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3D-Printed Lanthanide-Doped Micropolymers at the Tip of Optical Fibers for Remote Luminescent Temperature Sensing

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Highlights

The printed microstructures showed high stability in various solvents and temperatures, demonstrating their potential for high-performance, remote, and contactless temperature sensing.

Abstract

The integration of 3D printing and lanthanide-based luminescent thermometry enables the development of miniaturized and contactless temperature sensors with high spatial resolution. In this work, we explore two different approaches using Eu^{3+}-doped polymeric microstructures fabricated via two-photon polymerization. The first approach involves direct printing of microstructures at the tip of a multimode silica optical fiber, creating a fiber-integrated sensor for remote temperature monitoring. The second approach employs similar luminescent microstructures printed onto glass slides, expanding the versatility of these materials for planar sensing applications. In the fiber-integrated sensor, temperature sensing is performed using the Luminescence Intensity Ratio (LIR) method, leveraging the complementary emissions of the Eu^{3+} complex and the polymer coating of the fiber. Additionally, RGB colorimetric analysis of optical images enables an alternative approach for temperature evaluation. The sensor demonstrates a stable response in the range of 296 K to 363 K, achieving a maximum relative sensitivity of 5.0% K^{-1}. The printed structures exhibit remarkable chemical stability in various solvents and maintain their integrity across different thermal conditions, highlighting their potential for robust and high-performance optical sensing. In the planar substrate approach, we investigate luminescent microstructures doped with Eu^{3+}, Tb^{3+}, and Sm^{3+} for temperature sensing. Eu^{3+}-doped structures exhibit stable luminescence and efficient energy harvesting from organic ligands, making them highly suitable for thermal sensing. In contrast, Tb^{3+} and Sm^{3+} systems are affected by background fluorescence, reducing detection sensitivity. Temperature-dependent luminescence studies reveal complementary behavior between the polymer host and Eu^{3+} emissions, allowing ratiometric sensing across two distinct temperature ranges. Using LIR and luminescence lifetime analysis, maximum sensitivities of 5.5% K^{-1} (360 K) and 5.7% K^{-1} (370 K) are achieved, confirming the effectiveness of these microstructures for high-sensitivity temperature detection. These results demonstrate the versatility of 3D-printed luminescent microstructures for remote and contactless thermometry, either as fiber-integrated sensors or planar temperature-responsive platforms. The findings contribute to the advancement of functionalized optical materials for real-time thermal monitoring in diverse technological and biomedical applications.

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