

MWIR Photodetector Arrays Enhanced by Integration with Si Micropyramidal Structures

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Abstract — Truncated Si micropyramidal arrays with 60 μm pitch are integrated with 10 x 10 platinum/silicide Schottky barrier photodetectors with 22 μm square mesas. A four times stronger MWIR photoresponse is observed for micropyramidal arrays compared to the conventional planar photodetectors with the same size.

Keywords— *infrared photodetectors, Schottky barrier photodetectors, light concentrators, dielectric resonators*

I. INTRODUCTION

Silicon photonics is highly popular due to advanced manufacturing capabilities and simple integration of arrayed photonic devices with electronics. The detector applications of Si in mid-wave IR (MWIR) and long-wave IR (LWIR) regimes are, however, complicated by the low quantum efficiency (QE) caused by the indirect band gap of Si. In standard planar Schottky barrier photodetectors, the pathlength of the photons and the absorption coefficients are not sufficient to increase the QE. In this regard, recent advancements in low-cost anisotropic wet etching techniques have enabled the rapid production of Si micropyramidal arrays which allows for an increase in the collection of photons, resonant trapping of these photons inside the photodetector regions and, therefore, the potential to increase the photoresponse and QE of Si-based photodetectors [1-5].

Prior attempts at integrating Si micropyramid arrays with photodetectors relied on plasmonic concentration mechanisms to direct electromagnetic (EM) power towards the tips of the pyramids. In one example, the sidewall surface was coated with Al to convert incident photons into plasmonic excitations that were then adiabatically compressed towards the 50 nm tip of the pyramid, generating electron-hole pairs. However, this mechanism was complicated, and highly precise nanoscale fabrication and alignment were required. These designs resulted in a photoresponse increase of up to 100 times at $\lambda = 1.3 \mu\text{m}$ [6].

Our previous designs entail using large micropyramids with truncated tops that are optically connected to photodetectors. These truncated micropyramids function similarly to "tapered" waveguides or mirror light concentrators in solar cells [7], but are simpler to produce than their nanoplasmonic counterparts [6], as they require micron-scale fabrication accuracy that is achievable through standard photolithographic methods.

In this work, we explore a novel approach to increasing the optoelectronic functionality and QE of photodetectors integrated with micropyramids based on using the photon trapping ability of metallic mirrors with a 3-D spatial configuration obtained by depositing Au all over the entire micropyramid. The idea of this design is to concentrate photons into the active regions of platinum/silicide (PtSi) Schottky barrier photodetectors fabricated close to the smaller bases of such truncated Si micropyramids [8], thus increasing the pathlength of photons in the active regions and, consequently the QE of these photodetectors. Another benefit is that the photodetector mesa near the top of the truncated micropyramid can be smaller compared to standard planar devices. This could lead to a lower thermal noise in the proposed devices and potentially enable them to operate at higher temperatures. To simplify characterization, we combined 100 PtSi Schottky barrier photodetectors with 22 μm square mesas electrically in parallel and showed that such arrays provided a signal enhancement of approximately $\sim 4.1\times$ compared to similar arrays fabricated by the standard planar technology with the same size mesas.

II. DEVICE CHARACTERIZATION AND ANALYSIS

We integrated PtSi Schottky barrier photodetectors with light-concentrating truncated Si micropyramidal arrays, which have 54.7° sidewall angles. We tested two different samples (A and B), each consisting of 10 x 10 photodetectors with 60 μm pitch, combined in parallel with 22 μm square photodetector mesas on top of truncated micropyramids. The photodetectors were illuminated through the substrate's polished back surface and, for the devices with micropyramids, light was concentrated towards the tops of the micropyramids where photons were partially absorbed in the PtSi region. We measured the photoresponse data with a Bruker V80 FTIR spectrometer and a Keithley 428 current pre-amplifier, while the QE data were measured by changing the illumination source to a 900°C blackbody cavity and implementing a chopper with a lock-in amplifier fixed at the chopper's frequency. We conducted the measurements inside an 80K LN_2 dewar fitted with a germanium (Ge) window to minimize any ambient signal. By implementing these procedures, we were able to obtain reliable and accurate data for the performance of the devices.

