and 40-nm resolution monochromator were set as the radiation source, which provides 7.5 × 10^-7 W/cm^2 mean intensity in the specified wavelength range. The output radiation was modulated with an optical chopper at 179 Hz. The detector output was conditioned using a pre-amplifier (Stanford Research Systems; SR 570) with a 10-μA/V sensitivity and then measured using a lock-in amplifier (Optronics Laboratories; OL 750-C). Data was acquired with 1- and 1.5-s settling and integration times respectively. The uncertainty in the calibration transfer is estimated to be 1.2%. A temperature controller and thermoelectric cooler were used to set and stabilize the wafer temperature within 0.1°C. Nitrogen purging was used to prevent water vapor condensation and ice formation on the detector sensitive area at operating temperatures lower than 0°C (Ref. 7). The two distinctive responsivity peaks at 1.7 and 2 μm correspond to the band gaps of the GaSb and InGaSb materials respectively. Cooling down the device results in shifting the cutoff wavelength to shorter values, corresponding to the energy band gap change with temperature. Besides, cooling increases the device responsivity due to the increase of diffusion length of the minority carriers. For a fixed temperature, increasing the bias voltage had a negligible influence on the spectral response. The quantum efficiency (shown in the inset of Fig. 2) reaches a maximum value of 62.2% at about 1.4 μm, and 58.1% at 2 μm.

Figure 3 shows the dark current as a function of bias voltage at 20 and −20°C for the same device. Dark current was measured using a modulator DC source/monitor (HP; 4142B); 10-mV resolution, 10 averages, and 1-s settling time settings were used for data acquisition leading to an
Fig. 1 Schematic cross section of the InGaSb p-n photodiode on GaSb substrate.

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estimated measurement uncertainty of 5%. At a certain temperature, the dark current increases with increasing reverse bias voltage. Relatively high dark current was observed due to the leakage current through the non-passivated surface and the defects generated at the interface as a result of lattice mismatch. Cooling down the wafer insignificantly reduces the dark current, suggesting that tunneling is the primary leakage current mechanism. This was expected due to the present high substrate doping ($10^{17}$ cm$^{-3}$). Also shown in Fig. 3 is the detectivity ($D^*$) variation with bias voltage at 20 and $-20^\circ$C obtained at 2 $\mu$m. The detectivity was calculated assuming Johnson-limited performance using the dark current and responsivity data applying the relation

$$D^* = \frac{\mathcal{R}}{4kT} \cdot \sqrt{\frac{A}{\frac{\partial I_d}{\partial V}}},$$

where $\mathcal{R}$ is the responsivity at the specified temperature $T$ and wavelength $\lambda$, $A$ is the device sensitive area, $k$ is the Boltzmann’s constant, and $\frac{\partial I_d}{\partial V}$ is the derivative of the dark current with respect to the bias voltage (dynamic conductance) at the specified temperature $T$. Maximum detectivities of 3.4 and $4.7 \times 10^{10}$ cm Hz$^{1/2}$/W were observed at 145- and 165-mV reverse bias voltages for 20 and $-20^\circ$C, respectively. These correspond to noise equivalent power (NEP) of 2.1 and 1.5 pW/Hz$^{1/2}$, and equivalent to noise current spectral density of 1.9 and 1.6 pA/Hz$^{1/2}$ respectively at 20 and $-20^\circ$C.

InGaSb detectors grown on GaSb substrates are good candidates for 2-$\mu$m detection. Growth and characterization of InGaSb p-n photodetectors has been presented. Organic metal vapor phase epitaxial technique was used to grow InGaSb p-n layers on n-type GaSb substrates. Spectral response measurements indicated the necessity for optimizing the operating temperature to increase the quantum efficiency while maintaining the cutoff wavelength above 2 $\mu$m. Doping reduction and suitable passivation technique should be attempted to further reduce the dark current. For a certain operating temperature the detectivity was optimized with respect to the applied bias voltage. The calculated Johnson limited detectivity is comparable to high-performance 2-$\mu$m InGaAs PIN photodiodes operated at room temperature.

Acknowledgment

This effort is part of the Laser Risk Reduction Program funded by NASA’s Earth Science Technology Office and NASA’s Enabling Concepts & Technologies Program. The authors would like to thank Frank Peri for his support.

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