# Design Parameter Comparison for a Silicon-based Directional Low Drift Thermal Anemometer for Horticultural Applications

Thomas L. Hackett [a], Remco G.P. Sanders [a], Dennis Alveringh [a], Jurriaan Schmitz [a]

[a] University of Twente, MESA+ Institute for Nanotechnology, Enschede, 7522NB, The Netherlands
e-mail: t.hackett@utwente.nl

Controlled environment agriculture (CEA) facilities are estimated to yield 220-600 times more wheat crop than traditional farming techniques [1]. Within CEA facilities air speeds should be in the range of 0.3-0.5 ms$^{-1}$ to allow for optimal moisture exchange to reduce tip-burn and increase yield [2]. In this work a combined calorimetric and hot-wire anemometer is optimized for use in horticultural sensor grid applications to detect flow velocities between 0.05 and 1 ms$^{-1}$. This optimization is essential to obtain a linear response and high sensitivity within in the measurement range. The sensor is fabricated using p-doped silicon on insulator (SOI) wafers, allowing for drift-free, low-cost directional anemometry at low heating power (20 mW) with angle of attack (AoA) detection.

The thermal anemometer [3] was optimized by varying key design parameters which were determined to be sensing element spacing, heater size and thermal insulation. The design process is simpler in contrast to a previous parametrization study [4], while the fabrication is more straightforward compared to most state of the art anemometers [5]. Furthermore, the heater was used as an additional hot wire sensor to determine the flow speed and direction simultaneously without increasing sensor complexity, as opposed to a previous implementation that employed advanced packaging in order to deduce AoA [6]. The use of a differential measurement allowed for a doubled sensitivity and thus allowed for lower heating power consumption, which is especially relevant for the intended sensor grid application.

The sensors were made using a simple p-type SOI process consisting of three deep reactive ion etches, a silicon nitride deposition and one isotropic release etch. The device was measured in a custom-built wind tunnel capable of providing flows from 0 to 5 ms$^{-1}$ with an accuracy of 0.02 ms$^{-1}$. The 4 p-doped sensing elements were placed in a Wheatstone bridge which was powered by an arbitrary wave form generator and measured using a lock-in amplifier. The heater temperature was kept constant by controlling the electrical power provided with a proportional-integral controller, this supplied power was also recorded and used as the hot-wire measurement data. The AoA was automatically varied using a brushless DC rotating stage with a precision of 0.001°. The temperature and humidity were regulated by placing the wind tunnel in a climate cabinet [7].

Figure 2 shows that highest in-line calorimetric sensitivity was achieved by the narrowly spaced large heater device (23 $\mu$V / ms$^{-1}$), which showed slight improvement on the base design (18 $\mu$V / ms$^{-1}$). The sensitivity increased to 48 $\mu$V / ms$^{-1}$ when the sensor was placed at a 15° angle with respect to the flow (Figure 3), giving a 1.35 $\mu$V / deg sensitivity to angle changes from -5° to 15°. The large heater device was determined to have the best heat dissipation characteristics as most thermal energy is effectively transferred downstream through the air to the sensing elements instead of being lost to the surroundings. Furthermore, the change in power consumption of the large heater device is approximately 0.5 mW over the prescribed measurement range (Figure 4). Ultimately, the best design parameters were found and a sensor tuned for use in CEA facilities was realized, showcasing a simple design strategy for thermal flow sensors through the variation of geometric properties in the sensor design.

[1] S. Asseng et al., Proc. of the National Academy of Sci., 117 (2020), pp. 19131-19135.
[2] G. Agati et al., Appl. Therm. Eng., 235 (2024), p. 121553.
[3] D. Alveringh et al., IEEE Sensors Conf., (2022), pp 1-4.
[4] P. Bruschi et al., Micromachines, 3 (2012) pp. 295-314.
[5] K. Kuo et al., Micromachines, 3, (2012) pp. 550-573.
[6] M. Piotto et al., iMNE conf, proc., 88 (2011), pp. 2214-2217.
[7] T. Hackett et al., MFHS Conf. Proc, 5 (2024), pp. 126-129.

