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Resonant Cavity–Enhanced Photodiodes for Spectroscopy of C—H Bonds

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Resonant cavity-enhanced photodiodes targeted within the spectral region of absorption by C—H bonds are demonstrated. The 3.0–3.3 μm region of the infrared spectrum contains many substances that are useful to measure spectroscopically. However, the measurement of individual substances requires a high spectral specificity, that is achieved by the resonant cavity photodiodes with spectral response widths of < 40 nm. Two material systems are investigated for detection at this wavelength range—an InAs absorber on an InAs substrate and an InAsSb absorber lattice-matched to a GaSb substrate. The resonance wavelength of the InAs-based device responds at ≈3.3 μm, closely tuned to an absorption peak of methane to allow precise sensing of this gas. At 300 K a quantum efficiency of 52% is achieved, with a specific detectivity of 2.5×10^{10} cm$\sqrt{Hz}$/W. The InAsSb-based device is sensitive at ≈3.7 μm, but the structure could be tuned to the methane absorption peak. Devices could be simply created to target other substances in the C—H absorption region by altering the layer thicknesses in the structure. Both structures can be used for spectrally specific gas sensing in this region of the infrared.

1. Introduction

Resonant cavity-enhanced photodiodes (RCE–PDs) for the mid-wave infrared (MWIR) have seen significant developments recently, driven by the desire for improved gas sensing.[1,2] The narrow spectral response of this class of detectors allows for spectrally specific targeting of the individual gas absorption features. The MWIR region contains absorption peaks of many significant gases, including CO_2 at 4.3 μm and CO at 4.6 μm. The small part of this region between 3.0 μm and 3.3 μm contains absorption peaks of various substances due to stretching vibrations of the C—H bond. This bond is found within many notable organic compounds, including hydrocarbons, alcohols, and certain nerve agents—making this wavelength range a salient target for RCE–PDs.

Methane (CH_4) is one compound that is of particular focus as it is the primary component of natural gas and a significant contributor to global warming.[3] There are currently many types of sensors available for methane sensing, including optical, calorimetric, pyroelectric, semiconducting metal oxide, and electrochemical sensors.[4] Optical sensors can potentially offer excellent sensitivity, however, they can suffer from a lack of specificity—absorption peaks of other hydrocarbons can interfere with the detection.[5] RCE–PDs can overcome this challenge by deselecting all light outside a specific narrow band, which can be designed so that it only covers the absorption peak of methane. The specific wavelength of interest for methane detection is 3.3 μm.[6]

For an RCE–PD to target a specific absorption peak, the detector has to be designed for a specific target wavelength, which determines the layer thicknesses and the absorber material. III–V-based RCE–PDs have previously been demonstrated at multiple wavelengths, from the shortwave infrared at 2.2 μm,[7] up to 7.8 μm.[8] However, the MWIR has seen the most effort.[9–12] RCE–PDs grown on GaSb substrates have become well established, whereas for the target of ≈3 μm, a lattice-mismatched RCE–PD was grown on a GaAs substrate by Green et al.[11] RCE–PDs on InAs substrates have also been touched upon by O'Loughlin et al.[13]

In this article, we demonstrate an RCE–PD structure on an InAs substrate that has been fabricated to target the methane absorption peak in the MWIR. Use of an InAs substrate allows for native use of the InAs binary absorber material, with minimal defects and dark currents, as well as sensitivity at 3.3 μm. Previous work has demonstrated an RCE–PD utilizing an $InAs_{0.91}Sb_{0.09}$ absorber on a GaSb substrate[10] that could also be adjusted to sense at 3.3 μm. This Letter analyses the performance of the InAs-based RCE–PD and offers comparisons with the InAsSb-based RCE–PD where reasonable.

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The ORCID identification number(s) for the author(s) of this article can be found under https://doi.org/10.1002/pssa.202100056.

DOI: 10.1002/pssa.202100056