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14. ABSTRACT
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photonic jets, photodetectors, photodiodes, strained-layer superlattice, midwave-infrared, sensitivity of photodetectors, microspheres

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Photonic Jets for Strained-Layer Superlattice Infrared Photodetector Enhancement

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***Abstract*— Photonic jets are light beams focused by dielectric microspheres down to subwavelength dimensions. In this work we show that they can be used for enhancing performance of strained-layer superlattice (SLS) infrared (IR) photodiodes in the midwave-infrared spectral band (3-5 μm). We optimized the design of these structures and experimentally demonstrated the increased sensitivity compared to conventional photodetectors.**

Keywords— photonic jets; photodetectors; photodiodes; strained-layer superlattice; midwave-infrared; sensitivity of photodetectors; microspheres

I. Introduction

Over the course of the past decade there has been significant development in regards to the fundamental properties and potential applications of photonic nanojets (PNJs) [1-3] and nanojet-induced modes (NIMs) [4-10], spanning the areas from biomedical optics to super-resolution imaging [11,12]. Dielectric microspheres provide strong concentration of electromagnetic power which can be used for ultraprecise surgery and for increasing the sensitivity of the photodetector devices [13].

In this work, we used InAs/GaSb strained-layer superlattice IR photodiodes integrated with microspheres for focusing light in the near-surface active region of the detectors. Our numerical modeling results indicate that the optimal index of refraction of the microspheres for these detectors is n=1.8. Experimentally, we used soda-lime glass microspheres with sub-optimal index (n=1.44 in midwave-infrared) and demonstrated an order of magnitude increase of the sensitivity of the strained-layer superlattice (SLS) infrared photodiodes.

II. Numerical design

Modern IR photodetector devices often have active regions with the lateral dimensions below 30 μm and a thickness of a few microns located close to the surface of the structure. Our design goals were to: i) optimize the depth of focusing at a micron-scale depth below the surface of a high-index slab and ii) minimize the lateral dimensions of the PNJ.

Two-dimensional simulations were performed by finite element modeling using COMSOL Multiphysics for the wavelength of light λ = 4 μm. As shown in Fig. 1 (a), a dielectric cylinder was placed at the top of a dielectric slab with n = 3.3. We demonstrated that the optimal sphere index for focusing light in near-surface region of the slab is n=1.8, as illustrated in Fig. 1 (b). We also showed that the transverse width of the beam at its waist is about λ/3, as illustrated in Fig. 1 (c).

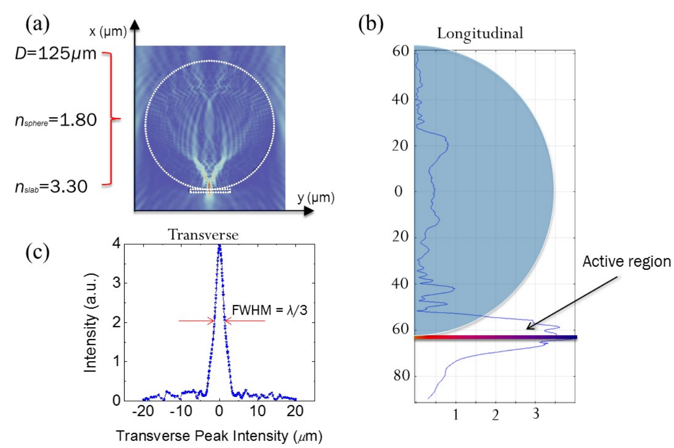

Fig. 1: (a) Electric field map calculated for a plane wave illumination of a 125 μm diameter cylinder with n=1.80. (b) Longitudinal line profile of the irradiance, showing the beam waist in the near-surface region of the slab. (c) Transverse line profile through the peak of the longitudinal line profile.

III. Experimental

A soda-lime sphere with diameter D = 212 μm and n ~ 1.47 was integrated on to the top of a 40 μm photodetector fixed into position using a silicone rubber. As illustrated in Fig. 2, the spectral response was characterized before and after positioning the microsphere. The results illustrate an order of magnitude enhancement of the sensitivity of the detector equipped with the focusing microsphere. The dip around 3.3 μm is likely due to absorption in soda-lime glass.

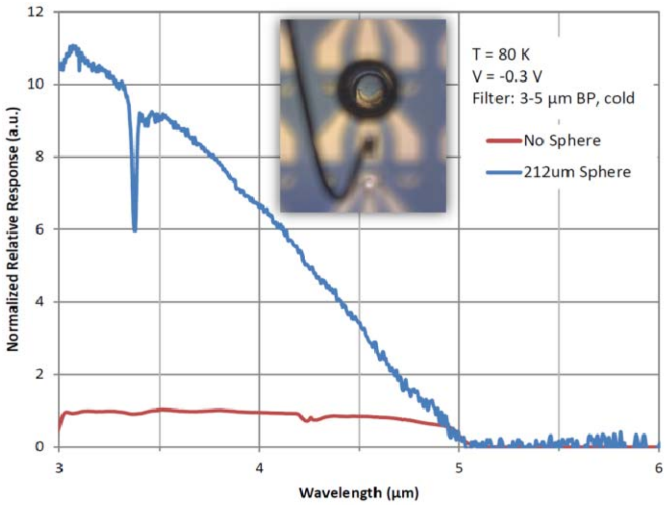

Fig. 2: Direct comparison of the photocurrent, with and without the soda-lime (D = 212 μm, n ~ 1.47).

The decreasing response from 3 to 5 μm is possibly a result of poor IR transmission of the glass but requires further studies which will be performed in the future.

IV. Summary

In this work, we demonstrated that the focusing effects produced by dielectric microspheres allow significant enhancement of the sensitivity of midwave-IR photodetectors.

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