ICCD and UV Gen 3 intensifiers

UV-Visible-NIR photocathode QE considerations

Composite phosphor coatings - such as "Lumogen" - are routinely used to extend the UV sensitivity of CCD / EMCCD / CMOS sensors. These phosphors absorb photons of higher energy, and re-emit radiation at wavelengths close to the maximum QE of the photocathode. A similar approach has been used successfully to extend the UV sensitivity of Gen 3 image intensifiers down to less than 200 nm.

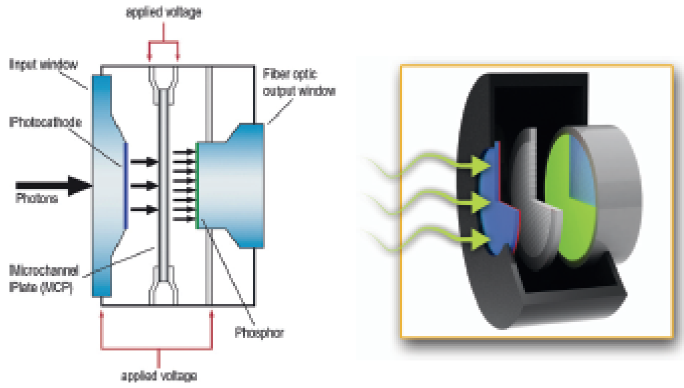


Figure 1: Overview of Image Intensifier construction

Generation 3 ('Gen3') photosensitive elements ('photocathodes') offer great Quantum Efficiency (QE) up to 50% in the visible range and good NIR sensitivity compared to Gen 2 devices. Gen 3 photocathodes can technically only be deposited on glass substrates or glass fibre optics plates, as this material presents the only suitable match to the photocathode thermal expansion coefficient. Gen 3 image intensifiers have therefore no sensitivity below ~ 350 nm due to the transmission cut-off of the Glass interface.

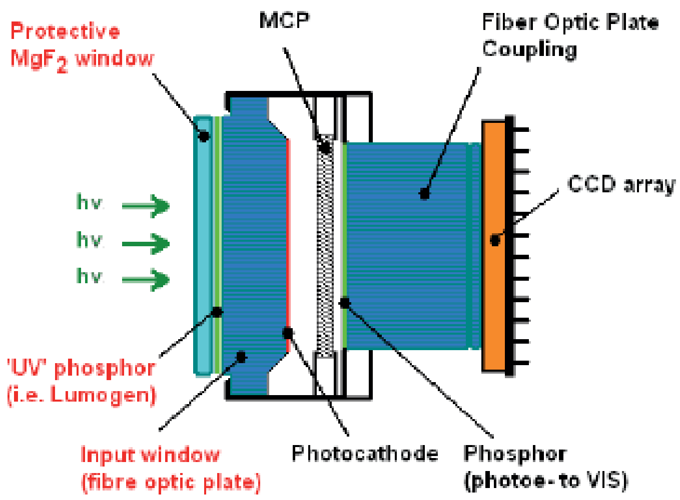


Figure 2: Overview of UV-sensitive Gen 3 image intensifier architecture with modified input interface (MgF2 window, 'UV phosphor' and fibre optic plate photocathode substrate instead of traditional glass window)

The present technical note explores the impact of the addition of a phosphor interface in front of Gen 3 image intensifiers in the Visible- NIR region, weighting pros and cons to such approach.

1. Image Intensifier construction

Originally developed for night vision, image intensifiers act as ultrafast (nanosecond-scale) optical shutters, as well as providing signal amplification up to x1,000 that proves invaluable to the world of research for studies of shortlived events, e.g. fluorescence decay time measurements, plasma or combustion kinetics.

Image intensifiers consist of an evacuated tube comprising of a photocathode, a Micro-Channel Plate (MCP) and a phosphor screen.

In brief, an incoming photon strikes the photocathode deposited on the inside of the input window, and a photo-electron (under a wavelength-dependant probability) is generated. This photo-electron is then drawn towards the MCP by an electric field. Through the glass channels of the MCP honeycomb structure, the incoming photo-electron is accelerated to gain enough energy to dislodge secondary electrons, which in turn will generate further electrons in a cascade manner. At the output of the MCP, the photo-electron cloud hits a phosphor which converts this signal back to photons detectable by the CCD/CMOS device.