These two measurement methods, namely QE and spectral photoresponse, enable a direct comparison of the samples A and B with the reference structure represented by a standard planar array of 10×10 photodetectors with a $60 \mu\text{m}$ pitch, combined in parallel with the same $22 \mu\text{m}$ square mesa size. Spectral sensitivity between $2\text{--}6 \mu\text{m}$ was determined for the photodetectors by measuring the photoresponse. Signal enhancement was calculated by dividing the scaled photoresponse from the micropylamidal photodetector arrays by the photoresponse from the conventional planar photodetector arrays of the same size. These results are presented in Fig. 1(c).

The experimental results indicate that the micropylamids function as light concentrators and can enhance the detected signal. The key finding is that despite some optical losses inside the micropylamids with a large base size of $60 \mu\text{m}$, the optical signal detected at the smaller base was significantly higher than that for the conventional planar $22 \mu\text{m}$ square photodetector. This suggests that, even though some of the incident power escaped from the micropylamids possibly due to sidewall leakage or reflection in a backward direction, a considerable amount of power was still delivered to the photodetector at the smaller base. As shown in Fig. 1(c), when compared with the same size ($22 \mu\text{m}$) planar photodetector, the micropylamids resulted in an average signal enhancement of $\sim 4.1\times$ for sample A and $\sim 2.6\times$ for sample B. However, further studies are needed to investigate the effect of the micropylamid geometry on the signal enhancement of MWIR photodetectors.

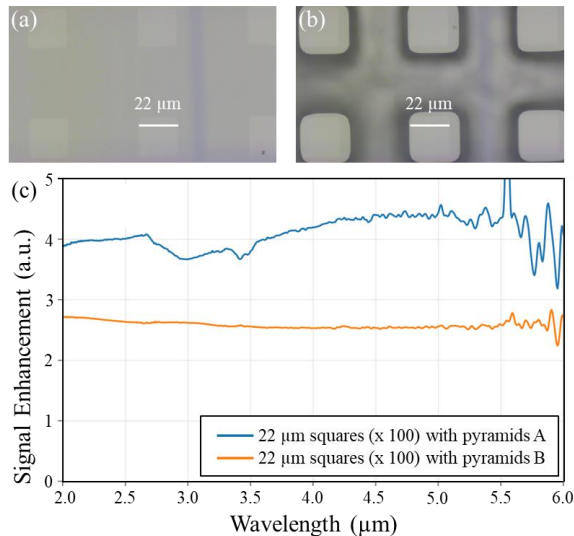


Fig. 1. Microscope images of PtSi detectors consisting of (a) $22 \mu\text{m}$ squares, and (b) $22 \mu\text{m}$ squares on micropylamids. (c) The signal enhancement plot calculated by dividing the signal from the micropylamidal photodetector array by the signal from the planar photodetector array of the same $22 \mu\text{m}$ square mesa size.

III. CONCLUSION

The Si-based micropylamidal arrays integrated with photodetectors offer several potential advantages over standard planar FPAs:

i) Significant photoresponse can still be maintained while reducing the size of the photodetector mesa. Smaller mesa size can lead to a reduction in thermal current noise and an increase in operational temperature.

ii) In the micropylamidal devices, approximately 25% of the EM power that hit the larger base was transmitted to the smaller base coupled to the photodetector, while the rest of the power was lost. However, even with this power loss, the delivered power was up to 4.1 times higher than the signal detected by a same-sized ($22 \mu\text{m}$) planar array.

iii) The potential power loss observed in the proposed technology is not necessarily a fundamental limitation, as it may be possible to reduce it by optimizing the micropylamid's geometrical parameters and improving the overall technology.

iv) Micropylamids can trap light inside the photodetector's active region, increasing photon pathlength, absorption probability, and QE. This addresses a significant issue in Si-based photodetector FPAs, making them valuable for uncooled MWIR cameras and thermal sensors.

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