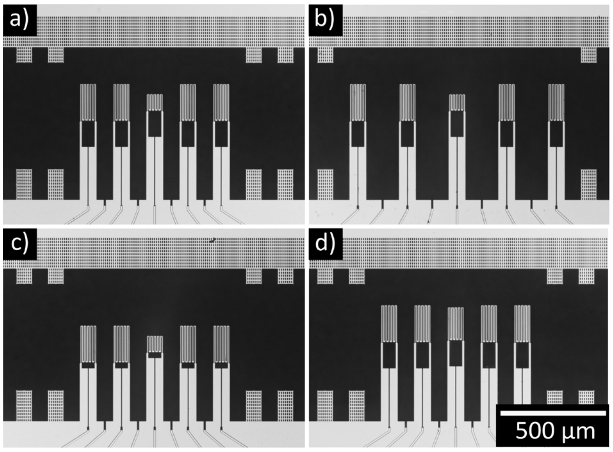

**Figure 1. a)** Base design, **b)** Wide design **c)** Low insulation design **d)** Large heater design.

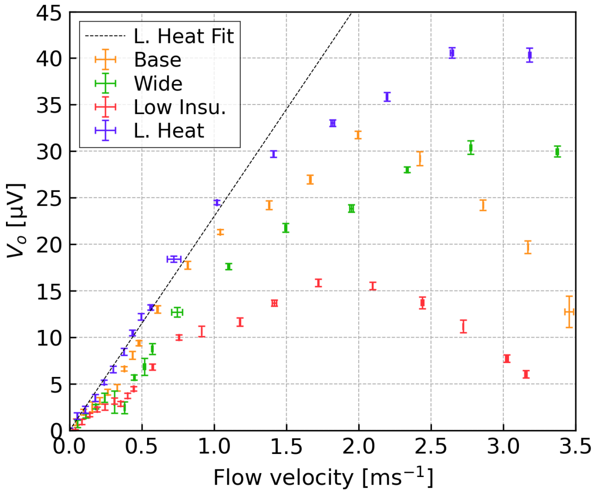

**Figure 2.** Calorimetric output voltage against flow speed for all 4 sensors designs. The large heater linear region is marked by the dotted line.

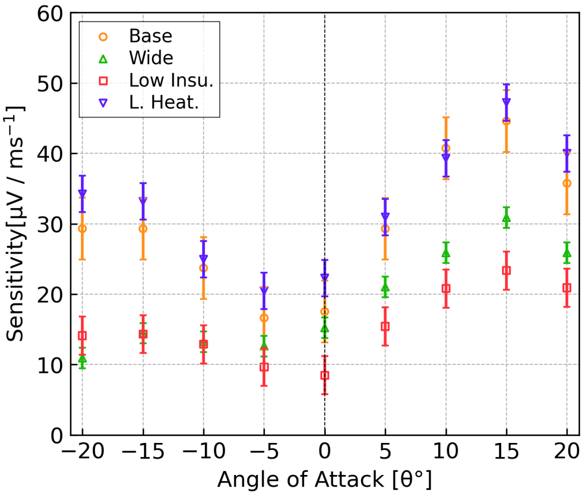

**Figure 3**. Sensitivities at a given angle of attack for all 4 sensor designs.

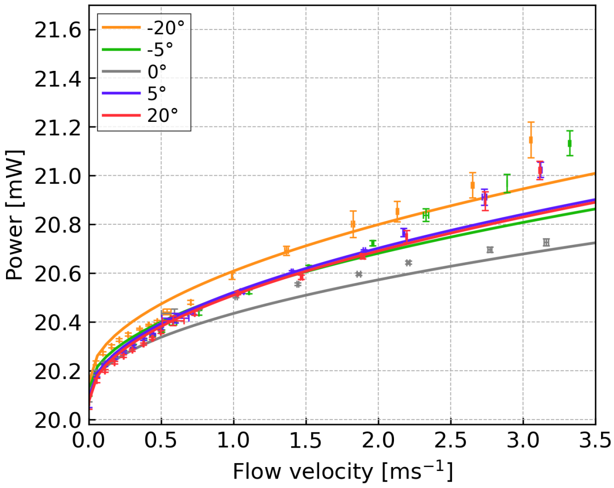

**Figure 4**. Power consumption of the Large hot-wire anemometer element against flow velocity. The best fit curves of King's law are included.

**Table 1.** Design Parameters

| **Sensor Type** | **Parameter** | | |
|---|---|---|---|
| | Spacing (µm) | Resistor Area (µm$^2$) | Insulation Gap (µm) |
| Base | 80 | 6400 | 129 |
| Wide | **160** | 6400 | 129 |
| Large Heater | 80 | **12800** | 129 |
| Low Insulation | 80 | 6400 | **29** |