New Quantum Dot Transistor Counts Individual Photons

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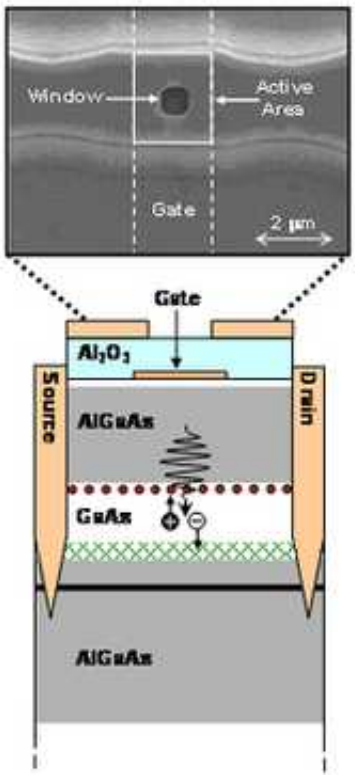

NIST&acutes modified field-effect transistor can count single photons, or particles of light. When light enters through the transmission window (see electron micrograph of top of device), it penetrates the gallium arsenide absorbing layer and separates electrons from the holes they formerly occupied. Quantum dots (red dots) trap the positively charged holes, while electrons flow into the channel (green Xs). By measuring the channel current, researchers can determine the number of photons absorbed. Credit: NIST

A transistor containing quantum dots that can count individual photons (the smallest particles of light) has been designed and demonstrated at the National Institute of Standards and Technology.

The semiconductor device could be integrated easily into electronics and may be able to operate at higher temperatures than other single-photon detectors—practical advantages for applications such as quantum key distribution (QKD) for “unbreakable” encryption using single photons.

The NIST device, described in a new paper, can accurately count 1, 2 or 3 photons at least 83 percent of the time. It is the first transistor-based detector to count numbers of photons; most other types of single-photon detectors simply “click” in response to any small number of photons.

Counting requires a linear, stepwise response and low-noise operation. This capability is essential for advanced forms of precision optical metrology—a focus at NIST—and could be used both to detect photons and to evaluate single-photon sources for QKD. The new device also has the potential to be cooled electronically, at much higher temperatures than typical cryogenic photon detectors.

Dubbed QDOGFET, the new detector contains about 1,000 quantum dots, nanoscale clusters of semiconductors with unusual electronic properties. The NIST dots are custom-made to have the lowest energy of any component in the detector, like the bottom of a drain. A voltage applied to the transistor produces an internal current, or channel. Photons enter the device and their energy is transferred to electrons in a semiconductor “absorbing layer,” separating the electrons from the “holes” they formerly occupied.

As each photon is absorbed, a positively charged hole is trapped by the quantum dot drain, while the corresponding electron is swept into the channel. The amount of current flowing in the channel depends on the

number of holes trapped by quantum dots. By measuring the channel response, scientists can count the detected photons. NIST measurements show that, on average, each trapped hole boosts the channel current by about one-fifth of a nanoampere. The detector has an internal quantum efficiency (percentage of absorbed photons that result in trapped holes) of 68 ± 18 percent, a record high for this type of photon detector.

The QDOGFET currently detects single photons at wavelengths of about 800 nanometers. By using different semiconductor materials, NIST researchers hope to make detectors that respond to the longer near-infrared wavelengths used in telecommunications. In addition, researchers hope to boost the external quantum efficiency (percentage of photons hitting the detector that are actually detected), now below 10 percent, and operate the device at faster speeds.

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Source: NIST