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Thermal Detector with Integrated Absorber Structure for MID-IR Gas Detection

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Abstract

Measurement of the concentration of greenhouse gases, such as carbon dioxide (CO^2) and methane (CH^4), in the atmosphere has received significant attention in the last few decades. The work in this thesis focusses on the development of high-performance membrane based thermopile detectors for measurement of such gases using non-dispersive infrared methods. Thermal detectors such as thermopiles generate output voltage by converting thermal energy into electrical energy. The performance of the thermopile detectors could effectively be increased by selecting, a membrane material with low thermal conductivity, selecting an efficient infrared (IR) absorbing material. Other improvements are by selecting thermoelectric materials with high difference in Seebeck coefficients, high electrical conductivity and low thermal conductivity.

Graphite black paint can be used as a radiation absorber, as it has high absorption for a wide spectral range (2.5–20 μm). By using spray paint or a paint brush, the application of the absorber is simple and fast. However, the process control suffers with these simple application methods. With an increasing absorber thickness and uneven distribution, the thermal capacitance of the detector will rapidly increase. Although the absorbed energy in the detector will increase with increasing absorber thickness, the time constant for the detector will be unnecessarily long.

In order to improve the performance of the SU-8 membrane based thermopile, infrared absorbers have been designed to utilise the membrane of the detector as an active part of the IR absorber. This utilisation of the SU-8 epoxy membrane will result in a maximum detector sensitivity and a minimum increase in both the thermal capacitance and thermal conductance of the thermopile. Absorber structures with a narrow absorption band at 4.26μm and a wider multi-layered absorption band at 3–6μm, were simulated, fabricated and characterized. The integration of the absorber into the membrane of thermopile detectors has been presented and the performance of the detector has been evaluated.
As mentioned above, the use of thermoelectric materials with high Seebeck coefficient, such as semiconductor materials, is also important for increasing the response of a thermopile detector. Semiconductor materials normal has higher Seebeck coefficient compared to the metals. In the thesis, molybdenum disulfide (MoS^2) samples were characterised, and the Seebeck coefficient was estimated through a constructed measurement setup. A maximum Seebeck coefficient for MoS^2 of almost -600μV/K was estimated at a temperature difference of 40°C.

The fabricated thermopile detector were characterised, and the time constant of a thermocouple with a multi-layered absorber structure has been estimated to be 21 ms. The detector has shown a high responsivity of about 90–65 V/W in the wavelength range of 3–4.5μm, which is used for CO^2 and CH^4 detection. The thermopile detector was evaluated for detection CO^2 gas through a long-path length NDIR platform. The results show that it could be used for the measurement of gas concentrations down to levels of a few parts per million (ppm).