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Princeton Instruments ACTON

Selecting the *Right* ICCD Camera!

The latest advances in intensified CCD camera technology

This technical note is intended to help the researchers make the best selection of ICCD cameras for low light time resolved imaging and spectroscopy applications. It briefly describes the benefits and trade-offs involved with the various components of the system including intensifier type, CCD resolution and frame rate. For more detailed information on intensifiers and gated ICCD technology, please refer to the technical notes "Introduction to Image Intensifiers for Scientific Imaging", "ICCD Gating" and "Comparison of Lens-Coupled and Fiber-Coupled ICCD cameras" available at http://www.piacton.com/products/pimax/whitepapers.aspx

Introduction

A typical high performance intensified CCD (ICCD) camera consists of an intensifier tube, coupled via a fiber optic taper or a face plate to a CCD (figure 1). Camera electronics consist of both high voltage gating and timing controls for the intensifier as well as low noise CCD readout circuitry.

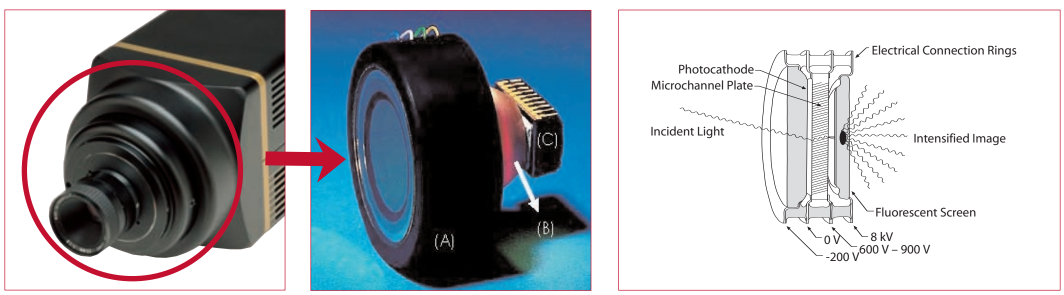


Figure 1. High performance cameras use fiber optic taper/face plate(B) to couple the intensifier (A) to the CCD (C). Also shown is the cross section of a Gen II intensifier.

Though, primarily used for military night vision applications, intensifier tubes possess several notable features such as ultra-low light sensitivity and sub-nano second shuttering (gating) -making them ideal for scientific time resolved imaging and spectroscopy applications. With continuous improvements in sensitivity and gate speeds, they are helping researchers with better insight into physical, chemical and biological processes.

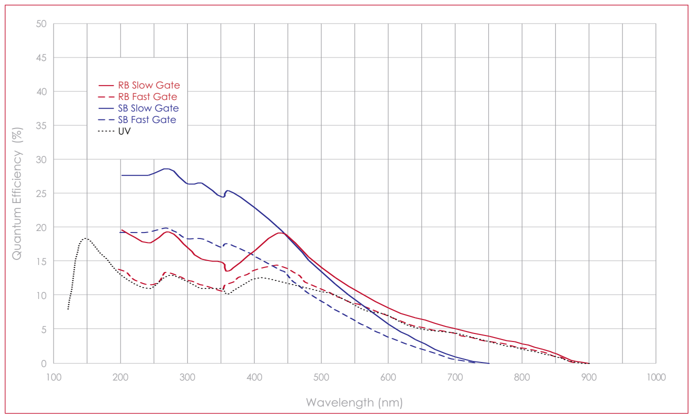
Intensifier - Performance parameters

In order to match the ICCD system performance to the requirements of the experiment, one should pay careful attention to the selection of the intensifier tube. The selection is primarily based upon

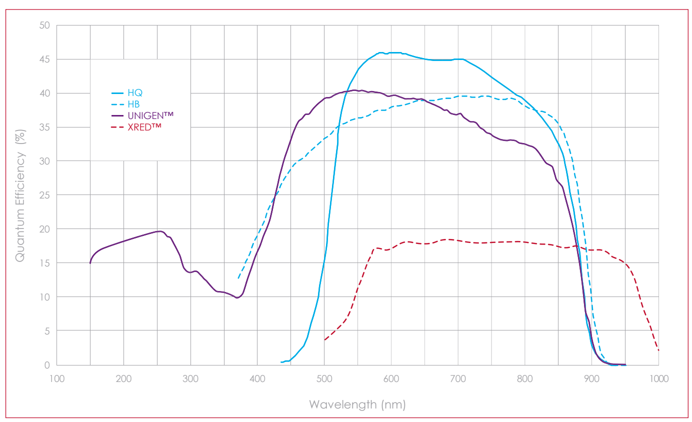
a) Quantum Efficiency (QE) of the photocathode
b) Gate speed

Quantum efficiency refers to the fraction of incoming photons that are absorbed by the photocathode at a specific wavelength. This is an important parameter as it sets, ultimately, the sensitivity of the entire detection system. Based upon different photocathode materials used, intensifier tubes are typically grouped into Gen II (generation II) or Gen III or the latest Gen III *filmless*. The QE curves for various generation intensifiers are shown in figure 2.

