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SNR Enhancement of a MEMS Thermal Acoustic Pressure Sensor

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Summary:

In this work, we investigate the different internal noise mechanism affecting the performance of our MEMS based dynamic pressure sensor based on thermal anemometric principle [1]. We present sensitivity and noise measurements for two different chip designs for a comparative analysis with theoretical values. Finally, we show that the design modification resulted in the enhancement of the Signal to Noise ratio (SNR) by 30 dB and the dynamic pressure detection lower limit by a factor by 20 dBSPL.

Keywords: thermal noise, acoustic, dynamic pressure, thermal sensor, lock-in amplifier

Motivation

To understand the performance limitations of our dynamic pressure sensor by measuring and calculating various internal noise affecting the sensor performance and develop a deeper understanding about the SNR enhancement via chip design modification.

Sensor Description and Noise Sources

The thermal flow sensor consisting of a heater and thermal sensors (thermopiles in this case) is modified by etching micro perforations with different dimensions as shown in Fig.1.

A periodic acoustic pressure difference across the membrane creates an oscillating flow through the perforations. This causes temperature oscillation (at double the acoustic frequency) at the right thermopile (TPR) which is measured as a voltage difference as shown in Fig 2.

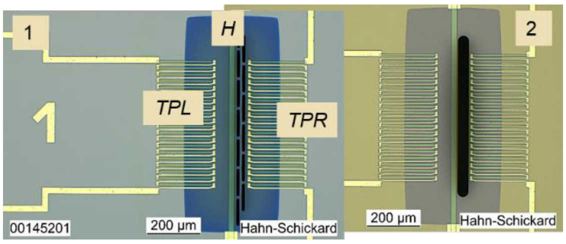

Fig 1: Top view of the fabricated chip design 1 (13 slits, 100 µm long, 10 µm wide) and design 2 (1 slit, 600 µm long, 40 µm wide) indicating the sensing thermopiles on right / left (TPR / TPL) and the heater in the center

The two internal noise affecting the system are discussed below.

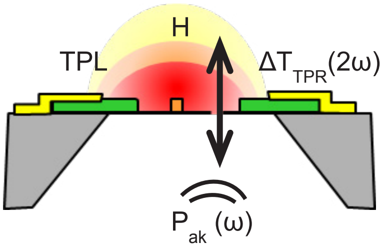

Fig 2: Side sketch of the sensor indicating input acoustic pressure generates an acoustic flow via the perforation that leads to a temperature (or Seebeck Voltage) oscillation at double frequency at the right thermopile TPR

1. Viscous Slit (Thermal-acoustic) Noise

This noise originates from the movement of particles in the slit due to thermal energy. It depends on the viscous resistance offered by the slit, the temperature of the gas molecules and is given as [2]

$$v_{n,ak}=\sqrt{4K_B T_{amb} R_{v,s}}\ [\mathrm{Pa/Hz^{0.5}}] \quad (1).$$

The viscous resistance of chip 1 is almost 100 times higher than chip 2 due to the inverse cubic dependence on the width of the slit. This results in the acoustic slit noise of around 2.2 µPa for chip 1 and 0.2 µPa for chip 2 (in 1Hz BW) which is significantly lower than the SPL generated by the loudspeaker at a frequency of 20 Hz and hence not the limiting noise to our sensor.

The big advantage is that by decreasing the acoustic resistance, we reduce this noise on one hand but we increase the sensitivity on the other hand. The bigger slit offers lower viscous resistance. This allows for more volume flow that eventually leads to higher temperature oscillations at the right thermopile.

2. Thermal Noise

This is the noise originating at the Thermopile (TP) due to its electrical resistance and it limits the lower temperature detection level. It is given by [2]

$$v_{n,th}=\sqrt{4K_B T_h R_{el,TP}}\ [\mathrm{V/Hz^{0.5}}] \qquad (2).$$

The thermal noise is calculated for both the chip designs as per Eq 2 and the results are summarized in Table 1.

Tab. 1: Thermal noise calculations for the right thermopile (TPR) for both the chip designs

Chip design	$R_{el,TPR}$ measured value	Calculated thermal noise using eq. 2
1	24.5 KΩ	20 nV/Hz$^{0.5}$ (-154 dBV/ Hz$^{0.5}$)
2	21.0 KΩ	18.6 nV/Hz$^{0.5}$ (-154.6 dBV/Hz$^{0.5}$)

Measurement Results and Discussion

The heater operates around 80°C above the room temperature. For a constant acoustic frequency of 20 Hz, the 40 Hz component of the TPR voltage is demodulated and plotted over an acoustic pressure sweep as shown in Fig. 3.

