National Aeronautics and Space Administration

Developing Quanta Image Sensor for UV Photon Counting Detectors in Space Applications

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Strategic Focus Area: Remote/In Situ/Life Detection Sensors and Instruments

Objectives: The objective of this effort was to develop a novel approach to low dark current, radiation tolerant, ultraviolet single photon counting detectors as a critical component of space astrophysics and planetary science instruments. We combined the complementary expertise at JPL and Dartmouth Thayer School of Engineering by ultraviolet enhancement of quanta image sensors (QIS) using 2D doping and NP processing.

Background: Astro2020 report recommended a 6-m UV/Optical/Infrared Great Observatory flagship mission inspired by the final reports of two flagship mission studies i.e., Large Ultraviolet/Optical/Infrared Surveyor and the Habitable Exoplanet Observatory concepts. Both LUVOIR and HabEx required UV photon counting detectors. We used these requirements as development guidelines, but all classes of astrophysics missions – explorers, CubeSats, and suborbitals as well as Planetary sciences and Heliophysics missions– could benefit from this development.

Approach and Results: QIS chips tape-out and fabricated were processed with 2D doping and nanophotonic (NP) for UV enhancement. We characterized the QE, read noise, and conversion gain (Figs 1, 2). Photon counting and QE were demonstrated and characterized in the UV (Fig. 1, room T). The read noise UV illumination is slightly lower than white light illumination (Figs 1a, 1c). Statistical distributions of read noise, quanta exposure level, and conversion gain confirms these parameters are similar for UV as in visible (Fig 2). Metal/dielectric nanophotonic UV bandpass filter fabrication, successful lift-off process of AlF3/Al/AlF3 dielectric layers were tested, (Fig. 3a, b). Measured reflectance spectra is consistent with theoretical modeling (Fig. 3c), which also indicates that the absorption in Si peaks at 78% at λ~260 nm while the visible light is reflected or absorbed by Al. These results show feasibility of integrating metal/dielectric UV filters with CIS pixels. We investigated e-beam lithography to implement NP UV antenna to further enhance UV photo-response and photon counting under weak UV illumination (Figs. 4a-d examples of bull's eye optical antenna). We also developed surface prep and 2D doped four that were packaged and characterized showing feasibility.

Significance/Benefits to JPL and NASA: QIS achieves photon counting via ultralow read noise by reducing detection node capacitance. The significance of this approach is that because this design does not rely on avalanche charge multiplication for improved signal to noise ratio, it will not suffer from the dark current penalty and it does not require high operating voltages, unlike microchannel plate (MCP) detectors.