Gen II Intensifiers



Gen III Intensifiers



Gen III *filmless* Intensifiers

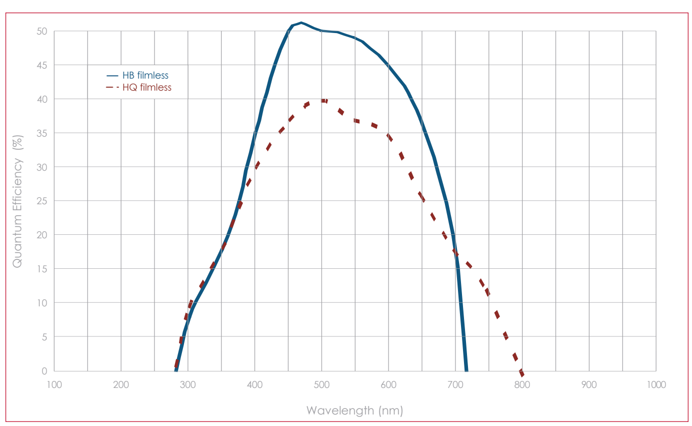


Figure 2. Quantum efficiency of Gen II, Gen III and Gen III *filmless* intensifiers

From the above quantum efficiency graphs, it is clear that

a) For applications involving UV-to-Blue region of the spectrum, Gen II intensifier tubes (UV and super blue, SB) intensifiers offer the best sensitivity. Notice the trade-off between the gating speed and the quantum efficiency. However, as described later, it is possible to minimize this compromise with intelligent gating schemes.

b) For blue-to-visible region, the latest Gen III filmless [italics] intensifiers (GaAsP) offer the best sensitivity

c) For visible-to-NIR applications, the standard Gen III tubes (GaAs) provide the maximum sensitivity

Gate speed is the time required to optically turn on and off a given intensifier. It is specified as the optical FWHM (full width at half maximum). Due to lower gate voltage requirements (~200V), Gen II fast gate and Gen III filmless intensifiers are capable of sub-nano second gate widths. Where as, the standard Gen III intensifiers achieve <5 nsec FWHM as they require higher gate voltages (~900V).

A feature comparison of all intensifier types is given in Table 1.

Parameter/Specification	Gen II Intensifiers	Gen III Intensifiers	Gen III *filmless* intensifiers
Photocathode	Bi- or Mult-alkali	GaAs	GaAsP
Peak QE	>25% (SB)	~40% (HB)	>50% (HB filmless)
Ideal wavelength range	UV to Blue	Visible to NIR (Unigen for broad coverage from UV to NIR)	Blue-to-Visible (NIR up to 780nm)
Gating voltage	~200V	~900V	~200V
Gate speeds	<2 nsec*	<5 nsec	<2 nsec*
Cost	+	++	+++

*sub-nano second gate speeds are possible

Table 1. Performance comparison between different generation intensifiers

Gen II intensifiers

Gen II intensifiers use bi- or multi-alkali photocathodes and are capable of broad wavelength coverage and can be selected to give the highest sensitivity over a specific wavelength range. For example, the "SB" style intensifiers can offer >25% QE around ~300nm region. A UV-sensitive intensifier with $MgFl_2$ input window offers the best sensitivity for deep UV measurements.

Typical slow gate Gen II intensifiers are only capable of 50 nsec to 100 nsec gate speeds. In contrast, fast gate Gen II tubes have a metal underlayer (to reduce the electrical resistance) and can be gated down to sub-nano second. The drawback of these tubes is the reduced QE caused by the metal under layer. In order to reduce the compromise between gating speed and QE, Princeton Instruments/Acton has developed innovative gating technologies such as MCP gating (see below).

