

# Photon-Number-Resolving Quanta Image Sensor

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Abstract. The Quanta Image Sensor (QIS) is a silicon photon-counting image sensor intended as a platform tool for many applications, including scientific and consumer image capture [1]. In this invited paper, the QIS concept is reviewed and its imaging characteristics discussed. Recent progress by the team [2] is presented including both pixel design and low power readout electronics design. Test devices were designed and characterized at Dartmouth, and fabricated by TSMC in a 45nm/65nm stacked, backside-illuminated (BSI) CMOS image sensor process, with some small process changes. The QIS pixel (or “jot”) with 1.1 $\mu$ m pitch operates at room temperature without the use of avalanche multiplication. It relies on small detector capacitance (<0.5fF) and correlated double sampling to achieve output voltages above thermal background noise. Quantum efficiency is high due using BSI with high fill factor. Average dark current is low (<0.2e-/s) and read noise typically under 0.22e- rms, allowing photon-number resolution with low photon-counting error. Dead time is less than 0.1%. The 1Mpixel digital readout QIS operates at 1040fps and dissipates less than 20mW including I/O pads due to low voltage operation.

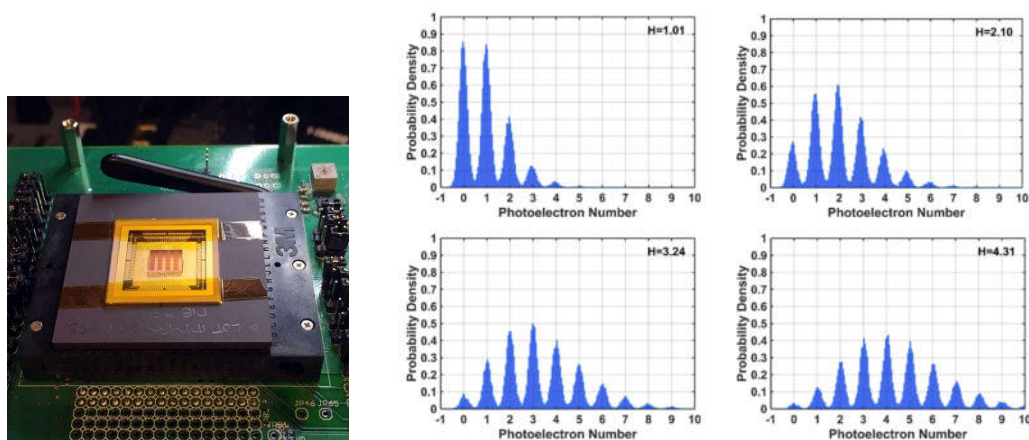


Fig 1. (Left) Test chip with 20 1Mpixel arrays implemented in a 45nm/65nm stacked BSI CIS process. (Right) four photon-counting histograms at different exposure levels,  $H$ , measured from one pixel with 20k reads of analog output. Read noise: 0.175e- rms, room temperature, no avalanche, 20 CMS cycles (to reduce board noise).

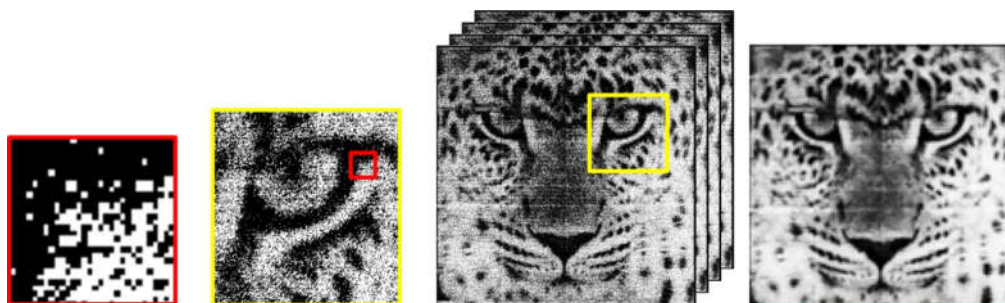


Fig 2. 1Mpixel single-photon image grabbed from 1b digital output sensor operating at 1040fps at room temperature, and then processed with time-adjacent frames to form gray scale image. Further denoising performed by S. Chan at Purdue.

## References

- [1] E.R. Fossum, J. Ma, S. Masoodian, L. Anzagira, and R. Zizza, The quanta image sensor: every photon counts, MDPI Sensors, vol. 16, no. 8, 1260; August 2016. (Special Issue on Photon-Counting Image Sensors) doi:10.3390/s16081260
- [2] Dartmouth: E.R. Fossum, S. Masoodian, J. Ma, and D. Starkey; TSMC: T.J. Wang and Y. Yamashita. Design supported by Rambus, fabrication by TSMC, and measurement by DARPA DETECT program.