

## PHOTON TIME INTERVAL DISTRIBUTIONS OF CATHODOLUMINESCENCE LIGHT FROM A $\text{YVO}_4 - \text{Eu}^{3+}$ PHOSPHOR

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Measured photon time interval distributions and spectral noise densities justify the assumption of a Poisson distribution for the number of excitations per bombarding electron. A lifetime of  $0.50 \pm 0.02$  ms was found for the  $^5\text{D}_0$  excited  $\text{Eu}^{3+}$  state.

In this paper measurements of the spectral noise density and the photon time interval distribution of cathodoluminescence light from a  $\text{YVO}_4 - \text{Eu}^{3+}$  phosphor [1] are reported.

We will interpret the light fluctuations, as measured by photoelectric means, in terms of a simple model for characteristics cathodoluminescence [2]. Here it is assumed that the luminescence centre can be in two electronic states. Deexcitation occurs spontaneously with or without the emission of a photon. Excitation occurs through the bombarding electrons, each producing on the average more than one excitation. The time a bombarding electron takes to induce an excitation, is considered negligible compared with the lifetime of the excited state. In addition it is assumed that the arrival times of bombarding electrons at the phosphor are statistically independent. The effects of stimulated emission, self-absorption and saturation are neglected.

From the model follows an exponential second order (auto) correlation function of the photocurrent with a time constant equal to the lifetime of the excited state [3]. For the probability of detecting zero photons during a time interval of length  $\tau$ , we find:

$$p_0(\tau) = \exp \left\{ -\bar{\phi} \int_0^\tau \frac{1 - G(1 - \lambda[1 - \exp(-\beta x)])}{1 - \exp(-\beta x)} dx - D\tau \right\} \quad (1)$$

Where  $\bar{\phi}$  is the mean bombarding electron flux,  $\lambda$  is the probability to detect a given deexcitation,  $\beta^{-1}$  is the lifetime of the excited state,  $D$  is the average dark counting rate of the detector, and  $G$  is a generating

function defined by:

$$G(z) = \sum_{\gamma=0}^{\infty} z^\gamma P(\gamma), \quad (2)$$

where  $P(\gamma)$  is the distribution of the number  $\gamma$  of excitations per bombarding electron. An account in detail will be published elsewhere [4].

From  $p_0(\tau)$  the probability density for time intervals between two successive photoelectric pulses can be found [5]. Actually, for practical reasons [4], the probability density  $w(\tau)$  of time intervals between an arbitrary moment and the first detected photon, was measured. It can be shown that [5]:

$$w(\tau) = -\frac{\delta}{\delta\tau} p_0(\tau). \quad (3)$$

In the  $\text{YVO}_4 - \text{Eu}^{3+}$  emission, deexcitations of the  $^5\text{D}_0$  state of the  $\text{Eu}^{3+}$  ion dominate [1]. Therefore the interpretation of the experimental data involves only these transitions. The measured spectral noise densities were in agreement with the expected exponential autocorrelation function. From this a lifetime of the  $^5\text{D}_0$  state follows of  $0.50 \pm 0.02$  ms.

The time intervals were measured with the help of a time-to-amplitude converter and a multichannel pulse height analyzer. Fig. 1a gives the measured photon time interval distribution for low bombarding electron energy, ( $\lambda \langle \gamma \rangle < 1$ ), and fig. 1b for high bombarding electron energy, ( $\lambda \langle \gamma \rangle > 1$ ). The values of  $\lambda \langle \gamma \rangle$  were obtained from measurements of the noise power of the photoelectric current fluctuations [4]. At low electron energy, correlations among the detected photons are absent. Thence photoelectron statistics is Poissonian,

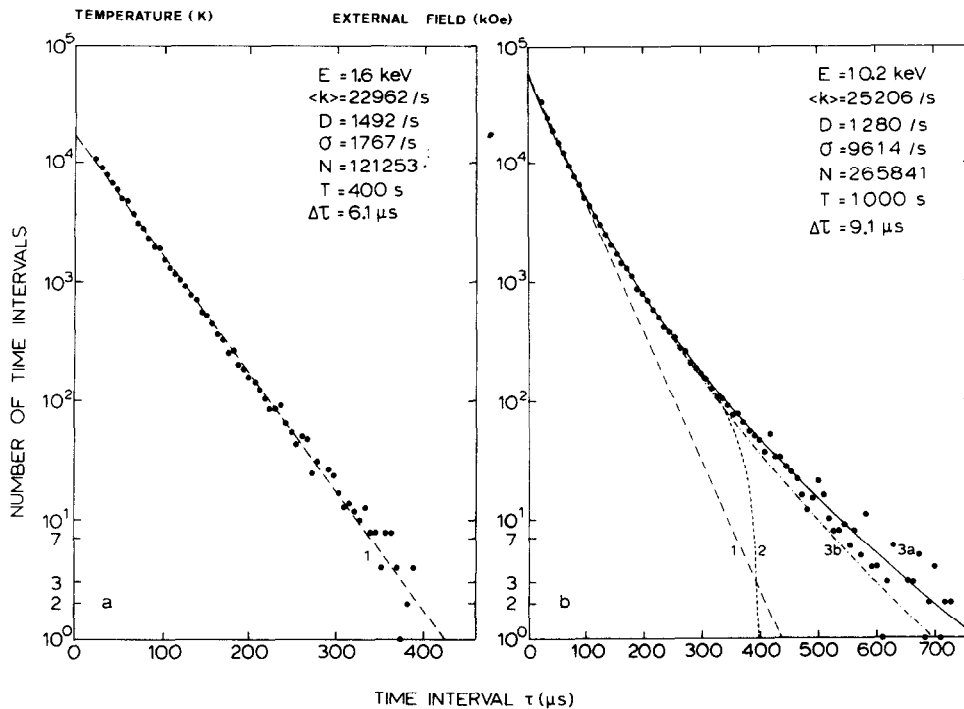


Fig. 1. Photon time interval distributions of cathodoluminescence light from a  $\text{YVO}_4 - \text{Eu}^{3+}$  phosphor. Curves 1 and 2 represent calculated distributions for Poissonian and Gaussian light fluctuations, respectively. Curves 3a and 3b are based on equations (1) and (3) if respectively a Poisson and a geometric distribution for  $P(\gamma)$  is assumed.  $\circ$  = experimental data;  $E$  is the bombarding electron energy;  $\langle k \rangle$  is the average counting rate where  $k(t)dt$  is the probability to detect a photon within a time interval  $dt$ ;  $D$  is the average dark counting rate;  $\sigma$  is the standard deviation of  $k(t)$ ;  $N$  is the total number of recorded time intervals;  $T$  is the observation time;  $\Delta\tau$  is the channel width.

which implies a negative exponential distribution for the time intervals. The dashed line in fig. 1a represents this calculated exponential distribution, which is fully determined by the mean photon counting rate  $\langle k \rangle$ . Note in figure 1a the good agreement between measured points and the theoretical curve.

In fig. 1b, besides the experimental points, four calculated time interval distributions are presented indicated by the numbers 1, 2, 3a and 3b. Curve 1 is the negative exponential distribution, curve 2 holds for Gaussian light fluctuations and is derived from formula 24 of reference [6] and the measured autocorrelation function. Using eqs. (1) and (3), we have calculated the curves 3a and 3b, assuming a Poisson and a geometric distribution for  $\gamma$  respectively.

The experimental data plotted in fig. 1b show clearly

that the light fluctuations are neither Poissonian nor Gaussian. They are, however, in good agreement with the theoretical calculations based on the simple model introduced before, if a Poisson distribution is assumed for  $\gamma$ .

## References

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