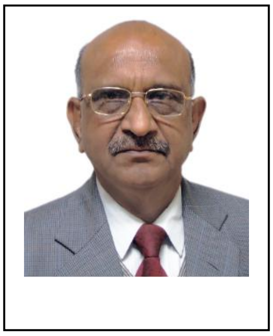
HOLOGRAPHIC OPTICAL ELEMENTS IN OPTICAL INTERFEROMETRY: NEW FRONTIERS IN QUANTITATIVE PHASE IMAGING AND PRECISE TEMPERATURE MEASUREMENT



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Holographic optical elements (HOEs) have emerged as versatile tools in optical interferometry, enabling high-precision quantitative phase imaging (QPI) and temperature measurement in both biomedical and engineering applications. Their ability to precisely shape and control light allows detailed analysis of thermal and structural variations in biological and industrial systems. Recent studies have highlighted the versatility of HOEs in measurement of freeform surfaces (non-rotationally symmetric wavefronts), facilitating label-free quantitative imaging of biological cells, accurate temperature measurement in micro and macro scale flames, and investigation of magnetic field effects on micro-flame stability. Volume phase holographic gratings fabricated on dichromated gelatin (DCG) can serve as beam splitters and high frequency noise filters in digital holographic interferometers[1]. Their high diffraction efficiency and minimizing stray light and coherent noise enhance interference fringe contrast and measurement fidelity. Using this system, maximum temperatures of ~1112 K in macro-flames and ~687 K in micro-flames were measured, with instabilities of ~24 K and ~38 K, respectively, demonstrating sensitivity to subtle thermal fluctuations. These properties enable precise full-filed temperature measurement and monitoring of fluctuations in micro and macro scale diffusion flames. A holo-shear lens-based interferometer captures sheared interferograms of micro flames under varying magnetic field conditions[2,3]. Fourier fringe analysis of these interferograms provides phase gradient information, allowing quantitative assessment of temperature profiles and stability. With a sensitivity on the order of ±5 K, the setup enables detection of temperature fluctuations on the order of tens of Kelvin within micro diffusion flames. Experimental results show that upward-decreasing and uniform magnetic fields enhance flame temperature and stability, whereas upward-increasing magnetic field reduce them, in contrast to the limited influence observed in macro diffusion flames under uniform magnetic fields. The holo-shear interferometer remains lightweight, less vibration sensitive, and well-suited for quantitative thermal diagnostics across flame scales. Beyond thermal diagnostics, HOEs have been adapted for high-resolution, label-free quantitative phase imaging of biological cells. A VPHG-based digital holographic interferometer achieved a lateral resolution of ~0.98µm, with markedly enhanced signal-to-noise ratio and temporal phase stability (~0.16 rad) compared to conventional Mach–Zehnder configurations[4,5]. Biological imaging experiments reconstructed quantitative phase maps of white blood cells (~11–12 µm), red blood cells (~7–8 µm), platelets (~3 µm), and *Staphylococcus aureus* (~1 µm), enabling submicron morphological visualization consistent with bright-field microscopy, while additionally providing phase-based thickness and refractive-index mapping. Holographic optical elements in optical interferometry demonstrate transformative potential, providing a unified platform for precise temperature mapping in combustion systems and high-fidelity quantitative phase imaging in biomedical applications, while opening new frontiers for probing complex freeform wavefronts and advancing toward real-world clinical and industrial deployment.

Keywords: Holographic Optical Elements, Optical Interferometry, Quantitative Phase Imaging, Digital Holography, Temperature Measurement, Biomedical Imaging.

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