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Study on Absorption of VOCs into PDMS Film using Heterodyne Interferometry for Application of VOCs Sensing.

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Abstract

A heterodyne interferometer using a Mach-Zehnder optical configuration is designed for detection of airborne VOCs. The design is based on film-mediated sensing technique in which the response of intermediate sensing film is monitored using interferometry. PDMS is used as a sensing film, which changes its volume and refractive index when absorbed VOCs molecules. Thin film of PDMS acts as a phase object and any variation in its state causes a proportional phase shifts in the transmitted light beam. The Mach-Zehnder interferometer is integrated with a microscope and acoustic-optic modulators. The information of the absorbed gas concentration into the film are encoded in the fringe patterns and are extracted by a temporal phase extraction heterodyne method. The film is exposed to different concentrations of air-borne toluene and its response is measured using interferometry.

Key words: VOCs, BTEX, Mach-Zehnder Interferometer, Optical sensor, film-mediated sensor

Monitoring of indoor air quality is important for healthy living. On average a person spends about 90% daily time in indoor environments where exposure to various indoor air pollutants like volatile organic compounds (VOCs) is inevitable [1]. Some of VOCs i.e. benzene, toluene, ethylbenzene and xylene (BTEX) are harmful and long-term exposure may pose a serious threat to human health. Among BTEX, benzene is identified as carcinogenic [2]. The monitoring of VOCs at sub-ppb level requires an ultra-sensitive technique. Interferometry based detection can be a viable option for detecting VOCs at ppb level.

Interferometry based sensing techniques are ultra-sensitive and have been employed for pressure, temperature and concentration measurements in microchannels [3]. Its application has been extended to gas detection by employing a VOCs sensitive film. In previous work, the VOCs sensing using interferometry is limited to ppm level. Martinex *et al.* used a Pohl interferometry setup for VOCs detection with a sensitivity of 1500 ppm [4]. Reddy *et al.* used FP interferometer integrated with µGC and detected toluene down to 25 ppb [5]. Kacik *et al.* developed optical fiber sensor by using a micro cavity in PDMS and detected toluene with a sensitivity of 0.15 nm/g-m^{-3} [6]. In this study, we investigated the application of Mach-Zehnder interferometer configured with heterodyning for detection of air-borne toluene. The integration of heterodyning with interferometer enhance its sensitivity. This technique is capable to retrieve nanometric level variations (40nm) [7].

The optical setup is designed based on Mach-Zehnder interferometer with heterodyning. A light from a coherent He-Ne laser (λ =633nm, 35mW, JDS Uniphase) source is guided by a single mode optical fiber. The light beam is split into two beams by 50:50 fiber coupler (BS1). One beam acts as a test beam while the other acts as a reference beam. An inverted optical microscope (Olympus IX41) is configured with the test beam through a fiber from the BS1 fiber coupler. The collimating lens allows a planar light wavefront to transverse the sample. The phase is same all across the plane and a proportional variation occurs while traversing the sample. Microscope objective collects the wavefront passing the sample which then interferes with the reference beam at the cubical beam splitter

(BS). The setup is shown in the Fig.1 (A). The reference arm acts as a wavefront shaping optical arrangement which can be used to control the number and shape of fringes on the camera. The interferograms are captured by high speed CMOS camera and then analyzed using homemade LabVIEW program.

A polydimethylsiloxane (PDMS) is used as a toluene sensing film, which changes its volume and refractive index when expose to toluene [8]. PDMS are silicone-based elastomer and are widely used in microfluidics applications due to its features like optical transparency, chemical inertness, bio-compatibility, low cost, flexibility, reversible deformation in mechanical stress and tunable permeability [9]. Although the swelling of PDMS is not desired for many application however it can be exploited for the actuation mechanism in sensing devices [8]. PDMS is shaped into a rectangular slab with thickness of 100µm and 500µm and enclosed in a small chamber. The gas chamber has size 25mm x 25mm x 25mm. Top and bottom are covered with glass to allow the light beam to pass through the PDMS film. The gas is flowing through the sides and the light beam is passing through PDMS from top to bottom as shown in Fig.1 (B). Highly precise mass flow controller (accuracy < 0.5%) are used to generate the desired dosage of toluene. The concentration of toluene down to ppb is generated with precision of 10%.

Heterodyning is realized with a pair of fiber coupled up-shifted Acoustic-Optic Modulator (AOM) in each arm of the interferometer as shown in Fig.1 (A). AOMs employ sound waves to diffract the light beam and shift its frequency. The AOMs introduce frequency shift and provide a linear phase shift for temporal phase extraction. The swelling of PDMS, Δh is calculated by using the phase information as given by

$$\Delta h = \frac{\lambda \varphi}{2 \pi n}$$

Where λ, φ and n represents the light wavelength, phase and reflective index of PDMS respectively. Experiments using different flow rate and concentration are designed to investigate the absorption of VOCs into PDMS. The developed Mach-Zehnder interferometer integrated with microscope and heterodyning is highly sensitive and has potential to detect VOCs at sub-ppb level.

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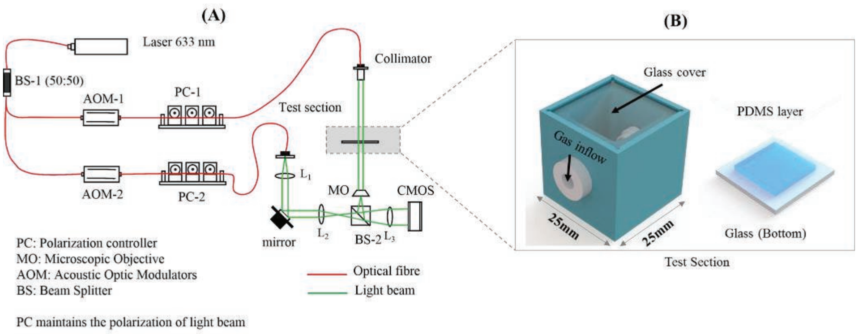

Figure 1. (A) Heterodyne interferometer configuration. AOMs are connected with a radio frequency driver and introduce frequency shift. (B) Micro gas chamber contain PDMS film. The chamber is 25 mm x 25mm x 25mm. Top and bottom are covered with glass.