Bridging UV and soft X-ray excitation in luminescent materials for scintillation and dosimetry

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The performance of luminescent materials for scintillation and dosimetry applications critically depends on the microscopic mechanisms governing light emission and on the role of structural defects, which strongly influence energy transfer, carrier trapping, and recombination dynamics. In many systems, radioluminescence (RL) and photoluminescence (PL) responses differ substantially, reflecting the distinct excitation and relaxation pathways involved in high- and low-energy excitation regimes; remarkably, significant discrepancies are often observed even when PL excitation energies lie well above the band gap. A systematic understanding of these differences is essential for the rational design of next-generation scintillators and dosimetric materials with improved efficiency, spectral tunability, and radiation hardness.

In this work, we investigate the evolution of luminescence emission spectra under excitation spanning a broad energy range, from the UV–VUV domain (few eV) up to soft X-rays (keV). The study encompasses several representative material families, including $CsPbBr_3$ perovskite nanocrystals, polystyrene-based nanocomposites, natural and synthetic quartz, as well as classical Ce-doped garnet scintillators such as YAG:Ce and GAGG:Ce both as single crystals and optical ceramics. These materials have been deliberately selected to span three distinct macroscopic response classes: materials exhibiting a smooth and continuous spectral evolution from PL to RL, systems characterized by markedly different emission behaviors under optical and ionizing excitation, and systems showing negligible differences between PL and RL. These systems cover a wide spectrum of scintillation mechanisms, defect structures, and radiative recombination pathways, providing a comprehensive framework for comparative analysis across different material platforms and excitation conditions.

To bridge the experimental gap between conventional UV and X-ray excitation, luminescence spectroscopy is performed using synchrotron radiation at the FinEstBeAMS beamline (MAX IV), enabling continuous excitation in the 4.5–1300 eV range with high spectral resolution and controlled excitation density. These measurements are complemented by radioluminescence experiments carried out using a laboratory X-ray tube operated at accelerating voltages of several tens of kV, allowing direct comparison between soft and hard X-ray excitation regimes. This combined approach enables a systematic investigation of excitation-energy-dependent emission features, charge carrier relaxation pathways, and their correlation with defect-related states and intrinsic PL properties.

The results of this study are expected to provide new insight into the interplay between excitation mechanisms, defect population, and emission processes, offering guidelines for tailoring emission spectra, enhancing the effective Stokes shift, and reducing self-absorption. These outcomes are relevant for optimizing scintillator performance in high-energy physics, medical imaging, industrial inspection, and radiation dosimetry, as well as for the development of advanced luminescent materials for emerging detection technologies.