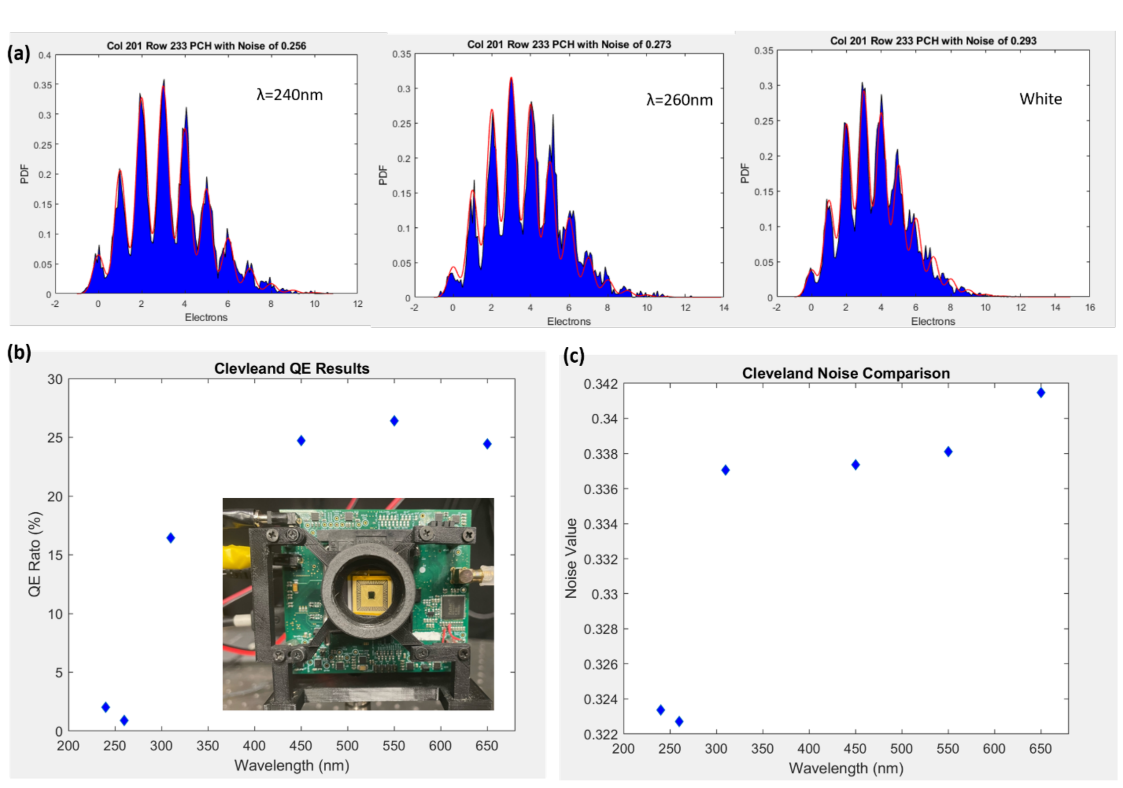

Figure 1. **(a)** A typical photon counting histogram (PCH) of the same pixel ("jot") at room temperature under UV illuminations at λ=240 nm and 260 nm in comparison with that under white visible light illumination. The discrete peaks correspond to the events of counting 0, 1, 2…10 photoelectrons in the detection process. The fitting yields a slightly lower read noise of 0.256 and 0.273 electron at 240 and 260 nm than the white light illumination case (0.293 electron). **(b)** Quantum efficiency vs wavelength. The inset shows a photo of the packaged ship on the testing board. **(c)** Read noise (in unit of electron charge) as a function of wavelength, consistent with the trend shown in **(a)**

