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Photoemission and optical constant measurements of a Cesium Iodide thin film photocathode

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ABSTRACT

The performance of cesium iodide as a reflective photocathode is presented. The absolute quantum efficiency of a 500 nm thick film of cesium iodide has been measured in the wavelength range 150 nm–200 nm. The optical absorbance has been analyzed in the wavelength range 190 nm–900 nm and the optical band gap energy has been calculated. The dispersion properties were determined from the refractive index using an envelope plot of the transmittance data. The morphological and elemental film composition have been investigated by atomic force microscopy and X-ray photo-electron spectroscopy techniques.

1. Introduction

Various photocathodes are currently used to improve the sensitivity of photon counting or imaging detectors. The choice of photocathode material is determined by the spectral range where the device sensitivity is crucial [1]. Alkali halide photocathodes have been shown to be very efficient photo-converters in the ultraviolet (UV) wavelength range. Cesium Iodide (CsI) is one of the most efficient among them, because CsI photocathode is relatively stable under short exposure to air and has the highest quantum efficiency (QE) among other alkali halide photocathodes [2]. Therefore it is widely used in many UV-detecting devices [2]. These devices consist of films of thickness varying from a few nanometers to a few micrometers, depending upon the mode of operation of the photocathode. Therefore it is important to know the absorbance, transmittance and refractive index as a function of wavelength to predict the photoemissive behavior of the photocathode. From the knowledge of these optical constants, the optical band gap of the film can be determined.

In the present work, we have measured the optical absorbance of a 500 nm thick CsI film in the spectral range 190 nm–900 nm. The transmittance, refractive index and optical band gap energy were estimated from the absorbance data. Photoemission measurements were performed in the wavelength range 150 nm–200 nm. The surface morphology, studied by atomic force microscopy (AFM), is also reported together with the elemental composition obtained by X-ray photo-electron spectroscopy (XPS).

2. Experimental details

The CsI film was deposited by thermal evaporation (TE) in a high vacuum (3×10^{-7} Torr) evaporation chamber. Prior to deposition, typical compositions of different residual gases including water vapor inside the evaporation chamber were monitored through a residual gas analyzer (SRS RGA 300 unit). A CsI crystal of high purity (99.999%) from Alfa Aesar,[1] was placed into a tantalum boat inside the deposition chamber and heated carefully to allow outgassing from the outer surface of the crystals, if any. After appropriate outgassing and melting of CsI crystals, a 500 nm thick CsI film was deposited on quartz and aluminum (Al) substrates. The typical deposition rate was 1 nm to 2 nm per second. The thickness of the film as well as the deposition rate were controlled by a quartz crystal thickness monitor (Sycon STM 100). After the film preparation, the vacuum chamber was purged with nitrogen (N_2) gas, in order to avoid the interaction of humidity on the prepared CsI film. Immediately after the chamber opening under constant flow of N_2 gas, the CsI film was placed into a vacuum desiccator and further moved to the characterization setup.

The photoemission measurement was performed on a 234/302 vacuum ultra violet (VUV) monochromator (see reference [3] for details), in the wavelength range 150 nm–200 nm. The UV/Vis measurement of CsI films was carried out on a Perkin Elmer UV/Vis spectrometer (Model: λ 25) in the wavelength range 190 nm–900 nm. Further, for morphological study, the CsI film deposited on an Al substrate was used for AFM measurement. AFM scanning was done by NEXT ND-MDT atomic force microscope, which

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provides a high resolution two dimensional (2-D) and three dimensional (3-D) surface image. The elemental composition analysis of the film was carried out by XPS.

3. Photoemissive properties of CsI

The absolute quantum efficiency (QE) of the film was measured with the 234/202 VUV monochromator. The absolute QE, which is the ratio of emitted photoelectrons to incident photons, is determined by illuminating the cathode with a photon flux of a given wavelength and the resulting photocurrent measured by a picoammeter (Keithley-6485). The QE measurement of the as-deposited CsI photocathode was performed in the wavelength range 150 nm–200 nm, with a step size of 2 nm. From the plot of Fig. 1, the maximum QE is about 40% at 150 nm. The QE was found to decrease with increasing wavelength. The observed QE data are in good agreement with most data reported in the literature [4].

