CORRELATION BETWEEN INTERNAL AND EXTERNAL QUANTUM YIELD OF MICRO-SCALE LUMINESCENT MATERIALS

XVI International Symposium on Luminescence Spectrometry
Rhodes Island, Greece, September 2014
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Background For gas discharge and solid state light sources a large variety of luminescent materials, also called phosphors, have been developed during the last decades. For the continuous improvement the determination of the quantum efficiency in a reliable way is of tremendous importance. This work relates to the clarification of different definitions of the term quantum efficiency and the obstacles in measuring the quantum efficiency in an integrating sphere.

Experimental Procedure

All experiments have been performed on $Sr_2Si_5N_8$:Eu powder samples. To determine the impact of re-absorption a dilution series by using $BaSO_4$ was investigated. As shown in Figure 1, the powder layer partially reflects and partially absorbs the incident radiation from the excitation source. The absorbed fraction of the ingoing radiation is partly converted by the phosphor and thus results in the emission of photons with the respective energy. It must be noted, that the generally used definition of quantum efficiency (ϕ) is the ratio of emitted photons divided by absorbed photons (Equation 1).[1, 2]

This definition for the quantum efficiency is only correct for those situations, wherein no re-absorption occurs. To our understanding the collection of photons from an integrating sphere can only yield a so-called external quantum efficiency (EQE) including re-absorption phenomena, i.e. the sample as a whole will be considered (Figure 7 and Equation 3). If only the conversion efficiency of the activator ions is meant, we call this figure internal quantum efficiency (IQE), which can be derived from the decay time.

$$\phi = \frac{n_E}{n_A}$$

Eq. 1: Definition of the quantum efficiency, i.e. it the ratio of emitted photons divided by absorbed photons

Fig. 1: A phosphor screen with incident violet photon, which are scattered or converted into red photons

Principle

The EQE is linked to the IQE by including the transfer efficiency ($\eta_{transfer}$) to the conversion center and the light outcoupling efficiency ($\eta_{outcoupling}$) (Equation 2). The EQE comprises thus all processes from the absorption of incident photons to the out-coupling of photons emitted by the luminescent species, here from μ-scale phosphor particles. The efficiency of the luminescent species, usually called the activator, is in this context the internal quantum efficiency. The latter can be determined by the decay time τ since the activator lifetime is related to its efficiency by the simple relation τ/τ_0, whereby τ_0 is the radiative decay time (only determinable if no quenching processes occurs). Therefore, it is of tremendous interest to know the correlation between the internal and the external quantum efficiency, which can be approximated by the equation

$$EQE = IQE * \eta_{transfer} * \eta_{outcoupling}$$
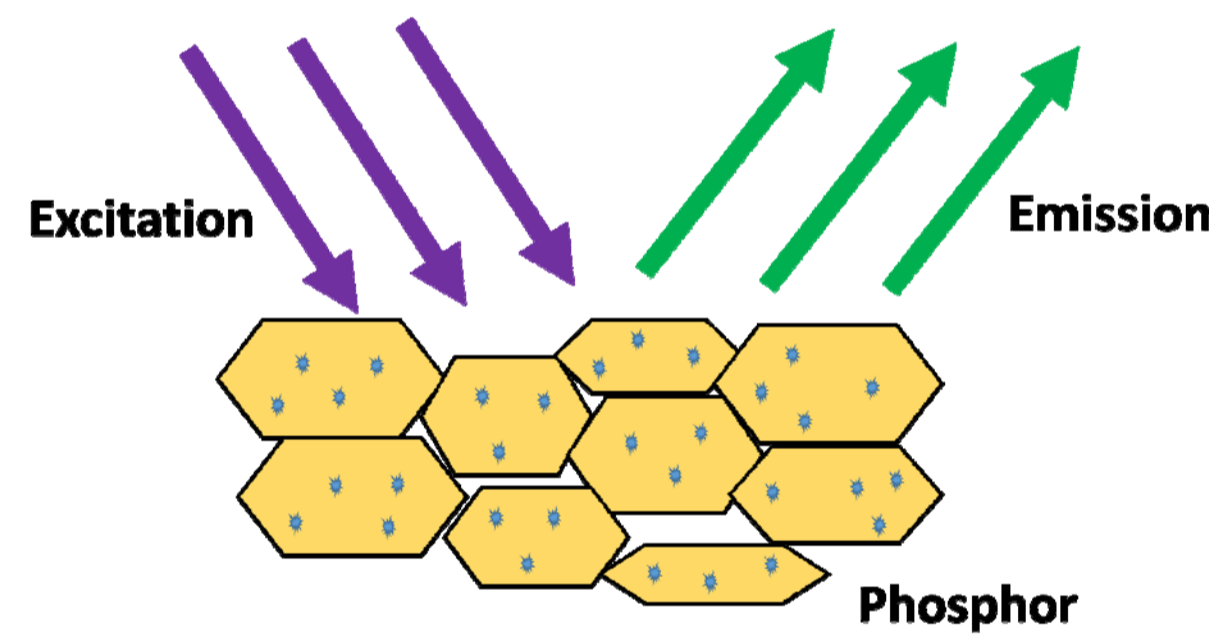
Eq. 2: Relationship between EQE and IQE

