

Photon Counting: SPCMs, CPMs and CCDs

Which Technology Works Best For You?



Introduction

Who would have thought, say 20 years ago, that photon counting would play such a critical role in so many cutting-edge industrial and scientific endeavors? Counting photons seems like a very limited or a fallback strategy at best - researchers only need it when emissions are so weak (approximately 10-14 watts) that ordinary detectors operating in linear mode cannot distinguish the light above the noise. How many applications could there possibly be for a technology like that?

A great many, in fact, and the number is growing.

Photon counting applications have had decisive impact on advances in a wide range of fields, from astronomy and metallurgy to environmental protection, health diagnostics, medical analysis and imaging, and - perhaps most spectacularly - biomedical research. For example, much of the recent dramatic progress in genomics has been made possible by microarray technology, which depends on the ability to detect reactions between reagents and thousands of DNA strands distributed across a microarray slide. Scientists use fluorescence detection techniques to achieve this, and they often detect fluorescence by counting photons. Photon counting has played an essential role in mapping the human genome.

Three Technologies

Scientists can choose between three different devices for the most advanced photon counting:

Single Photon Counting Modules (SPCMs) - A SPCM counts photons with an avalanche photodiode (APD). An APD is a solid-state, silicon-based device that converts photons into electrons in a dramatically different way than an ordinary photodiode. In ordinary photodiodes, the photon/electron ratio is one to one. In APDs, however, these photon-generated electrons can excite more electrons, which creates an avalanche effect, resulting in an internal gain that can be adjusted with the bias, e.g. 1 to 1000, and results in a signal that is proportional to the light's intensity.



PerkinElmer's Photon Counting Technologies

The PerkinElmer SPCM uses an APD that is 200 microns in diameter and operates at 20 volts above breakdown voltage to generate a gain of 108. Since a gain at this level cannot be sustained without burning the device, the SPCM comes with electronic circuitry that monitors and repeatedly quenches the current with a TTL pulse. Operation in this photon-counting mode is extremely fast, allowing users to count a photon every 50 nanoseconds.

Channel Photomultipliers (CPMs) - A CPM is actually an advanced monolithic version of the traditional glass photomultiplier tube (PMT), which can also be used to count photons. Photons entering the CPM produce electrons that are accelerated toward an anode through a multi-curved, semi-conductive vacuum channel. As the electrons hit the channel walls, secondary electrons are produced, which, in turn, produce still more. This creates an avalanche effect much like the APD. Although CPMs operate on basically the same principles as PMTs, they have several advantages: they generate significantly less dark current, are less influenced by external magnetic fields, are equipped with an internal electronic shutter, and are more rugged and less breakable. In addition, PerkinElmer's photon counting CPM modules (MP series) are extremely fast; photons can be counted every 30 nanosecond. The very low dark count rate enables a very high dynamic range.

Charged Coupled Devices (CCDs) - A CCD is an array of ordinary (non-avalanche) photodiodes that feeds information to a set of read-out electronics. Unlike other detectors, where each photon directly generates a single count of electrons almost instantaneously, the electrons produced in a CCD first charge a capacitor. Users can then read out the intensity of light, which is proportional to the amount of charge. Although CCDs are not specifically designed for photon counting, they can perform this function when thermo-electrically cooled to reduce dark current and noise. Unlike SPCMs and CPMs, which detect photons one element at a time, a single CCD provides information from multiple pixels at once. Hence, the device is particularly useful in applications where detail about the spatial relations within a collection area is important, e.g. spectroscopy, biotech imaging, etc.

