Single-photon counting

The detection of light at the single-photon level is important for tasks ranging from fluorescence imaging to quantum information processing, reports **Neil Savage**.

High-sensitivity detectors that are able to generate an electrical signal when struck by a single photon have two main applications. The first is for tasks involving very low light levels, such as fluorescence microscopy for biological imaging, free-space optical communications or laser ranging. The second is for single-photon counters in quantum optics, which must often capture individual photons for tasks such as quantum information processing and quantum key distribution. For example, in quantum cryptography for secure data communication, unbreakable codes can be produced by entangling the properties of two photons and measuring the quantum mechanical state of one of them.

"I think there is a general trend in the marketplace towards looking at dynamic processes," says Michael Mellon, general manager at Quantar Technology, a California-based developer of specialized test and measurement equipment. For instance, a sensitive enough detector can 'see' when a gate in a microprocessor switches, because the act of switching causes it to emit a few infrared photons. This has allowed computer chip designers to study processes such as how clock pulses propagate across a chip.

Quantar's equipment focuses on photon counting as an imaging technique, which is important when the spatial position of a photon provides information. In spectroscopy, for example, the position of a photon gives information about its wavelength.

Mark Itzler, chief technology officer at Princeton Lightwave, says that in the past five years he's seen an expansion in photon counting technologies, from silicon devices that work mainly at visible wavelengths to devices based on III–V materials systems such as InGaAs, which cover telecommunications wavelengths in the infrared. When quantum cryptography is widely deployed it will probably need to operate in the near-infrared windows that are commonly used for optical communication (1,300 and 1,500 nm). "However, that's a future market opportunity, not a current one. The challenge for those of us in the business is to see the opportunities in the longer wavelengths grow," Itzler says.

PRINCETON LIGHTWAVE

PRODUCT ROUND-UP

The single-photon bench-top receiver from **Princeton Lightwave** (Cranbury, New Jersey, USA) is based on an InGaAs/InP single-photon avalanche photodiode (APD) integrated with all the necessary bias and control electronics, and has particular application in quantum optics. The APD is designed to achieve a minimum detection efficiency of 20% at ambient operating temperatures for a wavelength of 1,550 nm, with a maximum dark count rate of 5×10^{-5} ns^{-1}. When using the ultrahigh-sensitivity receiver, the maximum dark count rate is reduced to 5×10^{-6} ns^{-1}. The front panel of the unit displays the number of photons detected in a selected interval, as well as other diagnostic information. All operating parameters and values can also be accessed through the RS-232 interface. Settings for the receiver include the APD's temperature, blanking value, trigger delay and discriminator level. Measurement results displayed include the pulse count, gate pulse count and ratio measurement. An internal pulse generator provides an internal or external trigger at repetition rates from 1 Hz to 20 MHz.
www.princetonlightwave.com

The SPMArray4, a scalable silicon photomultiplier (SPM) array from **SensL** (Cork, Ireland), is the first commercially available solid-state large-array detector based on SPM technology, according to the company. The 16-element array is based on SPM pixels in a 4 × 4 configuration in a low-profile ceramic package. The array is packaged in a way that allows tiling in a larger detection system. A 20-pin grid array provides electrical input/output to a printed electronics board or standard test socket connector. The pixel bias and read-out configuration have been designed for both differential and single-channel electronics to maximize signal-to-noise ratios. The detector is sensitive to light in the 400–850 nm range and is suitable for direct light detection at these wavelengths or for radiation detection through scintillation. It is designed for use in medical imaging, high-energy physics and fluorescence imaging and spectrometry, among other applications. Photon detection efficiency is 10–20% at 520 nm, with a dark count rate of 8 MHz per pixel. The device uses magnetic-free packaging.
www.sensl.com

The S10362-33 series multi-pixel photon counter from **Hamamatsu Photonics** (Tokyo, Japan) is made up of multiple APD pixels operated in Geiger mode, with an active area of 3 mm × 3 mm. Each APD pixel outputs a pulse signal when it detects a single photon. The reading on the counter is the total sum of outputs from all pixels, therefore providing high performance for applications that must detect extremely weak light signals. Depending on the model, the device offers 14,400 pixels over 25 μm × 25 μm, 3,600 pixels over 50 μm × 50 μm, or 900 pixels over 100 μm × 100 μm. The spectral response range is 320–900 nm, with a peak sensitivity at 440 nm. The maximum dark count rates are 8, 10 and 12 million counts per second (cps) for the small, medium and large pixels, respectively. The time resolution is 500–600 ps, and the photon detection efficiency is >50% at 440 nm. The device operates at room temperature and low bias (below 100 V). It offers a high gain of between 10^5 and 10^6. Applications range from medical and biological sciences to environmental analysis and high-energy physics experiments.
www.hamamatsu.com