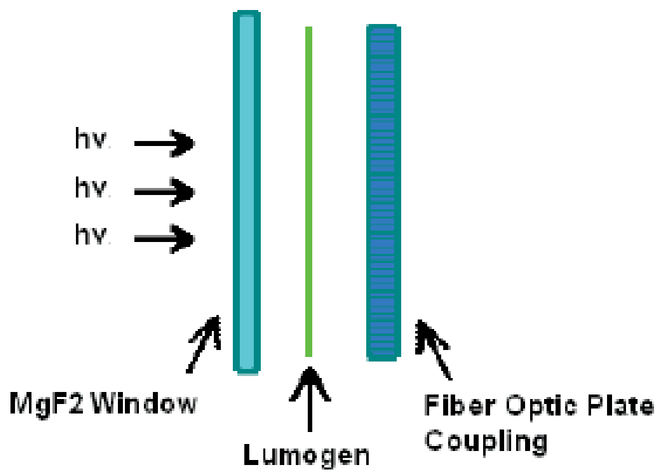


Figure 3 : Exploded view of the 'UV-phosphor' interface prior to the photocathode

2. Construction of a UV-sensitive Gen 3 image intensifier

UV sensitivity (below 350 nm) for Gen 3 image intensifier is achieved by adding a phosphor interface in front of the traditional image intensifier build, as shown on figure 2.

The photocathode substrate (input window) is replaced by a fibre optic plate in order to direct efficiently the up-converted radiation from the 'UV phosphor' towards the photocathode.

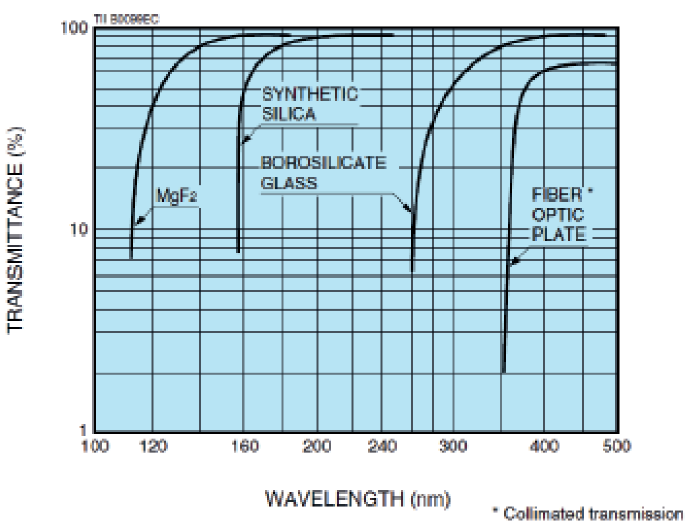


Figure 4 : Typical transmittance curve for MgF2 window showing < 95% transmission in the 200-900 nm

