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Fast MEMS-IR-Emitters for NDIR Sensors

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Summary:
Infrared emitters based on MEMS technology are ideal for miniaturizing NDIR spectrometers. However, commercial MEMS-IR emitters typically reach their operational limit at measurement frequencies around 20 Hz, while certain applications, require frequencies up to 100 Hz. To meet this demand, we have advanced our MEMS-IR emitters by optimizing both chip architecture and assembly techniques for high-speed NDIR spectroscopy. These enhanced IR sources enable gas analysis in the 2-20 µm wavelength range at pulse frequencies up to 100 Hz.

Keywords: NDIR, MEMS, infrared, emitters, gas sensors

Background and Motivation

NDIR (non-dispersive infrared) sensors are widely used for analyzing various gases. MEMS-based infrared (IR) sources are broadband, emit up to at least 12 µm, can be electrically pulsed, are resistant to minor vibrations and temperature fluctuations, and are cost-effective. Therefore, they currently represent the best solution for miniaturized NDIR sensors. However, commercially available IR emitters can only be effectively pulsed up to about 20 Hz. Although some emitters are listed with cutoff frequencies of up to 40 Hz [1, 2], our tests have not confirmed any cutoff frequency above 25 Hz.

The aim of this study was to optimize our own membrane-based MEMS-IR emitters for higher modulation frequencies while keeping sufficient intensities for our customer's NDIR-applications. Therefore, we built a model of our current chip in the simulation software Comsol Multiphysics Version 6.1 and tested various parameters before manufacturing and assembling new emitters.

Model Building

The parameters of the membrane layers deposited in our cleanroom required for a thermoelectrical model are yet unknown and can only be approximated roughly using values from the literature. Direct measurement of these material parameters is currently not feasible, so they were determined via an algorithm comparing simulation results with measured data.

First, we measured the temperature and electrical resistance of our legacy infrared (IR) emitter as a function of applied electrical power, at atmospheric pressure and in vacuum. The resulting characteristic curves served as target values for the development of the COMSOL model. Initially, physically meaningful boundary values were set for the desired material parameters, which guided the initial simulations. The simulated curves for temperature, electrical resistance, and power were used as input data of a neural network, which derived new estimations of the material parameters by comparing the simulation results with the measurement data. This process was repeated iteratively, with each simulation refining the parameters based on the neural network's outputs, gradually building a dataset.

This iterative process of simulation, comparison, and parameter adjustment eventually converged to a unique parameter set defining the thermoelectrical properties of the membrane layers. Figure 1 shows the comparison between simulation with these parameters and the measured values, demonstrating excellent agreement.

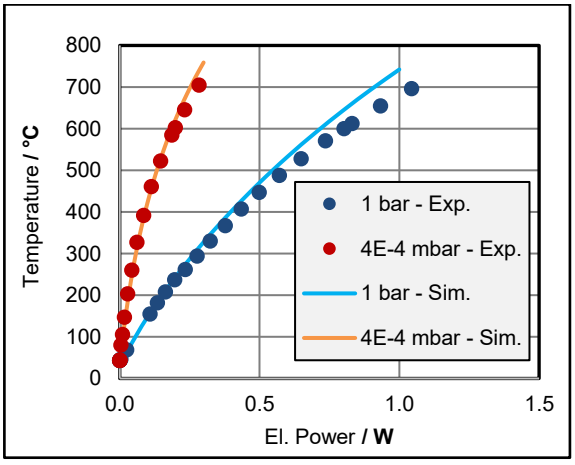

Figure 1: Comparison of the temperature-power curves (at two different pressures) between the

measured results (dots) and simulations (curves) based on the identified material parameters.

Design Study

With the obtained Comsol model, we were able to simulate over a hundred of different heating membrane geometries and the electric control. We analyzed potential designs before manufacturing with respect to resistance, power consumption, intensity and dynamic. The most promising designs were then chosen to be manufactured and assembled in our clean room facility.

Results

The dynamic response of MEMS-based infrared emitter chips is critically influenced by their physical dimensions. Larger chips possess a higher thermal capacity, which inherently slows their response times. Conversely, smaller chips, though more dynamic due to their reduced thermal capacity, often exhibit significantly lower intensity. Due to these limitations, we pursued two distinct approaches. First, we optimized the design of an existing larger chip, aiming to enhance its response speed while preserving as much emission intensity as possible. Second, we developed a single-chip-array of heating membranes, which combines the advantages of both high total emission area for increased intensity and small individual membrane size for improved thermal dynamics. In addition to fabricating newly optimized emitter chips, we successfully assembled highly compact emitter arrays from individual chips.

Extensive testing of these advanced emitter modules demonstrated noteworthy performance improvements. For instance, by implementing minor design modifications to our legacy chip, we achieved a 10% increase in modulation depth across a frequency range of 10 to 50 Hz. Furthermore, our novel in-chip array design, which retains the dimensions of the original chip, was able to deliver a 65% increase in emission intensity at 60 Hz without increasing electrical power consumption.

Moreover, our assembled 16-chip array exhibited the same intensity at 100 Hz as the legacy chip operating at 10 Hz. Despite being housed within the same TO-39 socket and therefore keeping the same packing size, the multi-chip array consumes three times the power of the legacy chip. Although the assembly of such a multi-chip array is complex and incurs higher production costs, it underscores the potential of this approach, particularly for high-value applications such as clinical breath analysis, where performance benefits justify the increased cost and power consumption.

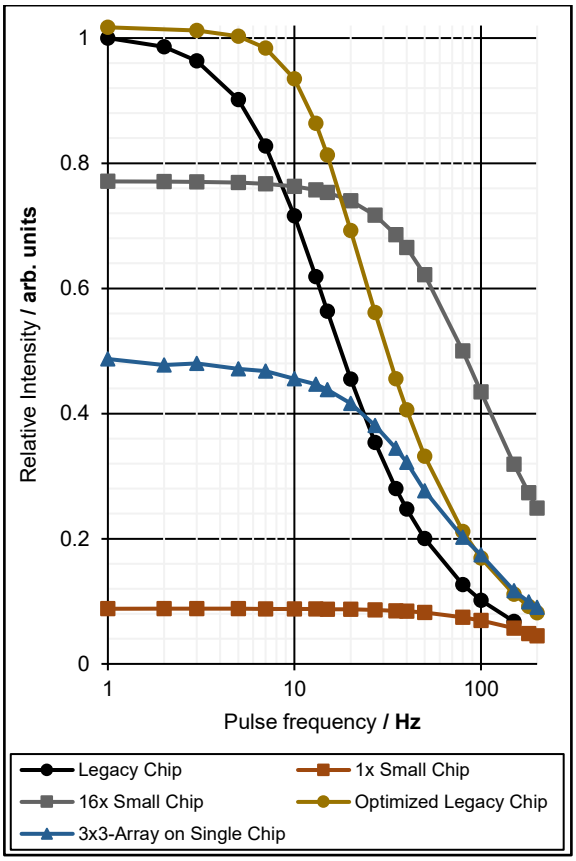

Figure 2: Comparison of the new IR-emitters to our legacy chip. The intensities are referenced to the legacy chip. The emitters were pulsed with a square-waved power signal at different frequencies and peak-to-peak intensity was measured.

References

[1] https://www.infrasolid.com/en/products, 11/13/2024

[2] https://cmosir.com, 11/13/2024

Acknowledgements

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