Decay curve must be recorded

Fig. 3: Emitted and absorbed photons from a phosphor. This is the external quantum efficiency (EQE)
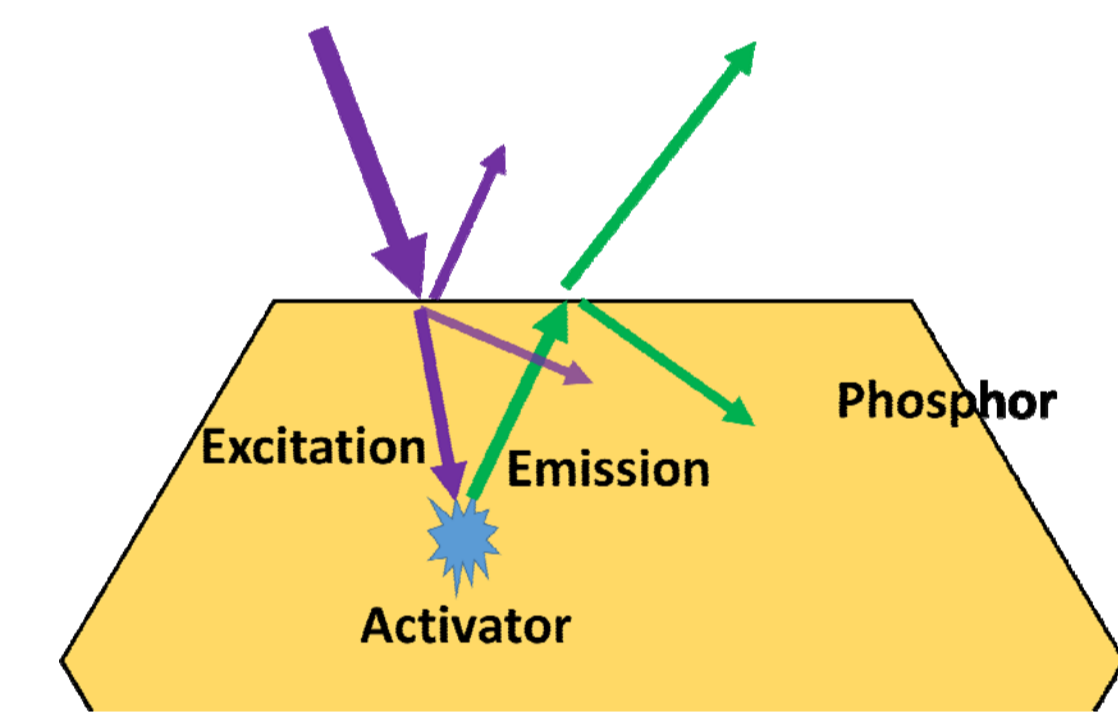

Fig. 4: Emitted and absorbed photons from an optical centre in an investigated converter material. This is called the internal quantum efficiency (IQE).

