MEMS-Based Non-Dispersive IR Gas Detection System Utilizing a Linear Variable Filter

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Abstract – We report on a new system for Non-Dispersive Infrared (NDIR) spectroscopic gas sensor. The system utilizes a MEMS torsional scanning mirror to scan an infrared beam across a narrow bandpass Linear Variable Filter (LVF) to search for characteristic gas absorption in the wavelength range of 3.0-5.0 µm. Detection of atmospheric CO\textsubscript{2} (concentration 400 ppm) has been demonstrated.

Keywords: Optical MEMS, NDIR gas sensor, Linear Variable Filter

Introduction

Recently the interest in consumer and commercial gas detection system has increased, creating a demand for inexpensive gas sensors with flexible functionality. Gas detection by IR spectroscopic techniques relies on the fact that many polyatomic gases have unique absorption signatures in the 2-14 µm region. Spectroscopic gas sensors measure the optical absorption at a wavelength where the target gas has an absorption line. Due to the non-availability of narrowband IR sources, typically a broadband IR source is filtered to the narrow band of interest for a particular gas and the transmitted power is monitored for a changes caused by absorption by the target gas according to the Beer-Lambert law [1], which states that when light with wavelength, $\lambda$, traverses a path with length, $l$, containing a gas of concentration, $c$, the amount of light absorbed, $A_\lambda$, is given by:

\begin{equation}
A_\lambda = \exp(-k_\lambda cl)
\end{equation}

where $k_\lambda$ denotes the absorption constant of the gas.

In comparison with solid-state gas sensors, spectroscopic sensors have the advantages of long life and specificity of detection. The most common solid-state gas sensors are those made from semiconducting oxides. These sensors respond to a wide range of reducing gases (such as hydrogen), and therefore display very poor selectivity, and are incapable of detecting inert gases such as CO\textsubscript{2} [2]. Because solid-state sensors must be exposed to the measurement environment, they are also sensitive to contamination or poisoning from chemicals, resulting in calibration errors, false measurements, and short service lifetimes.

System Description

A schematic of our gas sensor system is shown in Figure 1. An inexpensive 500 mW broadband IR lamp was used the optical source. The light from lamp was focused using a parabolic mirror (not shown) onto a torsional comb-drive micro-mirror [3], illustrated in Figure 2. The mirror is computer controlled with use of a high-voltage amplifier. The IR beam is then collimated with a second parabolic mirror which acts to convert the rotating scan of the MEMS mirror into a translation of the collimated optical beam. As a result, the beam is laterally translated across a linear variable filter (LVF). An LVF is a passive optical device composed of a precisely controlled thin film thickness across its length. As the film thickness changes the passband wavelength for the film changes proportionally. By positioning the optical beam at different locations on the LVF, specific narrowband IR regions can be detected. The LVF we used is 15mm in length, with a wavelength range of 3.0-5.0 µm, and a bandwidth of 200 nm. The filtered light is then collected by a third parabolic mirror and focused onto a thermopile IR detector (Dexter Research). The detector output is then amplified and digitized with a data

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acquisition system.

Figure 2 Torsional electrostatic comb drive. The mirror structure is formed in a 50µm thick single-crystal silicon layer bonded to a silicon handle wafer. The mirror is attached to the handle wafer through a narrow torsional hinge, and is actuated by means of an electrostatic comb-drive. When a bias voltage is applied to the comb teeth, the mirror rotates down into the plane of the handle wafer.

Our system provides great flexibility for gas detection. With the MEMS scanner, the full extent of the LVF range is available for gas sensing. Additionally the scanner can be operated in chopper fashion to provide rapid transition between the target absorption region and a reference wavelength or a beam block off at the edge of the LVF. The ability to accurately and quickly check the detected signal verses a reference signal is essential for accurate measurement and detection.

Results
We detected the absorption signature of atmospheric Carbon Dioxide (CO₂) with our system, see Figure 3. As voltage to the scanner increases, the deflection angle increases, moving the optical beam to lower wavelengths. The source we used has a monotonically increasing transmission power as the wavelength decreases (similar to a black body radiator). The absorption dip seen exists at a position corresponding to a wavelength of 4.26 µm with a width of over 200 nm and is the signature of CO₂. Atmospheric CO₂ typically has a concentration of 400 ppm.

Figure 3. Sensor voltage (proportional to optical signal) vs. MEMS scanner voltage (inversely proportional to LVF passband wavelength.

Conclusion and Future Work
We have demonstrated the detection of CO₂ with a novel spectroscopic gas detection system. Currently the detection of other gases (CO, various hydrocarbons) is being explored and will only require a sealed detection environment for safety concerns. The limit to miniaturization of the system is the size of commercially available parabolic mirrors.

Additionally, improvements will be made to the MEMS scanning system. Operating the scanners up to 120V we can scan roughly two-thirds of the full 15mm length of the LVF (and the same percentage of the wavelength range). These scanners are capable of a static rotation of 8° at 160V, and the use of the scanner to chop the optical beam will be explored.

References: