Intensifiers: A Low Cost Solution for Observing Faint Double Stars?

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Abstract Intensifier tubes have commonly been used for night vision, but could have potential to be a low cost solution to telescopes observing faint stars. Four total generations of intensifiers have been produced, but only Generations 2 and 3 show promise for Astrometric research due to the development of the microchannel plate and more efficient photocathodes. Although these intensifier tubes have potential to improve the performance of telescopes using speckle imaging, a new low cost CMOS camera is able to perform as well as we had hoped the intensifier could.

Introduction

Since the invention of speckle interferometry by David L. Fried in 1965, film cameras limited the capability of double star observations (Fried 1965). Speckle imaging became frequent in the 1970's, but the low quantum efficiency of these film cameras could only capture a small portion of light, making only bright double stars suitable for observations. The 1970's introduced the Charge Coupled Device (CCD) camera, shown in Figure 1, which is far more sensitive to light but has issues with high speed read noise when converting data from analog to digital. This is the same issue that most CMOS cameras are prone to. The high speed read noise limits small telescopes to seventh magnitude stars when using CCD or CMOS cameras at high speed for speckle interferometry. Shown in Figure 1, the Electron Multiplying CCD (EMCCD) camera, invented in 2001, does not face the same issues as its predecessors as it amplifies the signal with an on-chip gain register prior to the noisy analog-to-digital converter on the output, thus reducing the amount of read noise relative to the signal. However, EMCCD cameras cost $14,000 to $40,000, making them an expensive option for both amateur and professional astronomers.

Figure 1. A CCD camera, left, along with an EMCCD camera, right.

A potential alternative to an EMCCD camera is an intensifier tube, which is commonly used in night vision devices. Intensifier tubes amplify the light the telescope receives from distant stars. Photons over a range of the electromagnetic spectrum enter the telescope and are converted to electrons by a photocathode. Early generations of intensifier tubes convert the electrons back into photons, but later generations were able to amplify the quantity of electrons. The resulting photons are focused by an eyepiece lens, making an image much brighter than the original. Intensifier tubes cost approximately $200 to $3,000, making them a potentially cost efficient alternative to EMCCD cameras. This may make collecting speckle data from close, faint binary stars with a mere CCD actually plausible.

However, after this project was well along, it was found that a new, very low cost, CMOS camera was able to do what we had hoped for the intensifier tubes, on a smaller budget and with better performance (Genet, et al. 2015). Due to the quality of the new camera, we found it unnecessary to test and observe with the intensifier.

Intensifier Description

The concept of an intensifier tube was first proposed in 1757 by Mikhail Lomonosov. He proposed and later proved that tubes could be built which would allow the naked eye to view objects in the dark (Ponomarenko & Filachev 2007, p1). Although he originally proposed this idea, it was far ahead of its time and would not become a relevant idea until Broglie proposed that electrons, and matter, had wavelike properties (Broglie 1923). Ten years after Broglie's PhD thesis, scientists working for Philips developed the first infrared converter. Since then, there have been four generations of intensifier tubes invented throughout the past century.

Generation 0

The Generation 0 intensifier tube uses an objective lens to collect and focuses incoming photons onto a photocathode which emits an electron due to the photoelectric effect (Einstein 1905). The photoelectric effect states that when a photon hits a metal, a photoelectron can be "knocked" loose. The maximum kinetic energy of one of these photoelectrons is governed by the equation below.

$$KE_{Max} = hf - \emptyset$$

where h is Planck's constant, f is the frequency of the incoming photon and ϕ is the work function of the material. This means that for the photoelectric effect to occur, the energy of the incoming photon, hf, must be greater than the work function of the metal. Each photocathode is composed of different materials which causes the work function to change; therefore, the threshold frequency of incoming photons required to knock an electron loose varies by material.

In the Generation 0 intensifier, a S-1 photocathode consisting of silver, oxygen, and caesium (Ag, O, and Cs) is used. Due to the composition of the photocathode, it responds best to near-infrared electromagnetic radiation (Skatrud & Kruse 1997). This photocathode has a spectral range from 400nm to 1200nm and a peak quantum efficiency of .4% at 740nm (Hamamatsu Photonics 2006, p35). The quantum efficiency of a photocathode is the percent of incident photons that are converted to electrons by the photocathode. This percent can be calculated for a specific wavelength of light as seen in the equation below (Hamamatsu Photonics 2006, p38).

$$QE_\lambda = R_\lambda(hc/p\lambda)$$

where c is the speed of light, h is Planck's constant, λ is the wavelength of the incident photon, q is the charge of a photon, and R is defined as the photocurrent, or electric current, of the photocathode divided by the radiant flux, or the radiant energy transmitted over time.

After the photons are converted to electrons, they are then accelerated in an electrostatic field and inevitably hit a phosphor screen. The phosphor screen then releases 20 to 200 photons for every electron hitting the screen, multiplying the image even further. The phosphor screen is also what gives many intensified images their green color.

Generation 1

The difference between the Generation 0 and Generation 1 intensifier tubes was the discovery of more effective photocathode materials. The Generation 1 contains a S-20 photocathode consisting of sodium, potassium, antimony, and caesium (Na, K, Sb, and Cs). The S-20 photocathode peaks in quantum efficiency at a wavelength of 375 nm, which is on the border of ultraviolet and the visible spectrum (Hamamatsu Photonics 2006, p35).