4. Optical properties of 500 nm thick CsI film

4.1. Optical absorbance and band gap

The UV/Vis absorption of a CsI film, deposited on a quartz substrate was measured in the spectral range 190 nm–900 nm, as shown in the inset of Fig. 2. An absorption peak is observed in the UV wavelength region (wavelength smaller than 225 nm) and its amplitude is found to be ~3.5. The absorbance lies in the UV-region at a wavelength smaller than 225 nm. A similar result for absorbance spectra has been previously reported by Lu and McDonald [5] for a 200 nm thick CsI film. The band gap of the photocathode is one of the key parameters determining the range of its most efficient operation, in particular the sensitivity cutoff. In addition to an appropriate optical band gap energy, a good photocathode material should allow an efficient electron transport to the emission surface and should have low or negative work function or electron affinity.

The absorption of incident photons in the UV region is attributed to the band gap absorption of the CsI film. The large increase in the absorption for wavelengths smaller than 225 nm can be assigned to the intrinsic band gap absorption due to the electron excitation from the valence band to the conduction band. The absorption band gap energy (E_g) has been calculated by using the Tauc relation [6].

$$(\alpha h\nu)^n = A(h\nu - E_g), \tag{1}$$

where A is the edge width parameter, h is the Planck's constant, ν is the frequency of vibration, $h\nu$ is the photon energy, α is the absorption coefficient, E_g is the band gap energy and n is either 2 for direct band transitions or 1/2 for indirect band transitions. The absorption coefficient α has been determined using the relation [7]:

$$\alpha = \frac{1}{t}\ln\frac{1}{T}, \tag{2}$$

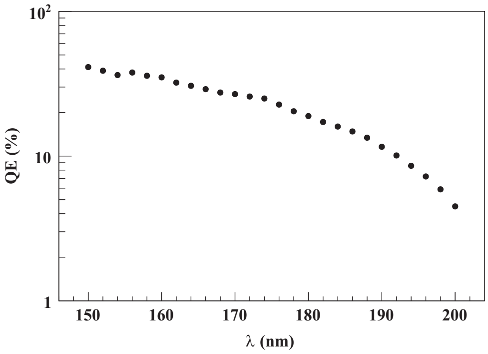

Fig. 1. Absolute QE (%) as a function of wavelength (λ) of a 500 nm thick CsI film photocathode deposited on an Al substrate.

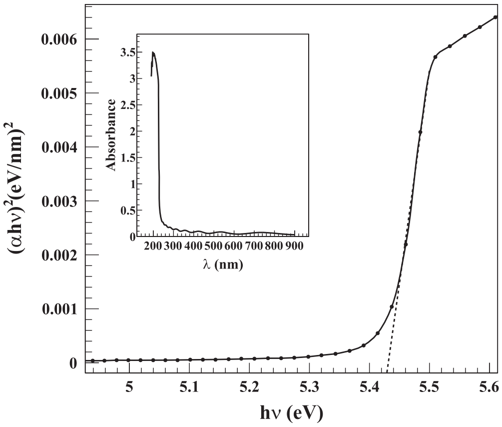

Fig. 2. Variation of $(\alpha h\nu)^2$ vs. photon energy ($h\nu$) and absorbance as a function of wavelength (inset) of a 500 nm thick CsI film deposited on a quartz substrate.

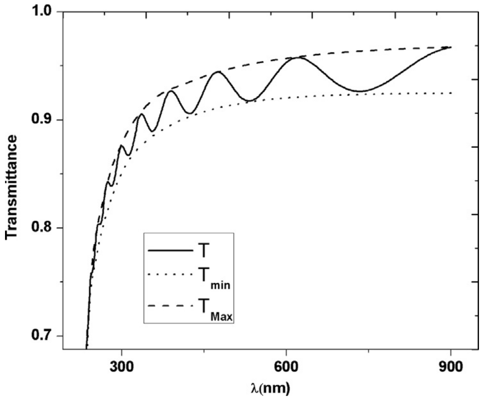

Fig. 3. Transmission spectrum of a 500 nm thick CsI film (solid line), including the maximum T_{max} and minimum T_{min} transmittance envelope curves (dashed and dotted lines).

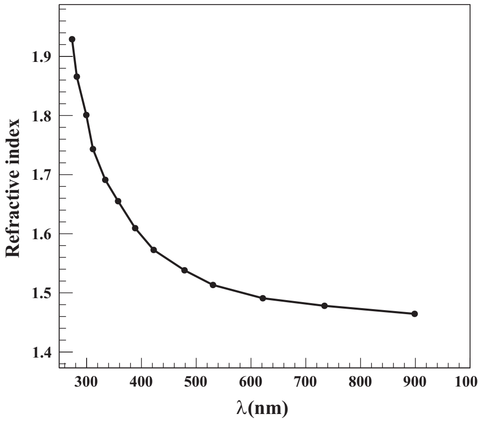

Fig. 4. Refractive index as a function of wavelength for a 500 nm thick CsI film photocathode deposited on quartz substrate.