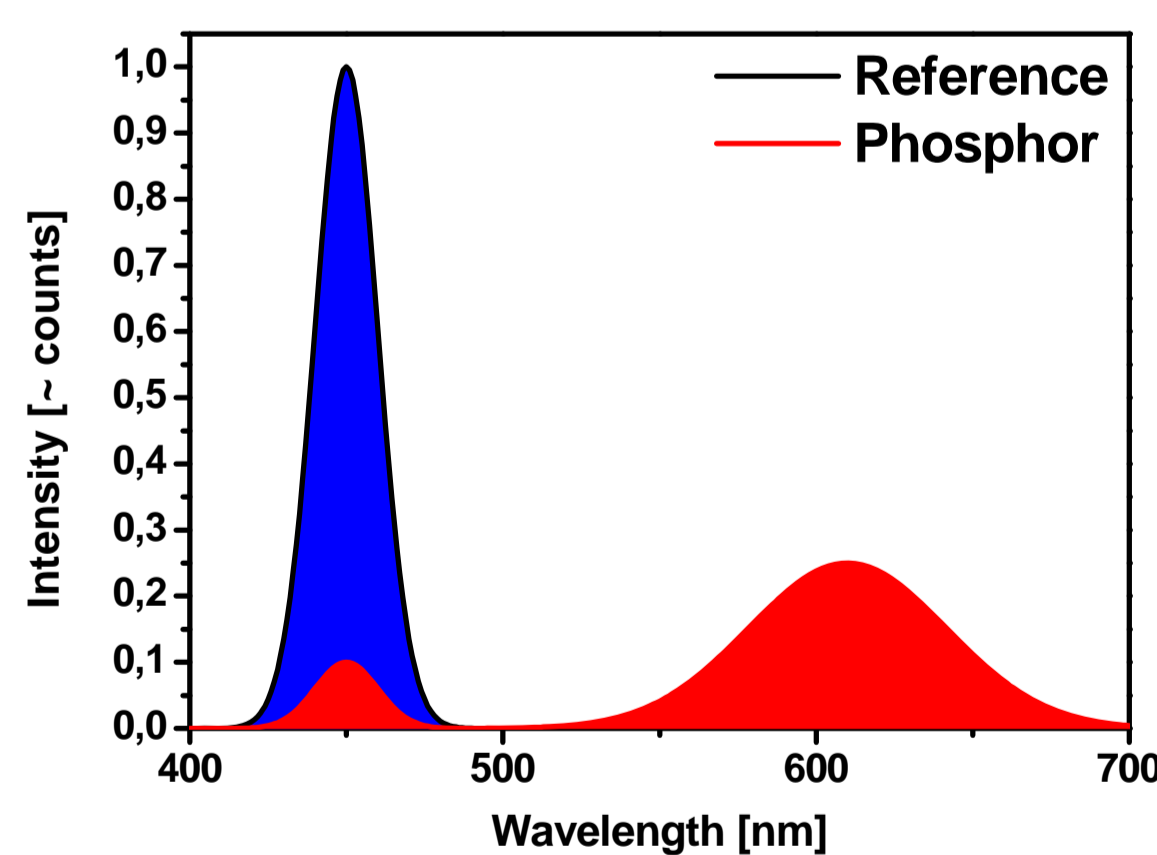**Emission spectrum integral relative to the excitation spectrum integral must be determined**

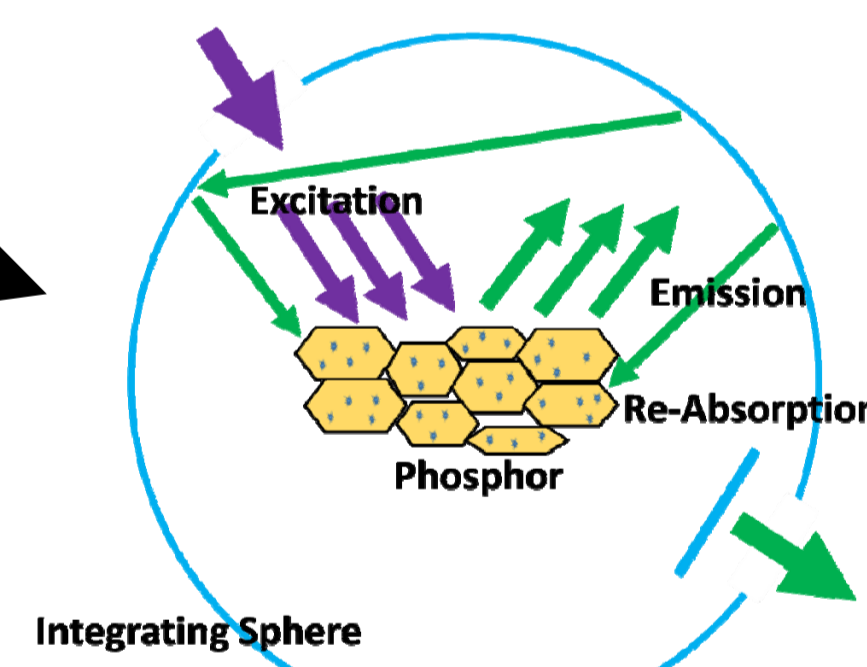**Fig. 5**: Emitting and absorbed photons from a phosphor in an integrating sphere. Different to the external quantum efficiency

Fig. 6: Measured external quantum efficiency and EQE data corrected for re-absorption

