Sb-based two-color photodetector fabrication and characterization

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Abstract. Sb-based dual-band detectors were fabricated and characterized. The first band consists of an InGaAsSb pn junction for long wavelength detection, while the second band consists of a GaSb pn junction for shorter wavelength detection. Both bands were grown, lattice-matched to a GaSb substrate, using metal-organic vapor phase epitaxy. Three metal contacts were deposited to access the individual junctions. Spectral response measurements indicated either independent operation of both detectors simultaneously, or bias selective operation for one detector while serially accessing both devices.
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Antimony (Sb) based materials are suitable for the fabrication of optoelectronic devices in the mid-infrared wavelength range. The availability of GaSb substrates allows the growth of multilayer structures, where lattice-matched ternary and quaternary layers could be tailored to detect wavelengths in the range of 0.8 to 4 μm.[1] Such detectors are useful for several applications, including atmospheric remote sensing. In such applications, the simultaneous detection of optical signals at different wavelengths allows monitoring several atmospheric species with a single excitation source and receiver. This addresses the necessity for two-color and multi-color detectors, which will reduce system complexity, weight, and cost.[2] In this paper, the fabrication and characterization of a dual-band detector are presented. The first band consists of an InGaAsSb pn junction for 600 to 1870 nm wavelength detection, while the second band consists of a GaSb pn junction for 600 to 1700 nm detection. Compared to HgCdTe and quantum-well (QWIP) two- and multi-color detector technologies, which usually require liquid nitrogen operation, the presented Sb-based detector is capable of room temperature operation.[3,4]

The growth of the dual-band detector films, as shown in Fig. 1(a), was carried out using in-house built horizontal metal-organic vapor phase epitaxy (MOVPE) equipment. The carrier gas was ultra-pure hydrogen (H_2) at a flow rate of 4500 sccm, and the growth pressure was maintained at 100 Torr with temperature stabilization at 600 °C. Organometallic sources include trimethylindium, trimethylgallium, tertiarybutylarsine, and trimethylantimony, and the n- and p-dopant sources were diethyltelluride and silane (0.01% in H_2), respectively. Dimethylzinc (0.1% in H_2) was also used as a p-type dopant for certain cases. The n-type doping density is about $8\times10^{16}\ \mathrm{cm}^{-3}$ for the GaSb layer and $10^{18}\ \mathrm{cm}^{-3}$ for the InGaAsSb layer. The growth rate was approximately 3.8 and 4.0 μm/h for the GaSb and InGaAsSb layers, respectively. Multilayer structures for the dual-band devices were grown on nominally undoped p-type GaSb substrates. The structure schematic is shown in Fig. 1(a) for p/n/n/p-on-p photodetectors. The as-grown multilayer films were characterized and analyzed with optical microscopes, atomic force microscopes (AFM), x-rays, and electron microprobes. The typical alloy composition for the quaternary material is $\mathrm{In}_{0.13}\mathrm{Ga}_{0.87}\mathrm{As}_{0.11}\mathrm{Sb}_{0.89}$ as determined by x-ray diffraction and electron microprobe analyses.

Device fabrication was carried out by applying standard processing using three masks. The first mask was used to delineate the upper diode mesa and the second mask was used to define the lower mesa diode structures [see Fig. 1(b)]. The third mask was used to pattern the contact metals using liftoff technique. Mesa diodes were patterned using wet chemical etching. The contact metals were evaporated using e-beam evaporation. The metal contacts consisted of Pd (150 Å, first layer)/Ge (300 Å)/Au (150 Å)/Ti (400 Å)/Au (1500 Å, last layer) for the front contact. The back contact was achieved by evaporating Ti/Au on the backside of the substrate. No passivation or antireflective coating was used for this device. Several wafer-based devices were fabricated and characterized. No attempt at dicing or packaging the detectors was performed.[5]

The detector characterization included dark current and spectral response measurements obtained at 23.5±0.1 °C. The dark current curves for the upper and lower photodetectors, shown in Fig. 1(b), indicate typical exponential dependence on the bias voltage, conforming to the diode theory. The spectral response of the dual-band photodetectors was measured by applying the substitution method, using two reference detectors.[6] The first is a 1-cm-diameter Si detector for the 500 to 1000 nm wavelength range, and the second is a $3\times3\ \mathrm{mm}^2$ PbS detector for 1000 nm up to 2200 nm. Figure 2 shows the spectral response of the upper and lower detectors under different bias voltages. To operate both devices separately, the top and middle contacts were used to access the upper GaSb p-n junction detector and the middle and bottom contacts were used to access the lower InGaAsSb p-n junction detector. The cutoff wavelength of the upper device is about 1.7 μm, which corresponds to the GaSb band gap, while the cutoff of the lower device corresponds to the InGaAsSb and was tuned to

