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3D-Printed Miniature Fiber-Coupled Multi-pass Cell with Dense Spot Pattern for ppb-level Methane Detection Using a Near-IR Diode Laser

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Tunable diode laser absorption spectroscopy (TDLAS) based on multi-pass cell (MPC) [1-4] is a powerful analytical tool for field applications in air quality monitoring, industrial process control and medical diagnostics. However, the conventional MPC as a core component in TDLAS devices has a large size, low utilization efficiency of the mirror surfaces and tight optical alignment tolerances [5]. Design of miniaturized long-path MPC for the development of handheld portable high sensitivity sensing devices is one of the mainstream trends nowadays. In this work, we designed and fabricated a mini-MPC with an effective optical absorption path length of 4.2 m and dimensions of 4×4×6 cm^3, which to our best knowledge is the current smallest MPC in terms of the same optical path length. The mini-MPC generates a seven-nonintersecting-circle dense spot pattern on two 25.4 mm spherical mirror surfaces providing a high fill factor of 21 cm^{-2}. A fiber-coupled collimator and an InGaAs photodetector are integrated into the mini-MPC via a high-resolution 3D-printed frame, hence removing the requirement of active optical alignment. Using a 1.65 μm distributed-feedback laser, the performance of this mini-MPC for methane detection was evaluated in terms of linearity, flow response time, stability, minimum detectable limit and measurement precision. Continuous measurements of methane near a sewer and in the atmosphere were performed to demonstrate the stability and robustness of the highly integrated mini-MPC based gas sensor. This work paves the way towards a sensitive, low-cost, miniature trace gas sensor inherently suitable for large-scale deployment of distributed sensor networks and for handheld mobile devices.

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