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Geometrical optimization of an acoustic thermal flow sensor

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Summary: *In this paper a thermal acoustic flow sensor that measures particle velocity (the 'Microflown') is analyzed. A model is developed that calculates the sensor sensitivity and its frequency dependent behavior, as a function of material parameters and device geometry. Consequently, improved devices could be fabricated, with a new geometry consisting of three wires of which the central wire is relatively most heated. These are the best performing sensors up to date with a frequency range attending over 5 kHz and signal-to-noise ratios improved by 10 dB to more than 20 dB over previous designs.*

Keywords: *thermal flow sensors, acoustic, optimization*
Category: *1 (General, theoretical and modeling); 2 (Materials and technology)*

1 Introduction

The Microflown is a micromachined acoustic sensor that measures particle velocity instead of sound pressure, which is usually measured by conventional microphones [2, 3, 4]. Originally a flow sensor [1], it is optimized for sound measurements.

The sensor usually consists of two closely spaced thin wires of 1500 µm (spacing 100-350 µm) of silicon nitride with an electrically conducting platinum pattern. This metal pattern acts as temperature sensor *and* as heater. The wires are electrically heated to about 600 K. When subject to a particle velocity, the temperature distribution around the resistors is asymmetrically altered. The temperature difference, and therefore the temperature dependent resistance difference, of the two sensor wires is in first order proportional to the particle velocity.

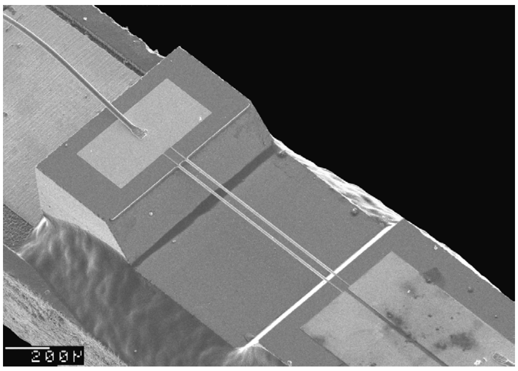

Fig.1 SEM-photo of a two-wire type Microflown (wire lengths 1 mm)

2 Sensor optimization

Using a numerical version of the model described in former work [5,6], a program was developed to calculate the sensitivities of geometrically different devices. Parameters such as the channel depth (l_z), the wire length (l_y), their mutual distance ($2a$), and the dissipated power are taken into account in this model, as well as a three-wire configuration.

3 Experimental

Many geometrically different devices were fabricated, with $40<l_z<300$ µm, $80<2a<300$ µm and $500<l_y<1500$ µm according to the process flow describe in [6]. In particular several three-wire sensors of different geometries were designed, and the sensitivity as a function of the dimensions and the relative power in the central wire was investigated. The total dissipated power was varied from 0 to 75 mW.

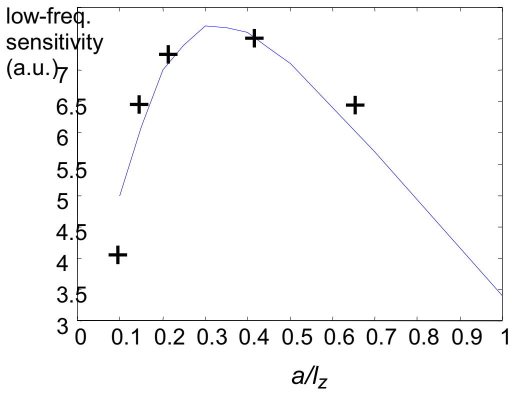

Fig.2 Low-frequency sensitivity $S(f=0)$ as a function of the ratio a/l_z (line represents the calculations). The crosses show experimentally obtained results, from devices with l_z=240 µm; $2a$=50, 80, 100, 200, 300 µm.

The sensitivity of all devices was experimentally determined using a standing-wave-tube, together with a loudspeaker and a reference microphone. The most relevant characteristics of the sensitivity are the low-frequency('DC'-)sensitivity and a characteristic frequency f_c [6], a measure of the bandwidth. Their dependences on a/l_z (Fig.2), l_z/l_y (Fig.3), a (Fig.4), and P (Fig.5) were compared to the model calculations; good agreement was found.

One sees that for given l_y, the sensitivity increases with l_z, up to $l_z \approx l_y$. See Fig.3. The optimum a at given l_z, is about $a \approx 0.3\ l_z$ (Fig.2). However, to obtain a broadband, flat, frequency response, a should be as small as possible (Fig.4). Both requirements cannot be fully satisfied simultaneously, but a very well performing device is obtained when $a \approx 100$ µm at $l_y = 1$ mm.

