Ni-Silicide Schottky Barrier Micropyramidal Photodetector Array

Grant W. Bidney,[1,2] Boya Jin,[1] Lou Deguzman,[1] Joshua M. Duran,[2] Gamini Ariyawansa,[2] Igor Anisimov,[2] Nicholaos I. Limberopoulos,[2] Augustine M. Urbas,[3] Kenneth W. Allen,[4] Sarath D. Gunapala,[5] and Vasily N. Astratov[1,2,*]

[1]*Department of Physics and Optical Science, Center for Optoelectronics and Optical Communications, University of North Carolina at Charlotte, Charlotte, NC 28223-0001, USA*

[2]*Air Force Research Laboratory, Sensors Directorate, Wright Patterson AFB, OH 45433, USA*

[3]*Air Force Research Laboratory, Materials and Manufacturing Directorate, Wright-Patterson AFB, OH 45433, USA*

[4]*Advanced Concepts Laboratory, Georgia Tech Research Institute, Georgia Institute of Technology, Atlanta, GA 30332, USA*

[5]*Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr., Pasadena, California 91030, USA*

**Tel: 1 (704) 687 8131, Fax: 1 (704) 687 8197, E-mail: astratov@uncc.edu*

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***Abstract*—In attempt to increase the quantum yield of metal/silicide Schottky barrier photodetectors, in this work we fabricated and tested Si micropyramidal arrays which are capable to resonantly trap photons in the photodetector areas. To simplify testing, Ni/silicide Schottky barrier photodetectors were formed on the entire 1.5 × 1.5 mm areas occupied by the micropyramidal arrays. Preliminary testing results revealed potentially stronger photoresponse of micropyramids with narrow tops, but further studies are required to compare the performance of such novel photodetector arrays with different geometrical parameters of micropyramids.**

Keywords*—*infrared photodetectors, Schottky barrier photodetector, light concentrators

I. Introduction

Silicon (Si) based photodetectors are widely used in the visible spectrum and have been attractive due to the ease they integrate with electronics. Silicon allows for the mass production of various arrays through the fabrication techniques common to the mature microelectromechanical systems community (MEMS). Some of these structures can be used as light-concentrating structures for integration with photodetectors. The wide variety of uses is appealing, but silicon photodetectors have disadvantages because of the indirect bandgap of silicon, its low absorption, and therefore low quantum yield in the infrared regime.

To create a Schottky barrier, a metal such as Au, Pt, Cu, Al, or Ni can be deposited on the surface of Si as a thin nanometric layer. As a result of such deposition a nanoscale silicide layer is formed in the near-field region. Due to the absorption of photons and transfer of the photoelectrons through the Schottky barrier, such structures can operate as short-wave infrared (SWIR) or mid-wave infrared (MWIR) photodetectors under reverse bias. The quantum yield of such photodetectors is usually not high due to limited absorption and collection of photocarriers in Si. Historically, several approaches have been used to increase the efficiency of such metal/silicide Schottky barrier photodetectors. The main approach is based on using photonic or plasmonic arrays capable to resonantly increase the photons' absorption and/or collection efficiency. In recent years, it has been realized that anisotropic wet etching of Si allows for fast and inexpensive fabrication of micropyramidal arrays which can facilitate light-matter coupling in Si photodetectors [1-4]. Some designs are based on the conversion of incident photons into plasmons, adiabatic compression of plasmon excitations towards the tips of the micropyramids followed by nonlinear processes leading to the generation of electron-hole pairs at the plasmonic hot spots. In the case of inverted micropyramids with 4 μm period, a photoresponse increase of close to 40 times was reported in a 1.15-2.70 μm wavelength band using Cu/silicide Schottky barrier photodetectors [2].

The plasmonic adiabatic compression as well as localized surface plasmon resonances usually take place in subwavelength-scale structures. On the other hand, by using numerical modeling we showed that sufficiently large Si microcones can be considered as dielectric microresonators which can be also used for increasing the sensitivity of Si photodetectors [4-6]. It should be noted that besides their resonator properties, such enlarged microcones or micropyramids can also operate as tapered waveguides or light-concentrating structures. The latter property becomes strongly pronounced in low-index microcones [7, 8]. Light-concentrating structures can be used in focal plane arrays (FPAs) to collect light from the wider areas and deliver it to the compact photodetectors. Since the thermal current noise of photodetector mesas is proportional to their area, use of light-concentrating structures allows for an increase in their signal-to-noise ratio and, potentially, their operational temperature [9, 10]. Previously, this approach was demonstrated using dielectric microspheres placed on photodetector mesas [11-14].

In this work, our motivation was to combine the advantages of the simple technology of fabricating Si micropyramidal arrays by anisotropic wet etching with potential microresonator and light concentrator properties predicted for these structures by numerical modeling [4]. To enable simple detection capability in SWIR regime not requiring significant cooling, we used Ni for fabricating Ni/silicide Schottky barrier photodetectors. This technology was previously used in the Air Force Research Laboratory (AFRL) for studying photodetectors fabricated on flat substrates with additional resonator properties [15, 16]. Since our goal was to study the sensitivity of such structures rather than to build a prototype of the imaging device, we deposited Ni uniformly on the tops and sidewall surfaces of the micropyramidal arrays to create a Schottky barrier over the entire 1.5 × 1.5 mm area. In a preliminary way, our results indicated that a stronger photoresponse can be obtained from the array with smaller tops, but further studies are required to obtain more detailed conclusions.

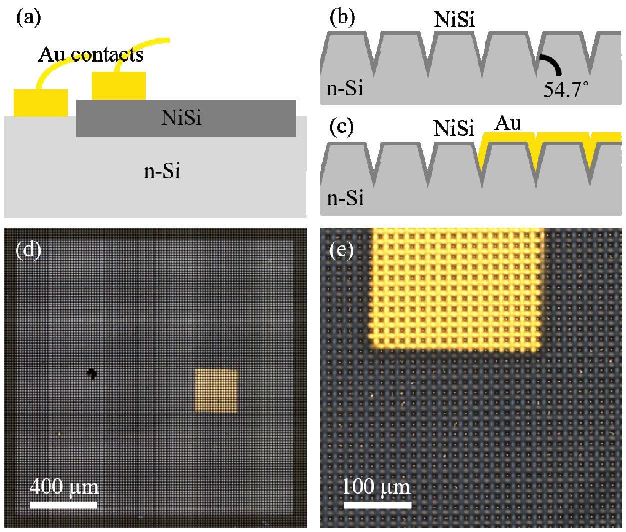

Fig. 1. (a) Diagram of a typical flat Ni/silicide Schottky barrier photodetector. (b-c) Diagrams of a Ni/silicide Schottky barrier photodetector fabricated on a micropyramid array. (d) Microscope image of one 1.5 × 1.5 mm photodetector.fabricated on 10 µm top pyramids. (e) Microscope image of a photodetector fabricated on 1.2 µm top pyramids.

II. FABRICATION

A typical flat Schottky photodetector is shown in Fig. 1(a) [15, 16]. To test how different three-dimensional geometries affect the photoresponse, on the first step micropyramid arrays were fabricated by anisotropic wet etching [17-22]. They were fabricated on a single-side polished (100) *n*-type Si wafer with resistivity from 1-10 ohm-cm and 300 nm thermal silica on both sides. Photolithography was used to create the photoresist squares and then placed in a 10:1 buffered oxide etchant (BOE) bath in order to transfer the pattern to the silica layer. The wafer was then anisotropically wet etched along the (111) planes with tetramethylammonium hydroxide (TMAH), where the surfactant Triton X-100 was added to the bath to reduce the rate of undercutting of the silica squares. Two different 54.7˚ sidewall angle micropyramidal arrays were produced, one with 1.2 µm top sizes (Fig. 2(a, b)) and another with 10 µm top sizes (Fig. 2(c, d)), both with 15 µm pitch.

After fabrication of the micropyramids was finished, the 1.5 × 1.5 mm square photodetector areas were defined through photolithography. A BOE etch was done to remove any leftover silica. 5 nm of Ni was deposited with an electron beam (e-beam) evaporator. Afterwards, the photoresist was removed with acetone and ultrasonic agitation to leave the 1.5 × 1.5 mm photodetectors. The Ni layer was baked for 5 minutes at 500˚ C in an oven to create a NiSi layer. No purging of the oven was done. Next, photolithography was used to define the electrical contacts to create either 250 × 250 µm square regions directly on top of the NiSi layer for the *p*-contact, or to create large regions directly on top of the silicon for the *n*-contact. Chromium and gold (Cr/Au) were deposited with an e-beam evaporator, then liftoff was performed with acetone and ultrasonic agitation. A typical NiSi Schottky barrier micropyramidal photodetector array is shown in Fig. 1(d).