The SQLightSensor is a family of low-noise near-infrared single-photon detectors from **Smart Quantum** (Lannion, France). Based on a Geiger-mode InGaAs APD with a thermoelectric cooler, the devices cover the spectral range of 900–1,600 nm with a quantum efficiency in the range of 5–25%. The dark count rate is 5×10^{-6} ns^{-1}

at 10% quantum efficiency. The detection rate can be varied in the range of 0–10 MHz. Cooling time is 60 s at 25 °C. The detectors can operate with a single- or multimode fibre input, and a free-space-coupled version is available with one or two channels. The detectors can receive a variety of input signals, including an external trigger of 0–10 MHz, gating in 5-ns steps from 5 ns to 20 ns and then 20-ns steps from 20 ns to 100 ns, a delay control of 0–128 ns in 0.5-ns steps, or an external gating of 2.5 ns to 1 μs. The output signal is an electric TTL signal. Parameters are easily adjustable, and the detector comes with a USB interface. It is fully compatible with all the major commercially available time-correlated single-photon counting cards. In addition to fluorescence and spectroscopy applications, it can be used for eye-safe light detection and ranging, quantum cryptography and quantum correlation.
www.smartquantum.com

PERKINELMER

The Gigahertz Photon Detection Module from **PerkinElmer** (Waltham, Massachusetts, USA) can detect ultralow levels of light in d.c mode. The company says this d.c. mode, in combination with single-photon sensitivity, makes the module superior to counting circuits that require high light-levels. It claims the module has a high dynamic range of 1–10^9 cps in a single operating mode, and has low noise performance. The module has four counting modes, including 'real counting mode', which presents digital information as to whether a photon has been detected or not. This mode can also be used for unit calibration and offers 1–10,000 cps. 'Straight output mode', which requires no internal switching, is compatible with counts between 1 cps and 50 Mcps. 'Fast counting mode', which extends the dynamic range by using fast gain switching, can achieve 1–10^9 cps. 'HV reduction mode', which extends the light intensity range by manual high-voltage reduction, can detect up to 10^{10} cps. Quantum efficiency at the peak wavelength is 20%. The module includes a channel photomultiplier, a high-voltage supply, an analog current amplifier, an analog-to-digital converter and a microcontroller with a USB/SPI interface for external computer communication. A synchronization input/output allows the measurement to be synchronized with other devices, such as flash-lamp triggers.
www.perkinelmer.com

The SR400 dual-channel gated photon counter from **Stanford Research Systems** (Sunnyvale, California, USA) combines amplifiers, discriminators, gate generators and counters into a single integrated microprocessor-controlled instrument. It has two independent channels that can count at rates up to 200 MHz, with counting modes that allow the user to count either for a fixed amount of time (until a certain number of counts have been received) or for a fixed number of triggers. Each channel has its own gate generator to provide counting gates as short as 5 ns or as long as 1 s. The gates can be set in a fixed position relative to the trigger signal, or scanned to measure lifetimes or recover time-varying waveforms. The device can be programmed to perform 1–2,000 count periods in a single scan. The front panel can display up to 10^9 counts and shows results from both counters individually or combined. Control and data retrieval are through built-in RS-232 and GPIB interfaces.
www.thinksrs.com

ID QUANTIQUE

A single-photon detector module for the near infrared, the id201, is available from **id Quantique** (Carouge, Switzerland). The system is based on a cooled InGaAs/InP APD operating in Geiger mode, and covers the wavelength range of 900–1,700 nm. It offers a detection probability of up to 25% at 1,550 nm. Signal-to-noise performance is optimized by setting the operating temperature at −50 °C with a thermoelectric cooler, which has a temperature variation of less than 0.1 °C. An external trigger with a variety of input types provides a timing signal for gate generation. An internal trigger is also available at frequencies of 1 kHz, 10 kHz, 100 kHz and 1 MHz. The gate width is adjustable and can be user-defined, and the dead time is also adjustable. The module uses either single- or multimode fibre input. It has an RS-232 interface and comes with a LabView Virtual Instrument that provides control through a graphical interface, which allows the user to set all parameters and displays the number of counts recorded as a function of time.
www.idquantique.com

PICOQUANT

A new version of the HydraHarp 400 multichannel picosecond event timer and time-correlated single-photon counting system from **PicoQuant** (Berlin, Germany) can accommodate up to eight independent input channels. Each channel is based on a new time digitizer that has a resolution of 1 ps, a processing rate of 12.5 Mcps and a short dead time. All channels operate independently but with a common crystal time base, allowing the user to obtain both time-correlated single-photon counting histograms and picosecond coincidence correlations, which are of interest to researchers doing single-molecule work and research in quantum information processing. A time-tagged data collection mode provides a stream of individual timing events to a host computer for analysis in applications such as photon burst detection and coincidence correlation, or for combined measurement of fluorescence lifetime and fluorescence correlation spectroscopy. The large number of channels also makes the instrument suitable for diffuse optical tomography. The instrument can achieve an overall time resolutions of 30 ps and can be used with all other common single-photon detectors.
www.picoquant.com

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