4 The three-wire configuration

A significantly better performing device is made of *three* instead of two wires. The central wire, the heater, is heated up to ~780 K, while the other two wires, acting as sensors, are relatively cold and thus attain lower noise levels.

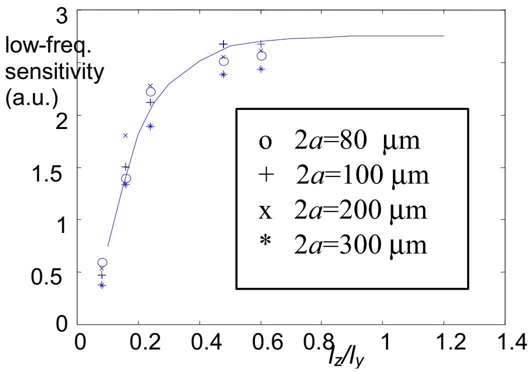

Fig.3. $S(f=0)$ as a function of the ratio l_z/l_y (line:model). The marks indicate experimentally obtained results from devices with $l_y = 500$ µm; $l_z = 40$, 80, 120, 240 or 300 µm and $2a = 80$, 100, 200 or 300µm.

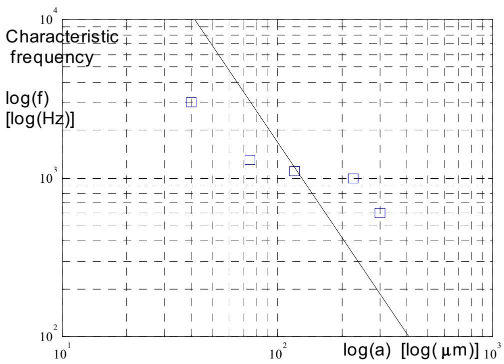

Fig.4. Characteristic frequency f_c of the sensitivity curve, as a function of the distance between the sensing wires, mutual wire distance=$2a$, plotted logarithmically. The line shows the theoretical dependence $f_c \propto a^{-2}$.

The sensitivity, however, is proportional to the total dissipated power. A three-wire device, with a relative heater power of 0.85, has a two times higher sensitivity than a two-wire sensor of the same dimensions and power. The optimal geometry, see Fig.6, is found to be near $l_y = 1$ mm, $l_z = 300$ µm, $a = 50$ µm and $P_{total} = 70$ mW. In the frequency bandwidth 1.0-4.0 kHz, its signal-to-noise ratio (at 1 Pa) is then about $1.3 \cdot 10^4$ to $3.3 \cdot 10^4$ √Hz.

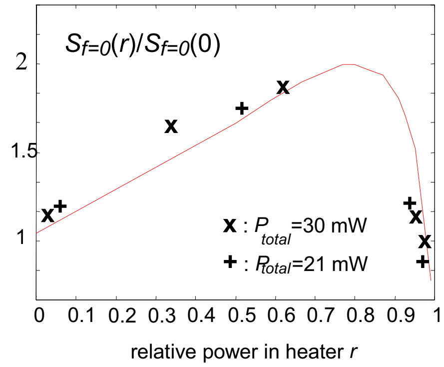

Fig.5 . Low-frequency sensitivity $S_{f=0}$ as a function of relative heater power $r = P_H/(P_H + 2P_S)$ normalized to the sensitivity $S_{f=0}$ at $r=0$, according to the model calculations (line), and the experimentally obtained points (crosses).

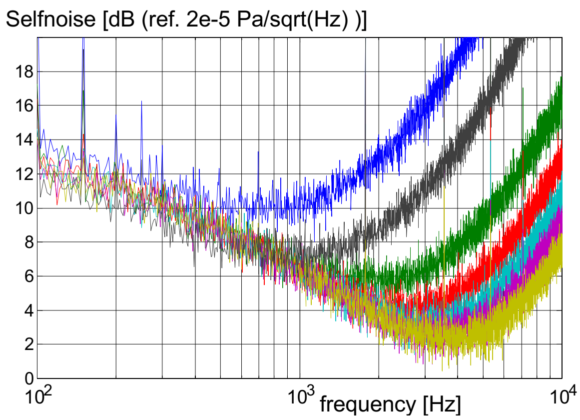

Fig.6. Selfnoise levels of the best up to date three-wire type Microflown, $a = 100$ µm, $l_z = 200$ µm, a sensor power $P_{S2} + P_{S1} = 11$mW and a heater power $P_H = 0$ mW (upper curve), 5, 10, 20, 32, 44 and 58 mW (lowest curve). The upper curve corresponds to the two-wire configuration.

5 Conclusions

Using a numerical model, two and three wire acoustic thermal flow-sensors have been geometrically optimized. Model and experiment showed good agreement and the resulting Microflowns are found to improve the frequency range to 5 kHz while improving the signal to noise ratio by 10-20 dB.

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