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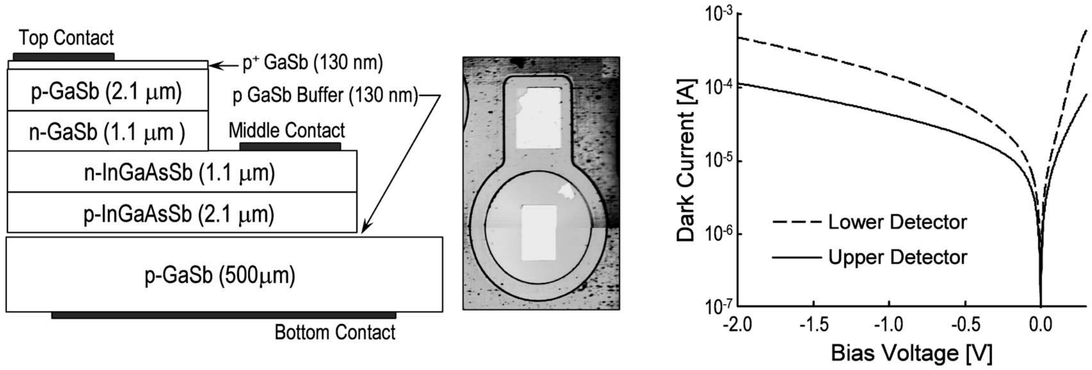

(a) (b)

Fig. 1 (a) Schematic and optical microscope image of the two-color detector. The upper GaSb layers form the upper detector, with 775 μm diameter (inner circle on the image). The middle InGaAsSb layers, along with the GaSb substrate, form the lower detector, with 900 μm diameter (outer semicircle on the image). The bright rectangles are the top and middle metal contacts. (b) Dark current measurements at 23.5°C.

about 1.9 μm. As indicted in Fig. 2, the response of the lower detector totally overlaps that of the upper one. This could be tailored using different composition, and yet preserving the lattice-match condition. Controlling the composition will also shift the cutoff wavelength of the quaternary material to a longer wavelength up to 4 μm. Biasing the pn junction changes the responsivity of the detector. For the reverse bias case the depletion width increases leading to enhanced drift of the photogenerated charge carriers, as opposed to the forward bias case in which it results in narrowing the same region.

Figure 3 shows the spectral response of the same sample, normalized to the device area. In this case both devices (upper and lower are serially connected) were accessed only by using the top and bottom contacts. While the bottom contact grounded, applying a voltage to the top contact leads to forward bias of one of the p-n junctions and reverse bias of the other. This results in selectable detection for the devices by the polarity of the applied bias voltage as indicated in Fig. 3. This behavior is attributed to the simultaneous change in the depletion regions with the bias voltage as discussed before, but for the two devices at the same time.

In this letter, fabrication and characterization of an Sb-based dual-band two-color detector are presented. GaSb and InGaAsSb pn junctions were grown lattice-matched to GaSb substrate using MOVPE. Dark current measurements illustrated the diode behavior of both lattice-matched detectors. Spectral response measurements indicated either independent operation of both detectors simultaneously, or selective operation of one detector, by the polarity of the bias voltage, while serially accessing both devices.

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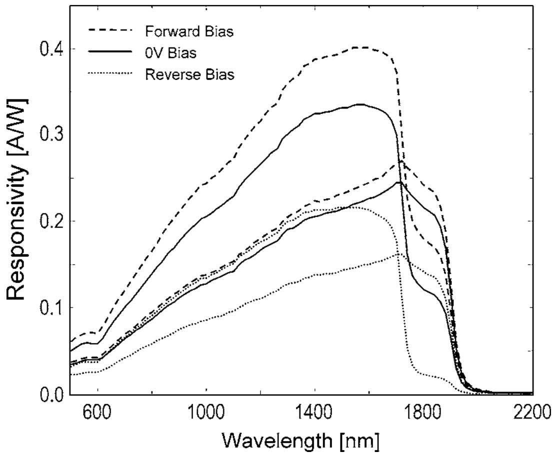

Fig. 2 Spectral response measurement obtained by independent operation for both upper and lower detectors at different bias voltages and 23.5°C temperature. Forward and reverse voltages were set to 100 mV. The upper GaSb detector has the shorter cutoff wavelength.

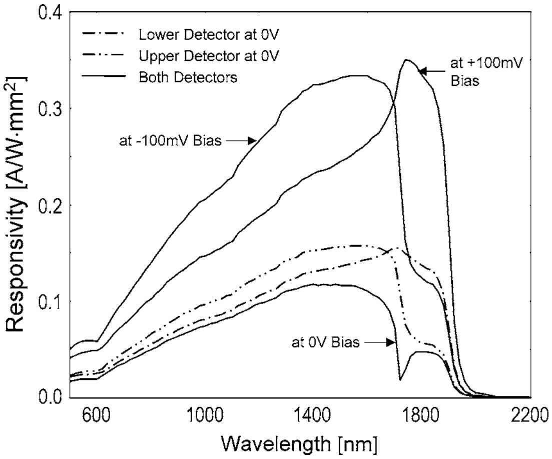

Fig. 3 Normalized spectral response for both detectors at different bias voltages, demonstrating the bias selectable operation. The detectors were accessed by grounding the bottom contact and applying the bias to the top contact. The normalized spectral response for the independent operation for both detectors are also shown for comparison.

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