Towards an optical magnetic gradiometer using integrated vapor cells

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Abstract: This research aims to develop an optical magnetic gradiometer using laser-written vapor cells with a double-chamber configuration for high-sensitivity gradient field measurements in miniaturized devices.

Optically pumped magnetometers (OPMs) [1] have emerged as ultra-sensitive quantum sensors with many applications such as biomedical diagnostics, remote sensing, and environmental monitoring. However, traditional OPMs face challenges, including limited spatial resolution and lack of integration into complete systems, relevant in environments requiring a combination of high sensitivity, robustness, and portability. This research seeks to address these limitations by developing an optical magnetic gradiometer leveraging laser-written vapor cells (LWVCs), offering scalable, integrated, and sensitive solutions for lab-on-chip quantum sensing applications.

LWVCs are fabricated using femtosecond laser irradiation followed by chemical etching (FLICE) [2,3], a method that combines ultra-fast laser pulses with controlled etching to create microstructures in transparent materials with 3D versatility. This project explores both single- and double-chamber configurations, aiming to combine sub-mm spatial resolution with sub-pT magnetic sensitivity in compact systems that could include microfluidic channels.

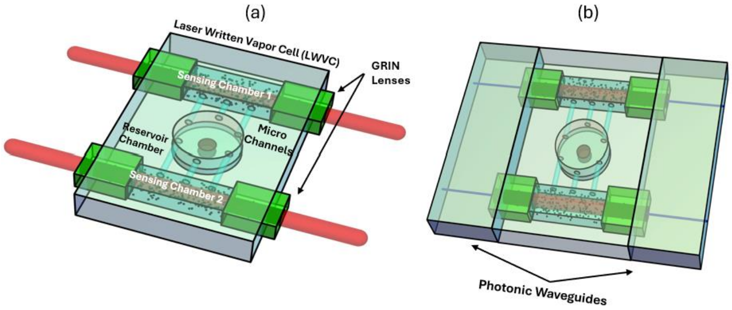

Fig. 1 Design schematic of a double-chamber laser-written vapor cell, with a configuration for optical rotation detection, integrated on photonic waveguides in a parallel setup.

Two novel designs are proposed, each featuring sensing chambers (3 mm length, 1.5 mm width) and a reservoir chamber (1.5 mm diameter), interconnected by microchannels (0.2 mm width) to allow the flow of alkali-metal-vapors. The cells are equipped with gradient-index (GRIN) lenses embedded in the glass substrate to enhance laser coupling. In the first phase, the intergated vapor cells will be tested in a single-channel configuration to measure absolute magnetic sensitivity. Subsequently, measurements will be conducted using the double-chamber design for gradient magnetic field measurements. The double-chamber configuration supports two distinct measurement approaches: optical rotation detection in the parallel configuration and phase shift detection [4], in a Mach-Zehnder interferometry configuration. This approach aims to comprehensively evaluate the effectiveness of the integrated cells in both absolute and gradient magnetic field sensing, advancing the robustness of OPMs through integration and enhancing sub-mm spatial resolution to detect unexplored magnetic signals from biological or microscopic samples.

References

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