QUANTUM EFFICIENCY OF AN OPTICAL MONOCHROMATOR

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1. INTRODUCTION

A calibrated optical monochromator is a most powerful tool in many quite diverse fields of research. The calibration itself will, however, rarely be the goal of a research project. Therefore, it is assumed here that the reader has a well-defined purpose for calibrating his optical system, and consequently, we will briefly mention some of the reasons for performing a calibration. For example, Andersen and others [1] have calibrated a McPherson model 218 monochromator used in atomic collision studies. They have defined the overall absolute quantum efficiency, $K(\lambda)$, as the mean output signal per incoming photon of wavelength λ. Also, the monochromator whose calibration resulted in this article (Jarrel–Ash model 82-410) is being used in Sputter-Induced Photon Spectroscopy (SIPS) studies. It was necessary to determine the absolute quantum efficiency of this monochromator in order to study the absolute photon yield in the sputter-induced optical emission process [2] and to investigate the possible mechanism of outer-shell excitation in sputtered atoms [3, 4]. The complete apparatus used in these studies is described elsewhere [4–6].

2. RADIATION STANDARDS

For calibration work, some standard of spectral radiance is often used. The spectral radiance, $J(\lambda)$, defined as the rate of emission of radiation energy per unit wavelength interval, per unit solid angle and unit surface area of the emitter, is given, for a gray body of temperature T, by the Kirchhoff–Planck Law [1]:

$$J(\lambda) = \varepsilon(\lambda)\left(\frac{2c^2h}{\lambda^5}\right)\left(\frac{1}{\exp(hc/\lambda KT)-1}\right) \quad (1)$$

where $\varepsilon(\lambda)$ is the spectral emissivity which is equal to the coefficient of absorption for the radiator surface. In this work the black-body calibration of the optical system was done against a standard quartz lamp tested and supplied by Ann Arbor Testing Laboratories, Inc. The color temperature (3000 K) and luminous intensity of the lamp were measured by Ann Arbor Testing Laboratories, Inc., in terms of standards provided by the National Bureau of Standards.

3. EXPERIMENT

The black-body calibration procedure used, is similar to that described by Andersen and others [1]. Figure 1 shows the schematic diagram of the calibration experiment. The unpolarized emitted radiation from the 0.33 cm^2 standard quartz lamp was focused onto the 250 μm entrance slit of the monochromator by a 3.81 cm (1.5 in) diameter quartz lens. The distance between the source and the

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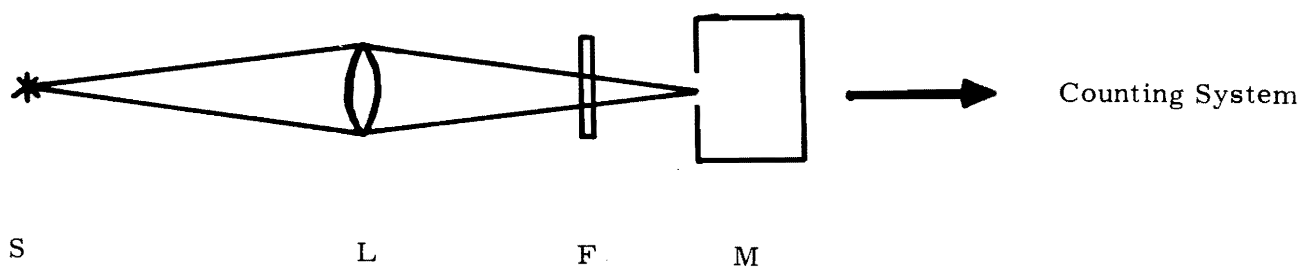

Figure 1. Schematic Diagram of the Experimental Set-up Used in Calibrating the Monochromator Where S is the Source; L is the Lens; F is the Neutral Density Filter and M is the Monochromator.

lens was 369 cm. The diameter of the image focused onto the slit was measured by a travelling microscope and found to be 0.4 cm. On applying 30.07 volts across the lamp and passing 2.776 amps through its filament, the lamp reached a steady color temperature (3000 K). Moreover, the same temperature was measured by a pyrometer. To avoid saturation of the photomultiplier tube, metallic neutral density filters with quartz substrates were placed between the source and the monochromator. A 0.9% transmission neutral density filter with a spectral flatness of 0.2% was used for wavelengths in the range 240–400 nm while for the wavelengths in the range 400–800 nm a 2.5% transmission neutral density filler with a spectral flatness of 0.25% was used in addition to the 0.9% transmission filter. The wavelength of the emitted radiation was manually scanned in steps of 10 nm and the count rate in counts s^{-1} was recorded for each wavelength by taking the average of four trials. It is worth mentioning that the calibration procedure was carried both with the optical system on and off the apparatus.

4. CALCULATION OF THE QUANTUM EFFICIENCY

In this work, the absolute quantum efficiency, $K(\lambda)$, is defined as the number of photons of wavelength λ detected per photon received by the monochromator. The number of photons, $S(\lambda)$, detected per second is experimentally obtained and the number of photons, $R(\lambda)$, received per second by the monochromator is calculated from the known spectral output of the standard lamp and the geometry of the experiment.