Although, like the Generation 0 intensifier, it does not peak in the visible spectrum, the quantum efficiency of the S-20 photocathode peaks at 20% (Hamamatsu Photonics 2006, p35). Compared to the Generation 0 intensifier, the Generation 1 intensifier's quantum efficiency is fifty times larger, due to the improved photocathode, making it superior in converting incident photons to electrons.

Generation 2

The Generation 2 intensifier tube, whose optical layout can be seen in Figure 2, differs from the Generation 1 in two specific ways. It uses a S-25 photocathode instead of the S-20, and a newly developed microchannel plate. The S-25 cathode consists of sodium, potassium, antimony, and caesium (Na, K, Sb, and Cs). The same materials are used in the S-20 photocathode, but the S-25 uses thicker layers of this material. As a result, the S-25 has a reduced quantum efficiency of 8% but causes the photocathode to peak in quantum efficiency at 580nm (Hamamatsu Photonics 2006, p35). Another property of the intensifier tube is that compared to the Generation 1, it is more sensitive to the infrared portion of the spectrum and less toward the blue end of the spectrum. Although there is a significant loss in the photocathode's quantum efficiency, the electron multiplication of the microchannel plate makes up for this.

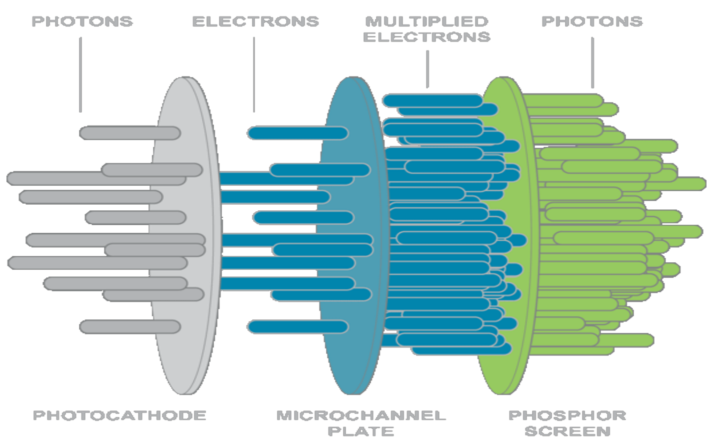

Figure 2. The optical layout of the Generation 2 microchannel plate. From left to right, the photocathode, microchannel plate, and phosphor screen.

In addition to the improved cathode, the Generation 2 intensifier uses the newly developed microchannel plate seen in Figure 2 to amplify the signal. This microplate is a thin glass wafer manufactured from thousands of individual, hollow glass fibers, or microchannels. A large potential difference is applied across the microplate. Electrons enter the microchannels within the high voltage plate and collide into the channel walls. Each individual electron elicits hundreds of additional electrons, as seen in Figure 3. This process greatly multiplies the number of electrons that entered the tube. These multiplied electrons hit the phosphor screen, resulting in a magnified image.

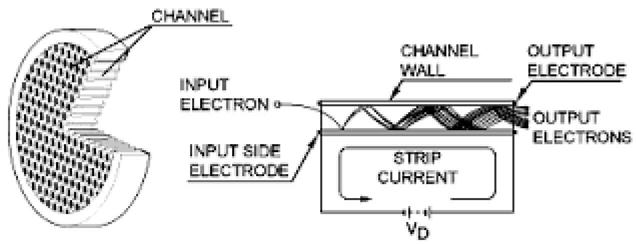

Figure 3. A Microchannel Plate, left, along with an individual microchannel, right.

Generation 3

Advancements in photocathode technology induced the development of the 3rd generation intensifier tube which used gallium arsenide (GaAs) for the photocathode. This gallium arsenide photocathode has a spectral range of 380 to 890nm and has a peak QE of 14% at 760nm (Hamamatsu Photonics 2006, p35). Although this QE is not as high as previous photocathodes, the photocathode "demonstrates a nearly flat, high-sensitivity spectral response curve from 300 to 850 nanometers" (Hamamatsu Photonics 2006 p31). This makes the photocathode sensitive to infrared and visible light where other photocathodes might drop off in the visible or infrared. The Generation 3 photocathode also includes a microchannel plate, but due to damaging chemical and electrostatic effects inside the tube, a metal-oxide coating, known as an ion barrier film, was added on the input side of the MCP to protect the photocathode. The film greatly increases the lifespan of the Generation 3 tubes to 15,000 hours in comparison to the Generation 2 tubes which have a lifespan of 2000 hours.

Discussion

Intensifier tubes show promise in aiding telescopes in seeing fainter and closer double stars due to their ability to convert a broad spectrum of a star's spectrum into visible light. By converting a broad wavelength of a star's spectrum along with many internal mechanisms, these intensifier tubes are able to multiply the light received from a star. Pairing an intensifier tube along with a typical CCD camera may be able to produce results equivalent to an expensive EMCCD camera.

Although intensifiers may be an adequate alternative to an EMCCD camera, a new low cost CMOS camera has produced results that are similar to what we had hoped for from the intensifier tubes (Genet, et al. 2015). This caused the testing of intensifier tubes in aiding speckle imaging to be overcome by the CMOS camera. Intensifier tubes may still prove useful for observing certain astronomical objects. Due to an intensifier's ability to convert light, particularly from the infrared end of the spectrum, intensifiers could be beneficial when observing objects whose spectrum lies in infrared light. Further investigation into this subject may prove to have valuable results.

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