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# Novel Machine Vision Cameras Featuring CQD Sensors for High Resolution, Lower Cost SWIR Imaging

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**Description of the innovation:**

SWIR Vision Systems Inc. (Durham NC, USA) is introducing a new class of cameras featuring a 400-1700 nm broadband image sensor technology based on colloidal quantum dot thin film photodiodes fabricated monolithically on silicon (Si) readout wafers. These sensors have the potential to achieve for SWIR imaging, what CMOS image sensors and micro-bolometer arrays have achieved for visible and longwave infrared imaging respectively. Namely, to leverage the scale and cost structure of the Si IC industry, moving SWIR imaging from a specialized niche into broad commercial markets.

Infrared imaging cameras operating in the short wavelength IR or SWIR wavelength band are not new to machine vision systems. Cameras based on InGaAs technology have been commercialized by several global companies and are already deployed in a range of industrial and defense applications. SWIR Vision Systems Inc. is now commercializing our patented CQD(TM) sensor technology for use inside the company's high definition Acuros(TM) cameras, with the potential to displace InGaAs cameras in several key applications.

Here, we will discuss the performance, fabrication, and cost trade-offs between the novel CQD sensor technology and existing InGaAs technologies, and the resulting applicability to machine vision applications.

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**Technical details and advantages of the innovation:**
The current SWIR imaging market is dominated by indium-gallium-arsenide (InGaAs) based sensors, a compound semiconductor grown epitaxially on lattice-matched indium phosphide (InP) substrates. To form pixel-level electrical connections between each InGaAs photodiode and the corresponding Si ROIC input cell, the two chips are joined by metal-to-metal bonding. The hybridization is most commonly carried out by forming an array of indium bumps on the detector chip, which is then thermocompression bonded with a corresponding indium bump array on the ROIC die. The hybridization yield imposes limitations on pixel size, pixel spacing, and sensor resolution. Due to these limitations, commercially practical InGaAs SWIR cameras are limited to VGA resolution, and even these are considered too costly for most machine vision applications.

Conversely, our CQD sensor technology utilizes a monolithic integration approach, in which the quantum dot-based sensor is fabricated directly onto CMOS ROICs using well-established, low-cost semiconductor deposition techniques. The process requires no hybridization, no epitaxial growth or exotic substrate materials, no pixel level sensor patterning, and can be easily scaled to wafer level fabrication. Our approach also employs low-cost, solution processed lead sulfide (PbS) colloidal quantum dots to form as small as 3 um pitch p-n photodiode arrays sensitive in both the SWIR and visible spectral bands. The relative crystalline disorder of colloidal quantum dots currently results in lower quantum efficiency when compared to InGaAs cameras, which may make these cameras less suitable for photon-starved applications. However, in the majority of machine vision applications a CQD sensor-based camera can be paired with relatively inexpensive active illumination, resulting in near InGaAs equivalent performance with a significant reduction in overall system cost.

To demonstrate applicability to imaging applications, SWIR Vision Systems has fabricated 2D arrays of quantum dot based photodiodes on numerous commercial-off-the-shelf (COTS) Si CMOS ROICs and integrated them with corresponding camera electronics. We have used these prototype cameras to collect critical voice-of-customer data across an array of use cases and to optimize the manufacturing process. Now, the company is releasing the production Acuros camera family featuring: InGaAs equivalent noise, pixel operability greater than 99%, 15 um pixel pitch, and three different pixel array sensor formats (640 x 512, 1280 x 1024, and 1920 x 1080). The cameras are capable of imaging at speeds up to 380 fps via GenICam compliant GigE Vision and USB3 Vision interfaces.

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**Relevance and application possibilities of the described innovation for the machine vision industry:**
Low cost silicon CMOS digital imagers have become ubiquitous consumer and industrial imaging devices. Billions of these image sensors are used annually across many industries, and they are the workhorse of the $2.2B Machine Vision camera market. However, these silicon sensors cutoff around 1000nm and so

are not useful in the short wave IR (SWIR band) from 1000nm to 2500nm. Notably, SWIR cameras have distinct value from silicon sensors in that they can: image though plastics, detect water/moisture, see through silicon, image thought obscured environments, detect laser pulse at eye-safe wavelengths, have broadband properties aligned with hyperspectral imaging of many chemicals, elements, gases, etc. and many more.

CQD camera sensors fabricated with low cost materials and CMOS-compatible fabrication techniques, represent a major advancement towards broadly accessible high definition SWIR imaging.  We expect the camera's lower cost points and it's non-ITAR, EAR99 export classification to drive higher adoption rates globally, broadening the market for SWIR camera technology.

These products should be more suitable for applications requiring higher definition images and for more cost sensitive SWIR machine vision applications. This pioneering technology will open up applications that InGaAs cameras cannot reach today due to constraints on image resolution, or due to their higher intrinsic cost.

Several targeted machine vision applications include: Defect inspection of hot glass bottles, inspection of liquid fill-levels via imaging through consumer and industrial plastic containers, defect inspection of semiconductor wafers and solar cell arrays, detection of oil and water on metal surfaces such as bearings, detection of liquid levels in pharmaceutical vials, hyperspectral imaging/sorting of food products, and detection of moisture on surfaces to name a few. These are among the first commercial applications being tested with colloidal quantum dot-based SWIR imaging cameras.