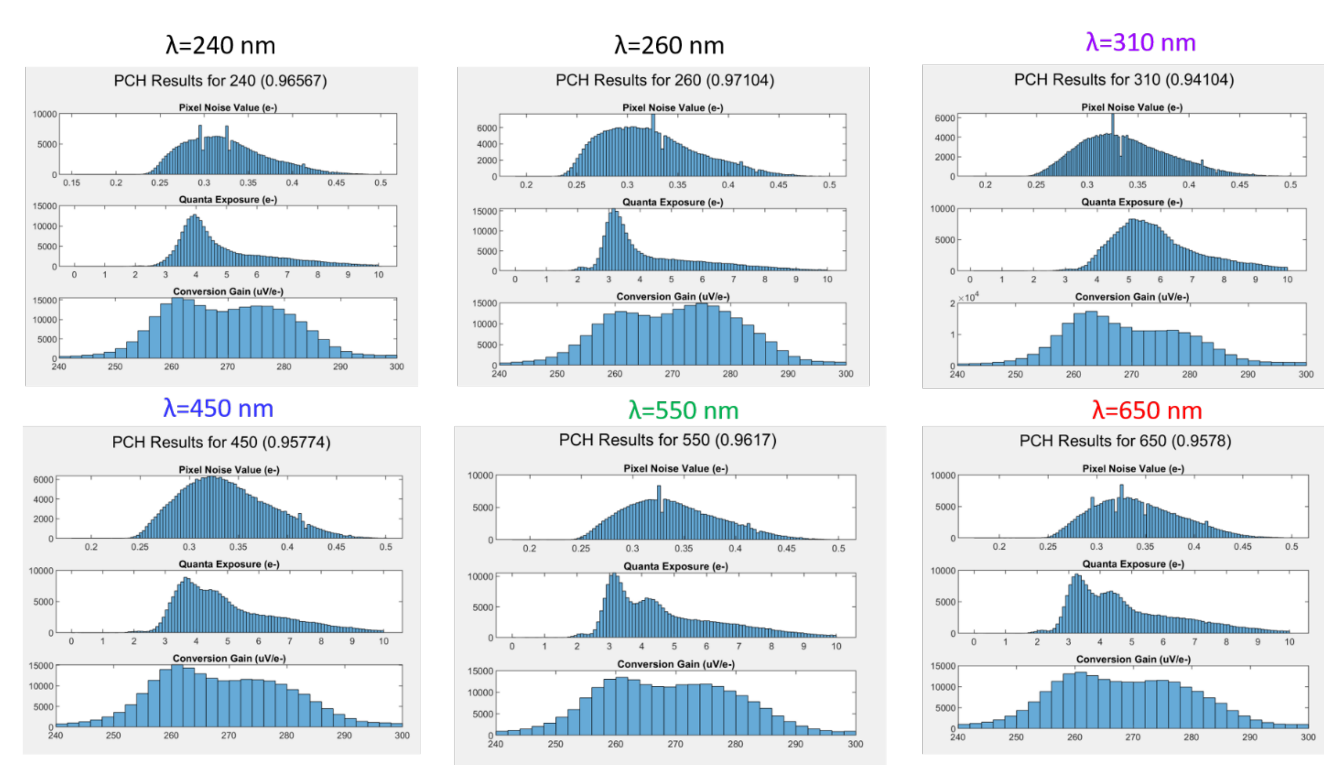

Figure 2. Statistical distribution of pixel read noise, quanta exposure level, and conversion gain of Cleveland QIS chip under different wavelengths of illumination from 240 nm to 650 nm.

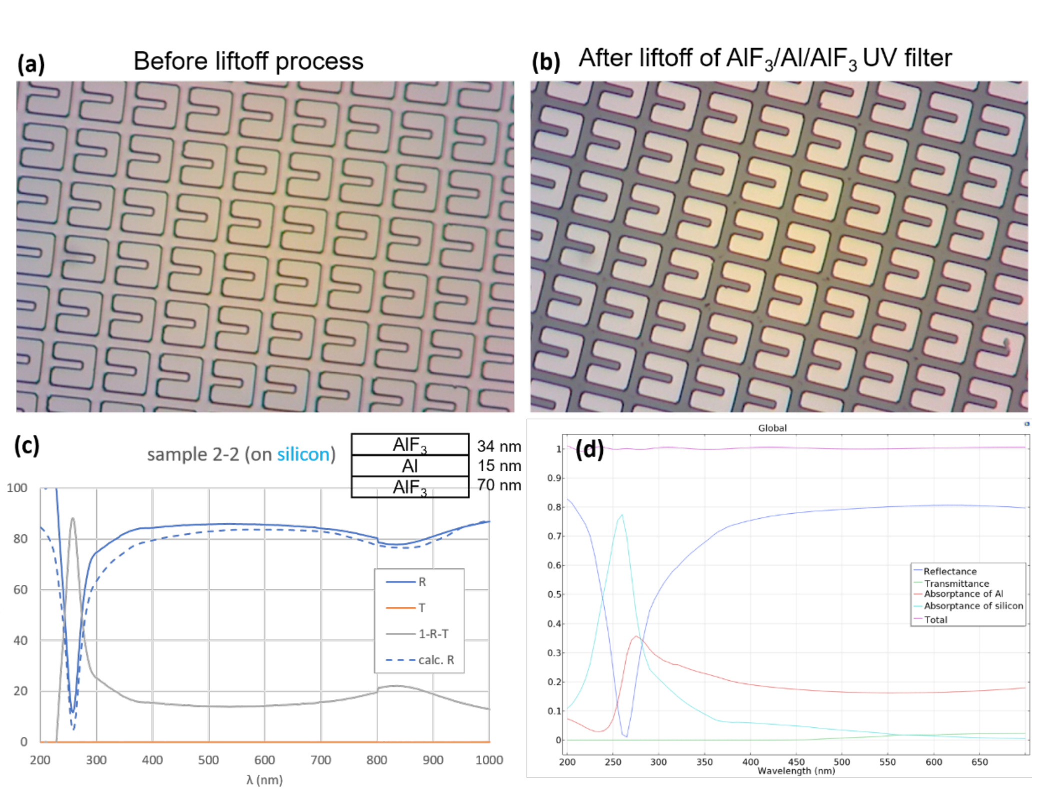

Figure 3. Figure 3. Optical microscopy images of patterned AlF3/Al/AlF3 metal/dielectric UV filters (a) before liftoff and (b) after liftoff. (c) shows the reflectance spectra of the regions with UV filters, which agrees well with the theoretical modeling shown by the dashed line. (d) further shows that the UV absorption in Si peaks at 78% at 260 nm, with excellent rejection of visible light.

