Mid wavelength infrared resonant cavity enhanced photodiodes for infrared spectroscopic sensing of chemicals and other narrow-band optical signals

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ABSTRACT

Inserting an infrared detector architecture into an optical cavity between two high-reflectivity mirrors allows incident light to reflect and pass through the detector multiple times, thereby enhancing absorption within the active region. This allows for a 40-100x thinner optical absorbing region compared to conventional infrared detector structures which reduces the detector dark current and noise and enhances SNR. We report the design, growth, fabrication and characterization of resonant cavity enhanced MWIR photodiodes on GaSb substrates. Devices on GaSb use AlAsSb/GaSb mirrors, AlAsSb spacer layers, and a narrow 96 nm InAsSb absorber. Dark current and detectivity behavior better than equivalent broadband nBn detectors in the literature have been observed. 34nm linewidth detector response is observed. Resonant cavity-enhanced photodiodes with resonant wavelengths of 3.6μm and 3.72μm are demonstrated with dark currents equal to or lower than Rule 07 over the operating temperature range of the device. D* in excess of $1x10^{10}$ cm $Hz^{1/2}W^{-1}$ at 300K and $8x10^{10}$ cm $Hz^{1/2}W^{-1}$ at 250K have been achieved. Amethyst Research has produced packaged resonant-cavity detectors. The 3.6 μm resonant-cavity enhanced photodiode was packaged within an Amethyst Research designed pre-amplifier package with an integrated TEC for detector cooling.

Keywords: Infrared, MWIR, Mid-Wave, Unipolar Barrier, Resonant Cavity, Detector, Narrowband, Photodiode

1. INTRODUCTION

Conventional, broadband infrared detectors utilize a thick optical absorber which results in increased detector dark current magnitudes, enhanced noise, and increased background photocurrent generation which leads to increased background-limited performance (BLIP) temperatures. Enclosing an infrared detector architecture within an optical cavity and surrounding that optical cavity with high-reflectivity mirrors allows light which enters the cavity to reflect and traverse the cavity multiple times, thereby enhancing the probability of photon absorption within the active region. Practically, this allows for a significantly thinner optical absorbing region than in conventional infrared detector structures, naturally reducing the detector dark current and thus detector noise and enhancing the signal-to-noise ratio (SNR). Such a detector structure is referred to as a resonant cavity-enhanced photodiode (RCE-PD) detector structure.

The concept of a resonant optical cavity is well known and has been used in semiconductor devices extensively[1]. As an example, consider the widely studied vertical-cavity surface-emitting laser (VCSEL) structure which shares the same defining features as the RCE-PD: highly reflective mirrors and an optical cavity[2]. Although there has been substantive research into RCE-PD technology across multiple wavelength bands, including the mid-wave infrared (MWIR), across several semiconductor material families, and utilizing various approaches to optical absorption, high-performance optical detection via RCE-PD detectors within the MWIR has remained elusive[3,4,5,6,7,8].

The advent of unipolar barrier technology for III-V semiconductor-based infrared detection has brought ultra-high resonant cavity-enhanced detectors operating in the MWIR within grasp[9]. Recent efforts by multiple research teams have shown improvements in MWIR RCE-PD detectors based on III-V semiconductors and opened the door to ultra-high performance from these structures[10,11,12].

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