"Gen II intensifiers are ideal for applications such as combustion (OH-PLIF) where high sensitivity in UV to Blue region and fast gate speeds are important"

Gen III intensifiers

A new generation of intensifiers using a new photocathode material, GaAs, was developed primarily to address the demanding requirements for military night vision applications. For the first time, these intensifiers are capable of very high sensitivity in visible-NIR region. However, they require higher gate voltage (~900V) which limits its fastest gate speeds to <5 nsec. The larger electrical field between the photocathode and the MCP results in a phenomenon called "ion back streaming" where the positively charged ions accelerate towards the photocathode with potential damage. To block this ion back-flow and to make the tubes extremely rugged to meet the stringent reliability requirements of the military, an ion barrier film is introduced between the photocathode and the MCP. The ion barrier increased the lifetime of the intensifiers, however it also blocks 10% to 20% of the photo electrons (signal) traveling between the photocathode and the MCP, thus reducing the effective QE. It must be noted that even after considering this loss, Gen III intensifiers still offer the best sensitivity in the NIR region.

Due to GaAs absorption characteristics, Gen III intensifier tubes do not provide sensitivity in the UV region. However, by using UV-to-visible converter phosphors, the new derivative tubes such as Unigen™ can deliver the widest wavelength coverage from UV to NIR. For gated LIDAR type applications around 1000nm, special extended Red (XRED) intensifiers are also available.

"Gen III intensifiers offer the best sensitivity in the NIR region (~800nm). Unigen™ intensifiers are the only intensifiers to offer the best combination of QE and wavelength range(<200nm-950nm)"

Gen III *filmless* Intensifiers

Recently, intensifier manufacturers have developed a new class of Gen III intensifiers using GaAsP photocathodes. They, for the first time, eliminate the ion barrier film and yet preserve the life of the intensifier. The technology behind these intensifiers remains a trade-secret, but the advantages to the scientific community are clear such as higher sensitivity and faster gate speeds.

In addition to the highest possible sensitivity in the visible region (<780nm), the Gen III *filmless* intensifiers are capable of ultra-fast gating (sub-nano second) similar to the Gen II intensifiers. With this combination, they are now the ideal choice for many time resolved applications that operate in the visible region of the spectrum.

"The new Gen III *filmless* intensifiers offer ultra-fast gating as well as >50% QE for the best combination of sensitivity and gate speed"

Gating

[For more detailed information, see technical note on "ICCD gating"]

Fast shuttering or gating capability of intensifiers allows capture of transient phenomena such as fluorescence or luminescence immediately following the excitation of a sample. Gating is also used to effectively eliminate ambient light. Typically, gating is performed by switching the voltage between photocathode and MCP. High performance ICCD cameras such as PI-MAX use optimum gating voltages in order to achieve effective gating and high spatial resolution.

As mentioned earlier, fast gate Gen II intensifiers are capable of sub-nano second gate speeds and slow gate intensifiers are capable of 50 nsec-100 nsec. However, by gating the voltage across the MCP (instead of photocathode-MCP voltage), it is possible to achieve < 9 nsec gate speeds on slow gate intensifiers. This has proved very beneficial for applications such as OH-PLIF, requiring high sensitivity in blue region (SB intensifiers) and fast gate times.

The Gen III intensifiers are capable of only <5nsec gate speeds due to higher gate voltage (~900V). Where as, the new Gen III filmless intensifiers are capable of sub-nano second gate speeds as they require only ~200V volts similar to the Gen II intensifiers.

Gen II and Gen III filmless intensifiers are capable of sustained 50 kHz (50, 000 gates/sec) repetition rate and 500 kHz in a burst mode. Due to higher voltage (and corresponding increase in power requirements), the standard Gen III intensifiers are capable of reduced 5 kHz sustained repetition rate and 50 kHz in the burst mode. It is important to note that these specifications are based on the fact that "full" gating voltage is applied. A faster repetition rate specification often means reduced gate voltage.

For ultra-high frame rates as in (>1 kHz), it is also important to consider P46 phosphors with faster decay time (<2 μsec) as opposed to P43 which has 2-3msec decay time.

CCD Performance

Though the performance of the intensifier tube plays an important role in the overall ICCD camera system performance, the choice of the appropriate CCD can not be overlooked.

In time resolved applications, it is often important to minimize the effects of photo-bleaching of the samples under study. This requires the data to be captured using minimum number of excitation pulses. For example, typical pulsed Nd: YAG lasers operate around 10 Hz, so it is often necessary for an ICCD camera to capture a frame every 100 msec. The requirement is met by the availability of higher readout rates to achieve greater than 15 full frames per second (for a 512x512 pixel resolution). See figure 3.