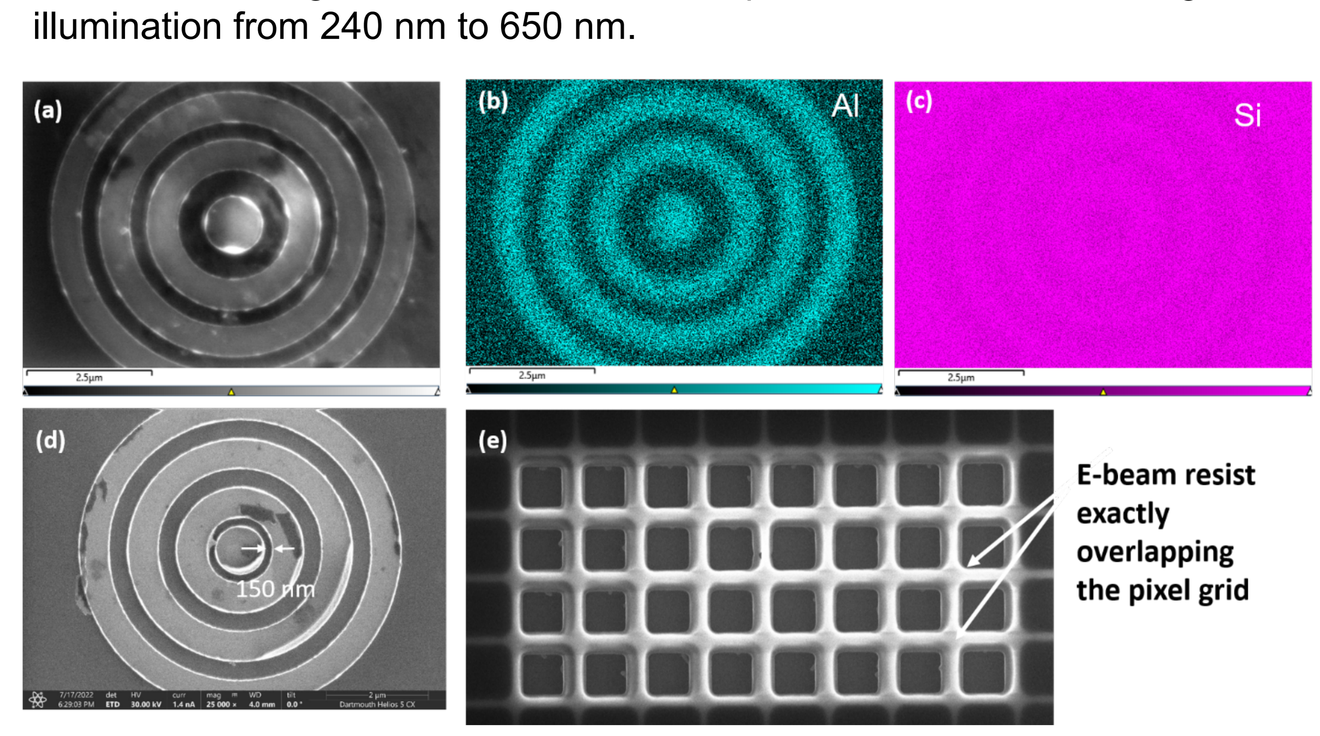

Figure 4. **(a)-(d)** show examples of bull's eye optical antenna fabricated by e-beam lithography. The gaps between metals can be as small as 150 nm, satisfying subwavelength requirement for UV optical antenna. **(e)** shows x-y scan calibration of the e-beam lithography processing, demonstrating exact overlapping between patterned e-beam resist (brighter parts) with the pixel grids on one of the Cleveland chips. The pixel opening is 720 nm and the period of the pixel arrage is 1150 nm in this case.

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J. Ma, S. Chan and E. R. Fossum, "Review of Quanta Image Sensors for Ultralow-Light Imaging," in IEEE Transactions on Electron Devices, vol. 69, no. 6, pp. 2824-2839, June 2022, doi: 10.1109/TED.2022.3166716.

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