

# Quantum-dot IR photodetectors get 'hotter'

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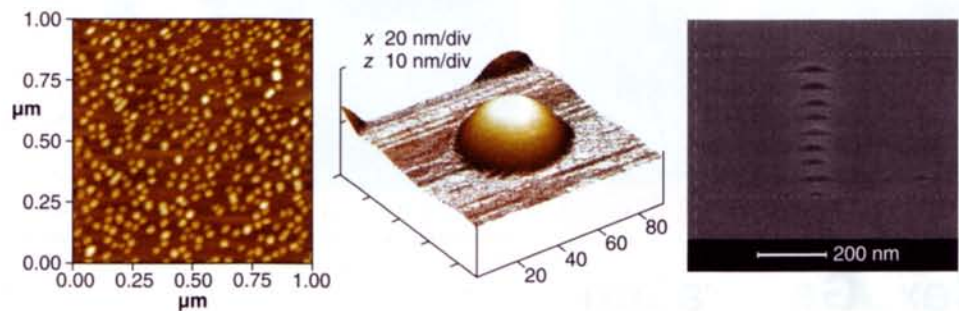


FIGURE 1. An atomic-force micrograph shows InAs quantum dots (left) and a zoom-in view of a single dot (middle) grown by self-assembly with MOCVD. A scanning-electron micrograph of the cross section of the QDIP active region shows that the quantum dots are vertically aligned due to the strain (right).

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ost current infrared focal-plane arrays (FPAs) are based on quantum-well infrared (IR) photo-

detectors (QWIPs) or mercury cadmium telluride (MCT) intrinsic photodetectors, and both types of detectors suffer from significant disadvantages.

Quantum-well IR photodetectors do not absorb much light at normal incidence because the optical transition for light striking normal to the surface is forbidden. Gratings can be used to get around this problem, but the additional fabrication steps increase cost. Furthermore, QWIPs are unsuitable for high-temperature operation because of their high dark current. So they are usually operated at low temperature and require cooling, which adds significant cost, bulk, and power consumption to the imaging system.

In the case of MCT-based detectors, instability of the MCT makes it difficult to achieve high-uniformity detec-

tor arrays—so focal-plane arrays based on MCT suffer from high cost and poor yield.

**Improvements in operating temperature and quantum efficiency of quantum-dot infrared photodetectors promise improved imaging techniques that may lead to high-performance imagers operating at or close to room temperature.**

Recent improvements to the operating temperature and quantum efficiency of quantum-dot infrared photodetectors (QDIPs) may lead to new imaging techniques that can be applied to medical and biological imaging, environmental and chemical monitoring, night vision, and infrared imaging from space. By using nanotechnology to form quantum dots, our research group is a step

closer to developing high-performance imagers that can operate at or close to room temperatures.

Quantum dots, also known as “artificial atoms,” have been widely investigated as a means of improving a variety of electronic and optoelectronic devices. Their small size, usually around 10 nm, gives quantum dots a unique physical property of three-dimensional confinement that can enable higher operating temperatures

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FIGURE 2. A thermal image of the human body (top) was produced by a QDIP focal-plane array operating at 130 K; a soldering iron (bottom) was imaged at 200 K.

when used in IR detectors.

Development of an IR photon detector that can operate at higher temperatures will enable the use of cheaper, lighter, and more efficient cooling methods when designing IR imaging systems. This will allow much broader application of IR detectors. Our group had previously fabricated and tested the world's first QDIP focal-plane array (see [www.laserfocusworld.com/articles/206910](http://www.laserfocusworld.com/articles/206910)).

#### QDIP operates at room temperature

More recently, we made a significant breakthrough in the development of high-performance QDIPs. We developed a QDIP that operates at room temperature with a peak detection wavelength in the technologically important mid-IR wavelength range—wavelengths between 3 and 5  $\mu\text{m}$  are important because they are not susceptible to absorption by Earth's atmosphere.

The QDIP device consists of 25 stacks of a hybrid structure of indium arsenide (InAs) quantum dots and an indium gallium arsenide (InGaAs) quantum well, with aluminum indium arsenide (AlInAs) as a barrier. The whole device structure was grown on an indium

phosphide (InP) substrate by low-pressure metal-organic chemical-vapor deposition (MOCVD). The InAs quantum dots were grown by self-assembly of the Stranski-Krastanow growth mode. The structural properties of the quantum dots, such as size and density, were characterized by tools including an atomic-force microscope and a scanning-electron microscope (see Fig. 1).

We measured the spectral response of the detector at several temperatures and applied biases in the normal incidence configuration without any optical coupling structures. Spectral response with a peak detection wavelength at 4.1  $\mu\text{m}$  was measured up to room temperature. The responsivity increased with temperature from 77 K to 200 K and started decreasing above 200 K. The peak responsivity was measured to be 822 mA/W at 150 K and  $-5$  V. The specific detectivity was measured to be  $2.8 \times 10^{11}$   $\text{cmHz}^{1/2}/\text{W}$  at 120 K,  $4 \times 10^{10}$   $\text{cmHz}^{1/2}/\text{W}$  at 150 K, and  $6 \times 10^7$   $\text{cmHz}^{1/2}/\text{W}$  at room temperature. The quantum efficiency at 150 K was 35%. This record performance was published in March of 2007.<sup>1</sup> Devices developed since then have exhibited further improved performance—with a quantum efficiency of 48%—through the optimization of the quantum-dot growth, which led to stronger IR absorption.

We have used this technology to build a  $320 \times 256$  FPA with 30  $\mu\text{m}$  pitch and  $25 \times 25 \mu\text{m}^2$  pixel size. We demonstrated thermal imaging at temperatures up to 200 K, which is the highest operational temperature ever demonstrated for a QDIP focal-plane array. The array had a peak detection wavelength of 4  $\mu\text{m}$ , a responsivity of 34 mA/W, a conversion efficiency of 1.1%, and a noise equivalent temperature difference (NEDT) of 344 mK at an operating temperature of 120 K (see Fig. 2).<sup>2</sup>  $\square$

#### AUTHORS NOTE

The work on the InP-based QDIP and FPA was presented at the 25th Annual Army Research Conference in November 2006 and won a Best Paper Award at the conference.

#### REFERENCES

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