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**Video:**
https://www.youtube.com/channel/UClp328uBuGEOwGm879WllLw?view_as=subscriber

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**Images:**
39402_acuros_swir_camera.jpg
39402_cqd_sensor.jpg
39402_cqd_structure.jpg
39402_swir_food_sorting.jpg
39402_swir_imaging_of_pharmaceutical_vials.jpg

39402_acuros_swir_camera.jpg

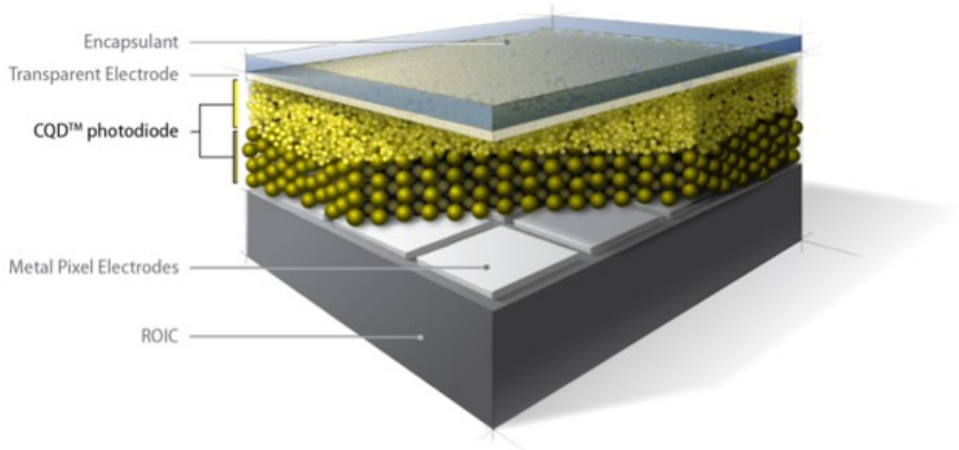
# SWIR Vision Systems Acuros CQD Camera


Acuros™ 640x512, 1280x1024, 1920x1080

39402_cqd_sensor.jpg

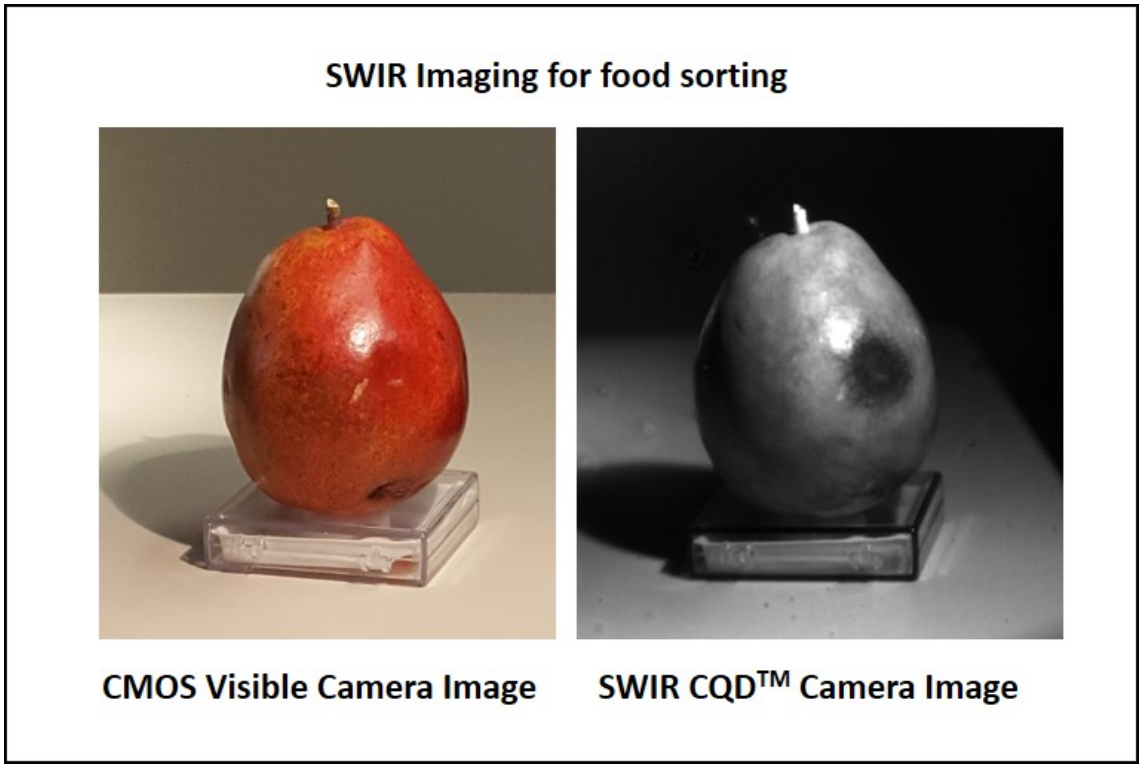
**SWIR Vision Systems Acuros CQD™ Sensor**

39402_cqd_structure.jpg




**SWIR Vision Systems CQD™ sensor structure**

39402_swir_food_sorting.jpg



39402_swir_imaging_of_pharmaceutical_vials.jpg

**SWIR Imaging of fill levels in plastic pharmaceutical vials**

**CMOS Visible Camera Image** **SWIR CQD™ Camera Image**