Decisions, Decisions

Since the devices vary in capabilities and limitations, design engineers will need to base their selections on what precisely they want to achieve and on how the detector complements other instrumentation. The most important considerations include:

Wavelength range - Different tasks require different wavelength sensitivities. For example, if researchers want to excite fluorescence on a microarray with a laser, they would most likely choose a SPCM. These devices are the most sensitive from the visible spectrum, the red, green and yellow regions, which are the wavelength range of lasers, up to the infrared. SPCM sensitivity extends from approximately 500 nm to 1100 nm, with a peak of 70 percent quantum efficiency at 650 nm. Yet SPCMs are virtually blind below 400 nm. If researchers want to use a flashlamp or another light source to excite a sample in the ultraviolet or visible wavelength area, the best detector would be a CPM. Although a CPM is most sensitive in the ultraviolet and blue region, the spectral sensitivity covers the entire range from the vacuum UV at 115 nm up to the near infrared at 900 nm. The CCD is a special case: since it is an array, the sensitivity depends on the specific photodiodes in the device. CCD sensitivity corresponds to the capabilities of silicon, which allows for a range of 300 nm to 1000 nm.



PerkinElmer's Photon Counting Technologies

Sample size - SPCMs can detect light emitted from extremely small volumes - centiliters in volume - and count photons at the molecular level. However, SPCMs themselves have very small detectors - 0.2 to 0.3 millimeters - too small for sample sizes that are much larger than a millimeter. A SPCM won't work well with a large volume because it is difficult to focus the sample's light onto such a small detector. If the sample size is bigger than several tenths of a millimeter, the CPM is the detector of choice. The detector size of CPMs range from a few millimeters to centimeters, enabling researchers to examine samples that extend from several tenths of a millimeter to several centimeters. Although CCDs have much smaller collection areas, generally as small as 7 μm , they can still look at extended sources, as long as these can be imaged on the CCD.

Speed - SPCMs and CPMs are the detectors of choice when speed is an issue. CCDs are inevitably far slower because of the time it takes to charge the capacitor. This becomes important when researchers need to make certain time-resolved measurements. Suppose, for example, researchers must choose between a SPCM, CPM and a CCD to examine fluorescence in a microarray. All the devices can count photons to measure the intensity, which, in the case of the CCD, is proportional to the charge of the capacitor. However, there are events that take place within the time frame required to charge the capacitor that a CCD cannot detect, e.g. the time it takes for fluorescence to decay or for molecules to diffuse through a volume. Since a SPCM and a CPM can count photons every 50 nanoseconds or 30 nanoseconds, respectively, both can measure decay and diffusion.

Electronic shutter - Applications in fluorescence and luminescence often use a high intensity flash lamp or laser pulse to excite the sample. The light level of the excitation light, in general, is far beyond the range of the detector. If there is a significant wavelength shift between the excitation and the emission light, filters can be used. If the excitation and the emission wavelength ranges are close or even overlap, filter techniques are not sufficient. An alternative, effective method used to suppress the excitation light is to employ the electronic shutter function of the CPM. This is a unique feature of the CPM, which is not available on a PMT or SPCM. The MP series CPM modules have an incorporated electronic gate function with rise times in the nanosecond region.

Engineers build different types of instruments for different tasks, and the design parameters will determine which photon counting technology works best. If they want to perform spatial-resolved analyses based on fluorescence alone, a CCD is appropriate. If a company wants to analyze sample sizes between less than a millimeter and up to a few centimeters in the UV or visible region, a CPM is well suited. The fast internal electronic shutter of a CPM will enable the possibility to suppress effectively short-time highlight events like the excitation of a flash lamp. The fast time response enables time resolved fluorescence and luminescence applications. If researchers use a laser, in the visible light range, to examine the intensity of single molecules from a point-like source, and also need to measure decay and diffusion, they should choose a SPCM. Each technology has its own niche, and design engineers will need to select a device based on their specific requirements.

USA

PerkinElmer Optoelectronics
44370 Christy Street
Fremont, CA 94538
Toll Free: (800) 775-6786
Phone: +1 (510) 979-6500
Fax: +1 (510) 687-1140

Europe:

PerkinElmer Optoelectronics
Wenzel-Jaksch-Str. 31, D-65199
Weisbaden, Germany
Phone: +49(0) 611-492-437
Fax: +49(0) 611-492-159

Asia:

PerkinElmer Optoelectronics
47 Ayer Rajah Crescent #06-12
Singapore 139947
Phone: +65 775-2022
Fax: +65 775-1008