The journey to the invisible: learning from visible LED phosphors to go towards the UV and NIR range

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Inorganic phosphors play a crucial role for thermally stable and longtime-durable solutions for warm-white indoor lighting and display technology [1]. Within this tutorial lecture, we will uncover the relevance of inorganic luminescent materials for this type of application and what is the special role of the control of the thermal quenching pathway. Special emphasis will lie in the challenges of the development of the red-emitting component and why narrow-band phosphors with the UCr_4C_4-type have finally been so successful. Based on this structure type, the modern developments for new green- and cyan-emitting phosphors on the basis of Eu^{2+} will be discussed [2]. The section will be concluded with an overview how rare-earth free alternative activators could be electronically fine-tuned in order to make them competitive to the well-established lanthanoid ions [3].
While inorganic phosphors for LED applications in the visible range are closer to perfection, efficient UV or NIR light sources that can be similarly exploited with blue light excitation from an InGaN semiconductor chip are still substantially underdeveloped. I will demonstrate what are the fundamental obstacles for these spectral ranges and which approaches can be used to overcome these. For the NIR range, Cr^{3+}-activated phosphors appear to be a promising solution with high internal quantum yields [4]. Within this lecture, I will show how the concepts of high-pressure chemistry for materials design and learning from the success of visible LED phosphors led to a serendipitous discovery that ultimately even outperforms ruby in its optical performance [5]. In contrast, the UV range may be accessed by upconversion of blue light with the Pr^{3+} ion [6]. As it turns out, several conditions have to be fulfilled simultaneously in order to make this approach successful [7]. Overall, this journey to invisibly emitting phosphors demonstrates what role a firm understanding of the interplay between the radiative and non-radiative pathways plays in an ultimate successful design of such materials.

References

[1] a) P. Pust, W. Schnick *et al.*, *Nat. Mater.* **13** (2014) 891; **b)** G. J. Hoerder, H. Huppertz *et al.*, *Nat. Commun.* **10** (2019) 1824; **c)** M. Zhao, Q. Zhang, Z. Xia, *Acc. Chem. Res.* **1** (2020) 137; **d)** S. Hariyani, M. Sójka, A. Setlur, J. Brgoch, *Nat. Rev. Mater.* **8** (2023) 759.

[2] a) F. Ruegenberg, A. García-Fuente, H. Huppertz, **M. Suta** *et al.*, *Adv. Opt. Mater.* **9** (2021), 2101643; d) F. Ruegenberg, A. García-Fuente, H. Huppertz, **M. Suta** *et al.*, *Adv. Opt. Mater.*, **11** (2023), 2202732.

[3] a) V. Morad, I. Cherniukh, L. Pöttschacher, Y. Shynkarenko, S. Yakunin, M. V. Kovalenko, *Chem. Mater.* **31** (2019), 10161; **b)** L. M. Träger, L. C. Pasqualini, H. Huppertz, J. Bruns, **M. Suta**, *Angew. Chem. Int. Ed.* **62** (2023), e202309212.

[4] M. Sójka, J. Zhong, J. Brgoch, *ACS Appl. Opt. Mater.* **1** (2023), 1138.

[5] a) I. Widmann, G. Kinik, R. Glaum, **M. Suta**, H. Huppertz *et al.*, *Adv. Funct. Mater.* (2024), *accepted*, doi:10.1002/adfm.202400054; **b)** G. Kinik, I. Widmann, B. Bendel, A. Meijerink, H. Huppertz, **M. Suta**, *Light: Sci. Appl.* (2024), *under review*.

[6] C. L. Sun, J. F. Li, C. H. Hu, H. M. Jiang, Z. K. Jiang, *Eur. Phys. J. D* **39** (2006), 303.

[7] a) D. Yu, H. Li, D. Zhang, Q. Zhang, A. Meijerink, **M. Suta**, *Light: Sci. Appl.* **10** (2021), 236 ; **b)** T. Förster, J. Reifenberger, Ž. Antić, M. D. Dramićanin, **M. Suta** *et al.*, (2024) *submitted*.