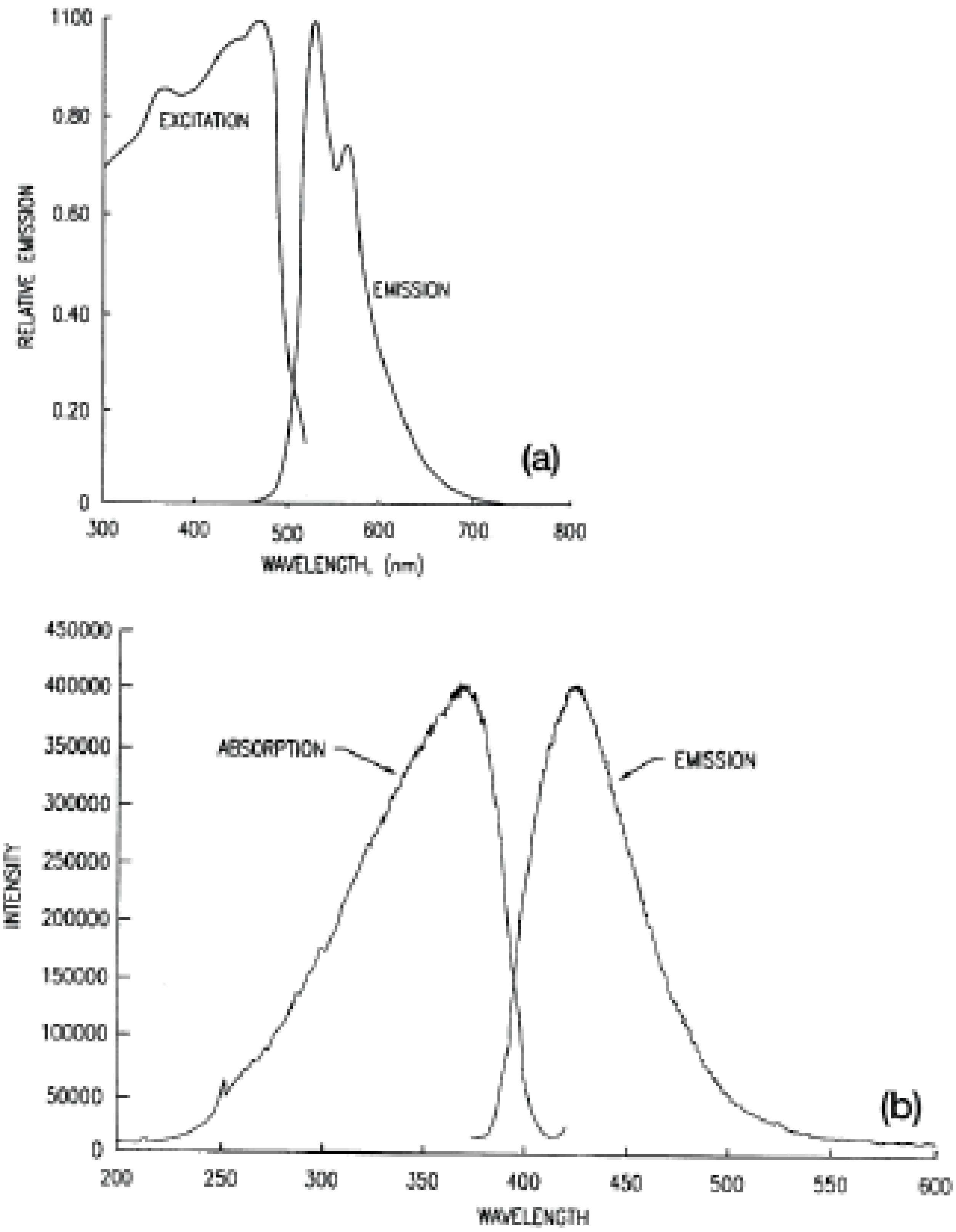


Figure 5 : Absorption/Emission profile of a) Standard Lumogen and b) Unichrome phosphor

The 'UV' phosphor (typically 'Lumogen' type) is deposited on the input fibre optic plate, and a further protective MgF2 window is used to protect the 'UV phosphor' from any degradation due to exposure to ambient air and contamination.

3. Key optical characteristics considerations for 'UV phosphor'

interface A simplified view of the optical interface preceding the photocathode is shown on the exploded view in figure 3.

a) Considering the transmission of the different components involved, the first optical element in the optical path is the protective MgF2 window. Figure 4 shows the typical transmission of such window, which is ~ 95% over the 200 to 900 nm range of interest for the present discussion.

b) The typical Excitation and Emission characteristics of the 'UVphosphor' used for Gen 3 image intensifiers are shown on figure 5a and b. Figure 5b shows the characteristics of a proprietary 'UVphosphor' - known as 'Unichrome' - used by Princeton Instrument for this type of Gen 3 image intensifiers with UV response.

'UV-phosphor' characteristics represented on figure 5a and 5b show absorption characteristics from 200-500 nm and 200-400 nm respectively, while exhibiting peak emission at 550 nm and 440 nm respectively.

c) The third key element to consider is the replacement of the glass photocathode substrate on the standard Gen 3 intensifier by a fibre optic plate. Figure 4 shows that the transmission of fibre optics plate in the re-emission region of the two ‘UV phosphors’ considered above is 25% lower than the traditional glass window, i.e sitting at ~ 65 % above 400 nm.

The last element to consider is the Gen 3 photocathode itself. Different flavours of Gen 3 photocathodes are available (GaAs, GaAsP, GaAsP enhanced red ...) with various wavelength coverage and peak efficiency. Given the absorption profiles of the phosphors shown above, the photocathode of choice for this UV-sensitive Gen 3 is the GaAs substrate, which typical QE as given by manufacturer is shown on figure 6. Peak QE is shown to be 30% @ 650 nm