The spectral output, $Q(\lambda)$, of the standard lamp is given in microwatts per steradian per 10 nm wavelength interval. This spectral output is converted into a number of photons, $N(\lambda)$, emitted at a given wavelength λ per second per steradian by dividing it by the energy of the photon, $h\nu$, *i.e.*,

$$N(\lambda) = \frac{Q(\lambda)}{h\nu}\left(\frac{\mu\text{W Sr}^{-1}(10\,\text{nm})^{-1}}{\text{J}}\right)$$

$$= Q(\lambda)\frac{\lambda}{hc} \times 10^{2}\ (\text{photons s}^{-1}\text{Sr}^{-1}) \qquad (2)$$

where $Q(\lambda)$ is taken in $\text{W Sr}^{-1}\ (10\,\text{nm})^{-1}$ and λ is in meters.

If the solid angle subtended by the lens at the source is $\Delta\omega$, and the total transmission between the source and the monochromator is $t(\lambda)$, then the number of photons, $N'(\lambda)$, incident per second on the monochromator entrance slit is given by:

$$N'(\lambda) = N(\lambda)\, t\, \Delta\omega \qquad (3)$$

where the transmission t is taken to be independent of the wavelength due to the constant transmittance of the quartz lens over the spectral range of interest. However, because the image of the source focused by the lens on the entrance slit is larger than the width of the slit, only a part of these photons, $N''(\lambda)$, will be incident on the monochromator. This $N''(\lambda)$ is, therefore, given by:

$$N''(\lambda) = N'(\lambda)\, \sigma \qquad (4)$$

where σ, the slit factor, is defined as the ratio of the illuminated area of the slit to the area of the image focused on the slit.

A monochromator with a wavelength bandwidth, $\Delta\lambda$, defined as the reciprocal linear dispersion times the slit width, will actually receive a part, $R(\lambda)$, of the photons incident on it. This part, $R(\lambda)$, is given by [1]:

$$R(\lambda) = N''(\lambda)\,\Delta\lambda\,. \tag{5}$$

The absolute quantum efficiency, $K(\lambda)$, defined as the number of photons of wavelength λ, detected per photon received by the monochromator is, therefore, finally obtained as:

$$K(\lambda) = \frac{S(\lambda)}{R(\lambda)}\,. \tag{6}$$

The result of these calculations, the quantum efficiency curve, is presented in Figure 2.

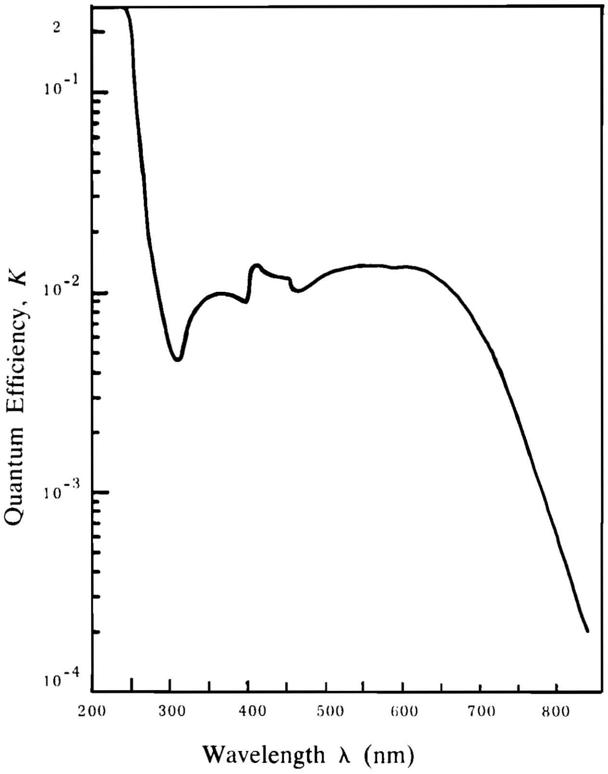

Figure 2. Quantum Efficiency of the Optical Detection System, K, *as a Function of Wavelength* λ.

5. DISCUSSION

It is important, in quite diverse fields of research to have a calibrated optical detection system. The calibration for absolute quantum efficiency of our detection system was done against a standard quartz lamp of known spectral output both on and off the physical apparatus. In both cases an excellent agreement was obtained. The main source of uncertainty of the calibration is due to uncertainty in the transmission of the neutral density filters indicated by the spectral flatness of the filters. Another source of uncertainty is due to the achromatic performance of the quartz lens used in this work. Due to the variation of the index of refraction of quartz with wavelength, the focal length of the lens varies resulting in different lateral magnification for different wavelengths. This variation in the magnification introduces some uncertainty in the slit factor, σ. This uncertainty is estimated to range between 10% at wavelength ($\lambda = 200\,\text{nm}$) to about 1% at wavelength ($\lambda = 700\,\text{nm}$). These two sources combined result in an estimated uncertainty of about 30% over the spectral range of interest.

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