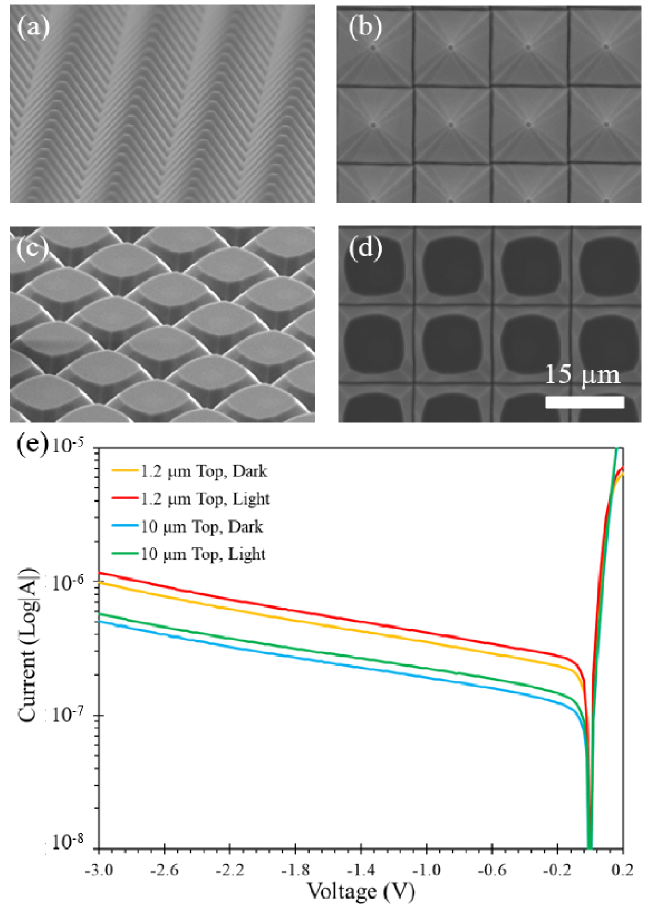

Fig. 2. SEM images of 1.2 µm top Si pyramids taken from (a) angeled and (b) top-down view. SEM images of 10 µm top Si pyramids taken from (c) angled and (d) top-down view. (e) Dark and illuminated I-V curves from a typical NiSi Schottky barrier micropyramidal photodetector array formed by the 1.2 µm and 10 µm top pyramids with the same area of the arrays. The detectors are illuminated with a 1000˚ C blackbody source in combination with a 1.3 µm longpass filter to remove the Si photoresponse.

III. EXPERIMENTAL RESULTS

The NiSi Schottky barrier micropyramidal photodetectors were illuminated in the back-side configuration with a 1000˚ C blackbody source such that the light propagates from the unpolished surface of the wafer, through the wafer to its opposite surface where the pyramids were fabricated and covered with Ni. A 1.3 µm longpass filter was used to remove the Si photoresponse. The dark and light I-V curves were measured using an Agilent 4156C parameter analyzer, and the results are shown in Fig. 2(e). Light is concentrated towards the tops of the micropyramids where it is partly absorbed in the Ni/silicide Schottky barrier photodetectors contributing to photocurrent. The smaller tops were found to produce larger photocurrent compared to the larger pyramid tops. However, the dark current was found to be also much larger for micropyramids with smaller tops. More detailed studies with small incremental steps for the size of the top base are needed to establish optimal geometry of the micropyramids required for maximizing their photoresponse. The comparison of the photoresponse of the arrayed photodetectors with flat detectors having the same area is required to quantify the quantum yield of fabricated devices. In addition, spectral response and angular dependencies of the fabricated detector arrays need to be characterized. These studies are planned in our future work.

IV. Conclusions

We fabricated Ni/silicide Schottky barrier photodetectors directly on top of Si micropyramidal arrays to study their photoresponse properties. The larger photoresponse was detected from arrays formed by micropyramids with smaller (sharper) tops. Trapping of photons inside the microcones can have resonant properties with some similarity to formation of whispering gallery modes in dielectric microspheres [23] that can resonantly increase the efficiency of Si photodetectors in IR regime [24]. However, more detailed studies of the observed effect are required to clarify its physical mechanism. Additional comparison with the photoresponse of conventional flat photodetectors is also required to further quantify the quantum yield of the fabricated photodetector arrays. These studies are important for increasing signal-to-noise ratio of MWIR FPAs and, potentially, for increasing their operation temperature. They can also allow developing MWIR FPAs with multispectral functionality due to resonant trapping of photons in such micropyramids.

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