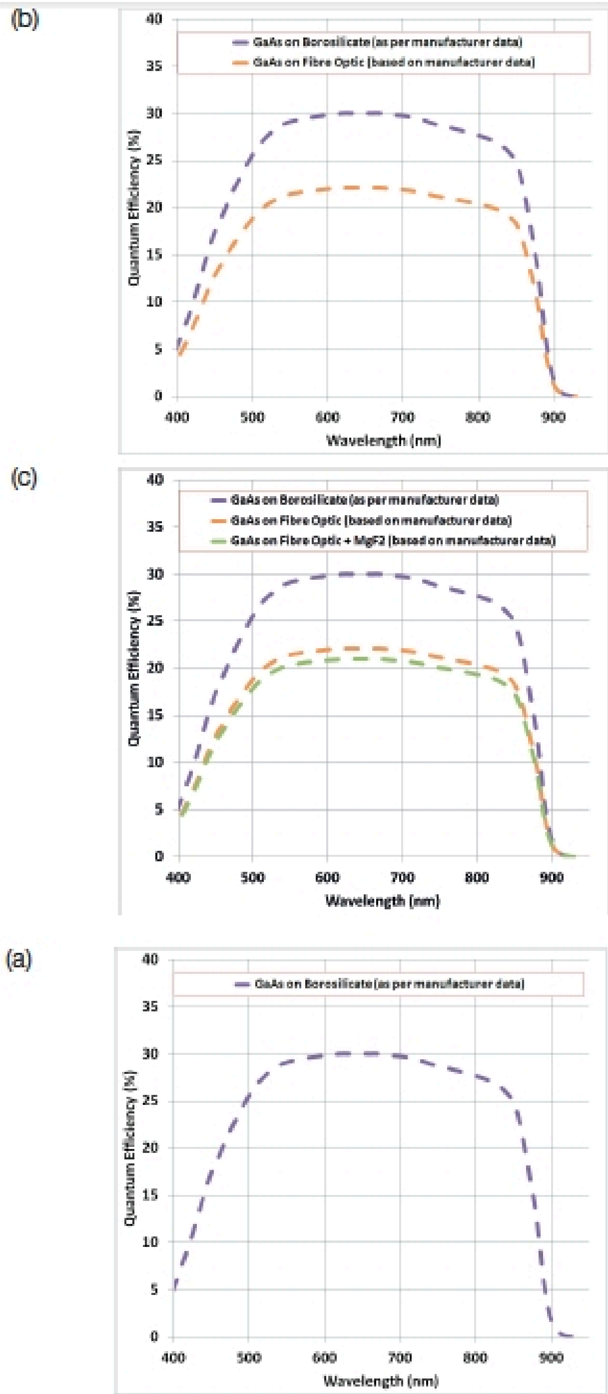
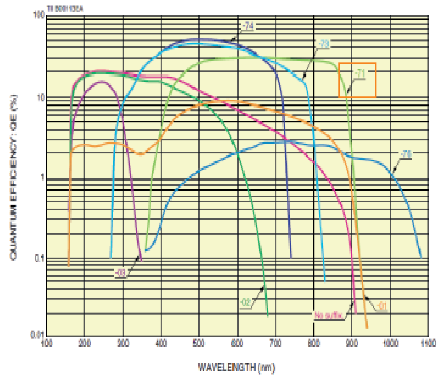


Figure 7 : Step-by-step impact on a) standard GaAs photocathode deposited on glass window by b) fibre optic substrate and c) MgF2 protective window, based on Image intensifier typical data



Suffix	Photo Cathode	Input Window
-71	GaAs	Borosilicate Glass
-73	Enhanced Red GaAsP	Borosilicate Glass
-74	GaAsP	Borosilicate Glass
-76	InGaAs	Borosilicate Glass
Non	Multialkali	Synthetic Silica
-01	Enhanced Red Multialkali	Synthetic Silica
-02	Bialkali	Synthetic Silica
-03	Cs-Te	Synthetic Silica

The sensitivity at short wavelengths charges with typical transmittance of window materials. Please refer to figure 4 (P6).

Figure 6 : Manufacturer data showing typical QE of GaAs photocathode (suffix '-71') - peak QE is 30% @ 650 nm

Summary

Over the GaAs photocathode useful QE range :

- MgF2 window has a transmission of ~95 %
- Fibre optic window has 25% lower transmission than traditional glass substrate on which Gen 3 photocathodes would be deposited

Assuming - for simplification - complete transparency of the phosphors to VIS and NIR radiation, and no transmission impact from the gluing interface between MgF2 window & phosphor, and phosphor & fibre-optic plate, one should therefore expect the following scenario:

QE ('UV'-sensitive photocathode, 650 nm)
= QE (GaAs photocathode on glass, 650 nm)
x
MgF2 transmission
x
Fibre-optic transmission impact vs. glass substrate
= 30 x 0.95 x 0.75

= ~21 % (from 30%)

4. Extended impact on Quantum Efficiency in the Visible / NIR region

Figures 7 present the overall expected impact on Quantum Efficiency in the Visible and Near-Infrared-only based on the summary assumptions and conclusions in paragraph 3.