Resonant cavity enhanced photodiodes on GaSb for the mid-wave infrared

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ABSTRACT

We report the design, growth, processing, and characterization of resonant cavity enhanced photodiodes for the midwave infrared at ~3.72 μm on GaSb. Using AlAsSb/GaSb mirrors, AlAsSb barrier and spacer layers and a thin 96 nm InAsSb absorber, we observed dark current and detectivity behavior superior to common InAsSb nBn detectors in the literature, with peak specific detectivity values of 8×10^{10} and 1×10^{10} cm $Hz^{1/2}$ W^{-1} measured at 250 K and 300 K, respectively. In the same temperature range, the linewidth of the detector response was <44 nm and the quality factor ~80. The peak quantum efficiency was >60% where the enhancement due to the resonant cavity was ~20x. We estimate that the devices can operate close to, or slightly above, the background-limited infrared performance limit imposed on broadband detectors for a 300 K scene.

Infrared photodiodes operating in the midwave infrared (MWIR) have been subject to much development in recent years.[1–5] In particular, nBn detectors,[6] as well as bulk InAs, InSb, and InAsSb, are now commercially available.[7,8] More intricate designs such as quantum wells and quantum cascade detectors are also being improved.[9,10] The spectroscopic sensing of toxic or pollutant gases is a primary application of MWIR detectors: CH_4, CO_2, and CO are well known examples, with absorption features around 3.3 μm, 4.3 μm, and 4.6 μm, respectively.[11] However, given that many chemical agents, pollutants, or biological markers, have "fingerprint" IR absorption signatures, the detection of these substances is a further application. Warfare agents such as VX or Sarin are salient examples, known to exhibit signatures between 9 and 10 μm.[12] Spectroscopy-based detection is usually achieved using tunable lasers paired with broadband sensors. From the literature, it is found that resonant cavity enhanced (RCE) photodiodes can offer high spectral discrimination and reduced dark currents and noise compared to conventional photodiodes.[13–15] The principle of operation is the placement of a thin absorber layer within an optical cavity typically comprised of distributed Bragg reflector (DBR) mirrors. The dark currents and noise are reduced with the absorber thickness, whilst the mirrors select and enhance sensitivity in a narrow spectral band. From theory, it is found that the dark currents due to Auger and trap-related processes scale with the absorber volume, and both can be reduced by as much as two orders of magnitude compared to a conventional photodiode whilst maintaining strong quantum efficiency (QE). RCE photodetectors were first practically realized in the 1980s and 1990s using GaAs/AlGaAs DBR mirrors, which are a mature technology due to vertical cavity surface emitting laser development. Several authors have reported InAs-based devices grown mismatched on GaAs, sensitive at ~3.1 μm.[16] Others have used InGaAs/GaAs quantum wells.[17] InP-based devices have further been demonstrated with an InGaAs absorber, sensitive at 1.55 μm and grown lattice matched.[18] Further studies have used PbTe films and Ge/As_2S_3 mirrors on Si.[19] For this work, III-Sb RCE photodiodes were envisaged as ideal candidates for use in detection systems targeting a wide range of substances, due to their extended detection wavelength, high spectral selectivity, and low dark currents and noise. An RCE photodiode design was conceived and grown on GaSb. The choice of a GaSb substrate allows for an extension of the operating wavelength. For the present work, 96 nm of $InAs_{0.91}Sb_{0.09}$ allowed for sensitivity at