Fig. 6 and Eq. 3: Principle of QE measurement in an integrating sphere

$$\phi_f = \frac{N(em)}{N(abs)} = \frac{\int \frac{\lambda}{hc}\left[I_{em}^{sample}(\lambda) - I_{em}^{reference}(\lambda)\right] d\lambda}{\int \frac{\lambda}{hc}\left[I_{ex}^{reference}(\lambda) - I_{ex}^{sample}(\lambda)\right] d\lambda}$$
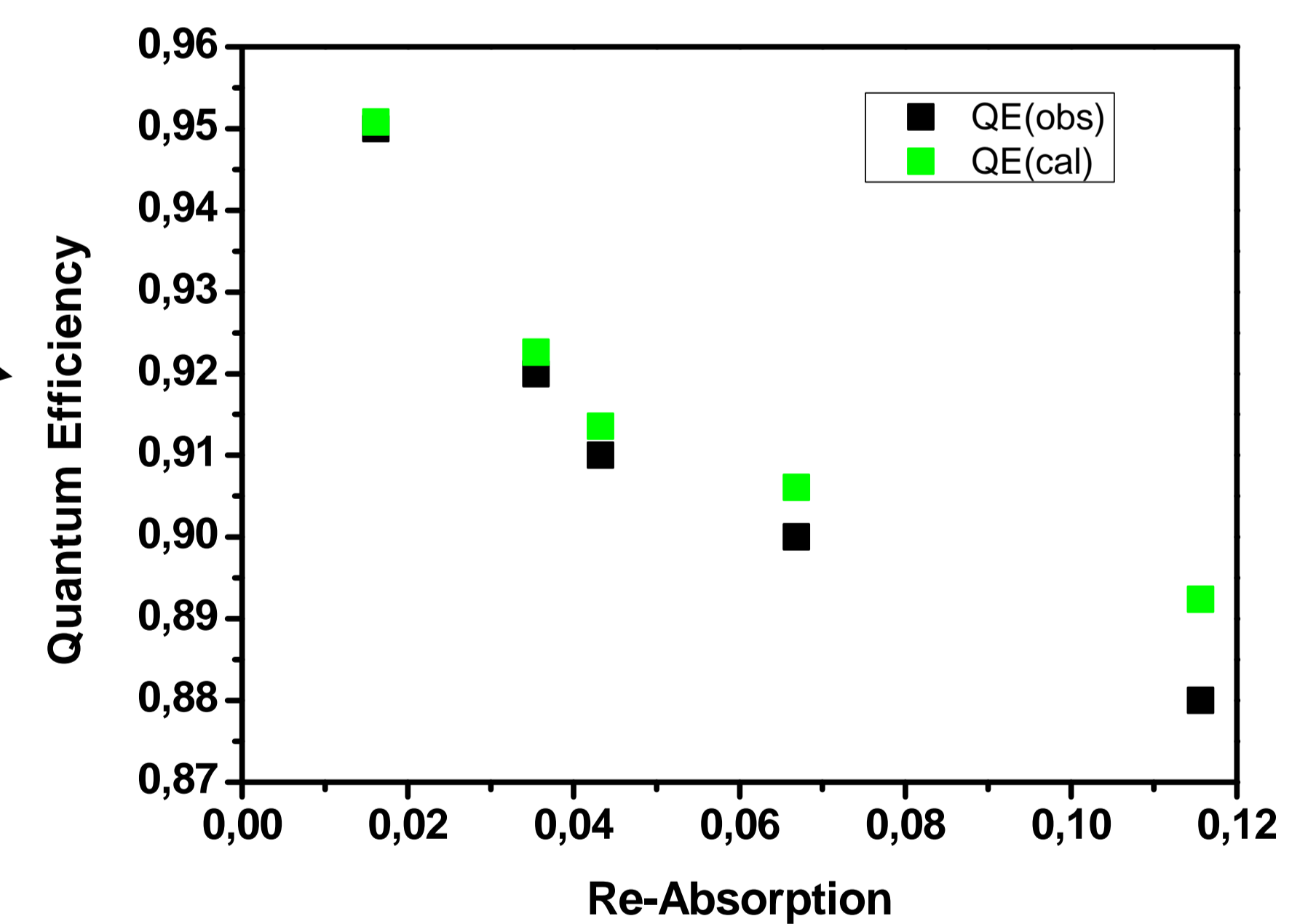
Results

EQE determination due to an integrating sphere gives reproducible results. However, a clear influence of re-absorption processes can be observed. Figure 6 shows a dilution series of an $Sr_2Si_5N_8$:Eu phosphor. The calculation of the re-absorbtion as in non-scattering samples (phosphor layer or phosphor solution)[4] does not work so easily in powder samples.

Conclusions

The IQE in the dilution series is constant, based on the constant decay time of 1.23 μs of the $Sr_2Si_5N_8$:Eu phosphor. The EQE remains constant in the dilution with the white standard. The measured QE from the samples in the integrating sphere decreases with increasing phosphor concentration also after the back-calculation of the Re-Absorption. This fact shows the measurement of the Re-Absorption in scattering samples does not work in the same way as in non-scattering samples. In order to solve this challenge, more physical parameters such as refractive index, particle size and particle morphology must be involved [5].

References

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