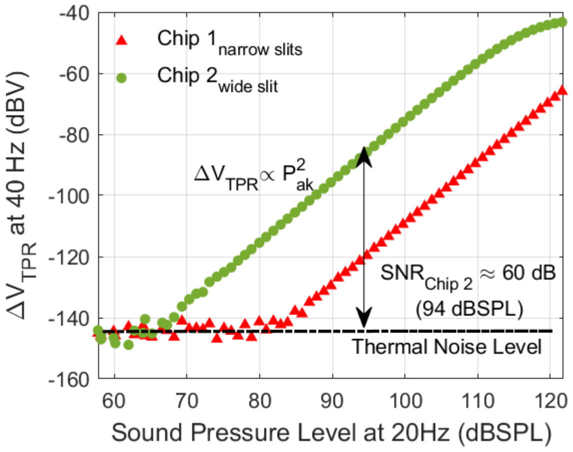

Fig 3: Pressure sensitivity measurements for both the chip designs at a frequency of 20 Hz. The SNR for chip 2 at 94 dBSPL is indicated

The sensitivity increases quadratically with the acoustic pressure in both the chip designs. However, the sensitivity of chip 2 is around 30 dB higher than chip 1 due to reduced acoustic slit resistance. However, the noise level remains the same for both the designs indicating that the thermal noise is the limiting factor in our sensor.

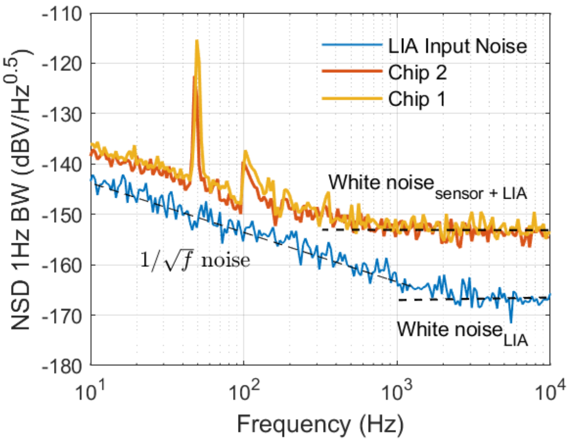

Fig 4: Noise measurements for the Lock-in amplifier (LIA) and the TPR of both the chip designs. The Flickr noise ($1/\sqrt{f}$) dominates at lower frequencies and the White noise dominates at higher frequencies

The noise measurements are performed inside an acoustic chamber to avoid any acoustic disturbances and to isolate from the external noise and are plotted in Fig 4. We can see that the noise spectrum contains Flickr noise that shows $1/\sqrt{f}$ response up to ~1 KHz (for Lock-in amplifier) and then the white noise starts to dominate and has flat response. For both the chips, the noise is almost similar and shows the similar response as the Lock-in amplifier (LIA) noise.

We can also see that the noise values calculated in Table 1 very accurately match the thermal noise level as shown in the measurements in Fig 4. The thermal noise level indicated in Fig 3 also closely corresponds to the noise values at 40 Hz as seen from the noise measurements in Fig 4.

Conclusion

The modification of the slit design increases the sensitivity without affecting the noise floor of the sensor. This eventually leads to an increased SNR (more than 50 times) and lower pressure detection limit (from 84 to 64 dBSPL) as proven by the measurements. Hence, this sensor offers an advantage in the ease of SNR enhancement by modifying the perforation design. Other SNR enhancement methods such as the operating heater temperature are currently under investigation.

References

[1] Gupta, A., Bittner, A., & Dehé, A., Novel Thermal MEMS Dynamic Pressure Sensor. Paper presented at the *2023 22nd International Conference on Solid-State Sensors, Actuators and Microsystems (Transducers), Kyoto, Japan*.

[2] T. B. Gabrielson, Mechanical-thermal noise in micromachined acoustic and vibration sensors, in *IEEE Transactions on Electron Devices*, vol. 40, no. 5, pp. 903-909, May 1993, doi: 10.1109/16.210197