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.

The views, opinions and/or findings contained in this report are those of the author(s) and should not contrued as an official Department of the Army position, policy or decision, unless so designated by other documentation.

Photonic jets, photodetectors, photodiodes, strained-layer superlattice, midwave-infrared, sensitivity of photodetectors, microspheres
Photonic Jets for Strained-Layer Superlattice Infrared Photodetector Enhancement

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.

Conference Name: National Aerospace and Electronic Conference (NAECON)
Conference Date: June 25, 2014
Photonic Jets for Strained-Layer Superlattice Infrared Photodetector Enhancement

Kenneth W. Allen,1,2 Joshua M. Duran,2 Gamini Ariyawansa,2,4 Jarrett H. Vella,5 Nicholas I. Limberopoulos,2 Augustine M. Urbas,2 and Vasily N. Astratov1,2*

1Department of Physics and Optical Science, Center for Optoelectronics and Optical Communications, University of North Carolina at Charlotte, 9201 University City Blvd., Charlotte, NC 28223-0001, USA
2Sensors Directorate, United States Air Force Research Laboratory, Wright-Patterson AFB, OH 45433, USA
3Materials and Manufacturing Directorate, United States Air Force Research Laboratory, Wright-Patterson AFB, OH 45433, USA
4UES, Dayton, OH 45433, USA
5Wyle, Dayton, OH 45433, USA

*Tel: (704) 687 8131, Fax: 1 (704) 687 8197, Email: {kallen62, astratov}@uncc.edu

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 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 $\lambda/3$, as illustrated in Fig. 1 (c).

Two-dimensional simulations were performed by finite element modeling using COMSOL Multiphysics for the wavelength of light $\lambda = 4 \mu$m. 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 $\lambda/3$, as illustrated in Fig. 1 (c).

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.

Fig. 1: (a) Electric field map calculated for a plane wave illumination of a 125 μm diameter cylinder with $n=1.8$. (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 $D = 212 \mu$m and $n \sim 1.47$ 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.
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.

ACKNOWLEDGMENT

The authors thank I. Vitebskiy, J. Derov, R. Ewing and M. Schmitt for stimulating discussions. This work was supported by the U.S. Army Research Office (ARO) through Dr. J. T. Prater under Contract No. W911NF-09-1-0450 and by Center for Metamaterials, an NSF I/U CRC, award number 1068050. This work was sponsored by the Air Force Research Laboratory (AFRL/RYD) through the AMMTIAC contract with Alion Science and Technology.

REFERENCES