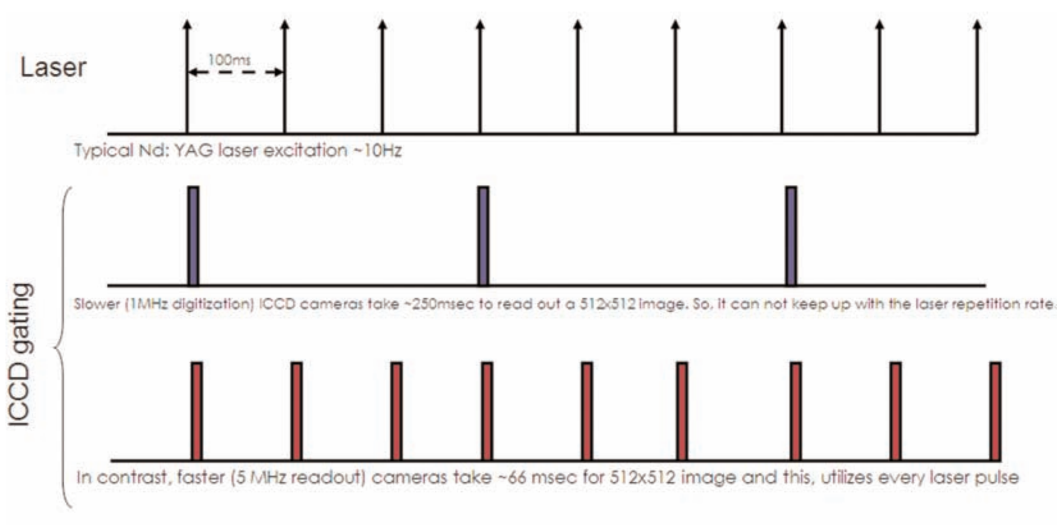


Figure 3. Higher frame rate helps more efficient use of excitation light sources such as pulse lasers operating higher repetition rates.

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The new interline CCDs (PI-MAX2: 1003) offer a very unique capability that allows capture of two distinct frames in as short as 2 μsec (limited mainly by the decay time of P46 phosphor) making it ideal for time resolved flow measurement applications.

The dynamic range and linearity of the ICCD camera is often determined by a combination of MCP saturation and CCD full well. Empirical data show that it is possible, in transient as well as CW applications, to achieve >15-bits of true dynamic range.

Ease of use

The scientific grade ICCD cameras should not only provide the no-compromise performance, they should also be easy to use. For example, the PI-MAX cameras from PI/Acton are offered with built-in programmable timing generator (PTG™), plug-n-play USB2.0 interface, fiber optic data interface option for remote operation. And complete software support.

Summary

A high performance ICCD camera should be able to meet, often conflicting set of requirements to achieve the optimum performance for a given application. With the availability of Gen III filmless intensifiers and enhancements to the older generation intensifiers (e.g., UnigenTM, MCP Gating) they are able to allow researchers to design new experiments that have hitherto been difficult.

About Princeton Instruments/Acton

Over the past two decades, Princeton Instruments/Acton has been the leading pioneer of high-performance detection systems for imaging and spectroscopy. Princeton Instruments/Acton's innovations include the world's first spectroscopy camera to use a photodiode array (and later, the first to use a CCD), as well as the introduction of the first high-performance, gated, intensified CCD camera. In addition to breaking new ground in the field of spectroscopy, Princeton Instruments/Acton has also designed the highest-sensitivity CCD cameras available for scientific imaging applications (read noise of approximately 2 e- rms with quantum efficiency eclipsing 90%).

Today, Princeton Instruments/Acton continues to expand the boundaries of technology:

- High-frame-rate, gated, intensified CCD cameras (PI•MAX®)
- Integrated, state-of-the-art Programmable Timing Generator™ (PTG™)
- Deep cooled EMCCD cameras with single photon sensitivity (PhotonMAX)
- Latest plug-and-play data interfaces (USB 2.0)
- Guaranteed lifetime vacuum (PIXIS, PhotonMAX)
- Thermoelectric cooling to -100 °C without liquid assistance (XTE platform)
- InGaAs detectors with sensitivity to 2.2 μm (OMA V™)

References

(Available at http://www.piacton.com/products/pimax/whitepapers.aspx)

1. "Introduction to Image Intensifiers for Scientific Imaging"
2. "ICCD Gating"
3. "Comparison of Lens-Coupled and Fiber-Coupled ICCD cameras"

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