

# In-Situ Spatial Mapping of Microjet Impingement with a Piezoresistive Silicon Nanowire MEMS Sensor

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## Summary:

We present an in-situ sensing framework for spatial mapping of impinging microjet plume-surface interaction at the sub-mm nozzle scale using a piezoresistive silicon nanowire (SiNW) MEMS sensor. A bilinear response surface in jet momentum ( $J$ ) and stand-off ratio ( $h/d$ ) measures resistance change ( $\Delta R/R_0$ ) across  $h/d = 2.5$ – $10$ . Spatial maps acquired with  $20\ \mu\text{m}$  along-track sampling and sub-nW power resolve stand-off-dependent changes in both peak loading and spatial structure of the impingement.

**Keywords:** MEMS, force sensor, piezoresistive silicon nanowires, jet impingement, flow sensing

## Background, Motivation and Objective

Impinging microjets govern near-wall loading in applications from micro-propulsion plume-surface interaction [1] to compact cooling, printing, and needle-free injection. Optical diagnostics such as  $\mu\text{PIV}$  deliver microscale vector fields but suffer from depth-of-correlation averaging, reflections, and seeding constraints at small stand-off [2]. Physical sensing at sub-mm nozzle scale remains rare; a pressure sensor for jet momentum spatial distribution has been demonstrated [3], and point-wise jet impingement on suspended SiNW MEMS sensors showed initial feasibility [4]. However, in-situ spatial mapping of micro-jet plume-surface interaction across a broad stand-off range has not been addressed.

## Description of the New Method or System

The sensing element is a suspended shuttle with SiNW piezoresistors ( $\langle 110 \rangle$ , p-type,  $10^{17}\ \text{cm}^{-3}$ ) (Fig. 1) [5]. A nitrogen jet from a  $d = 200\ \mu\text{m}$  nozzle impinges on the shuttle, generating strain in the SiNWs; gas delivery, electrical readout, and stage motion are coordinated through a DAQ system (Fig. 2). Sensor characterization at  $h/d = 2.5$ – $10$  and three momentum setpoints ( $\sim 9$ – $13\ \text{mN}$ ) establishes the response surface in ( $J$ ,  $h/d$ ) (Fig. 3). For raster mapping across  $h/d = 2.5$ – $10$ , the sensor remains fixed while the nozzle rasters

8 passes over  $x/d = \pm 10$ , stepping increments of  $\Delta(y/d) = 0.5$  from  $y/d = 3.5$  to  $0$  at  $400\ \mu\text{m/s}$ , giving  $20\ \mu\text{m}$  along-track sampling at  $20\ \text{Hz}$ .

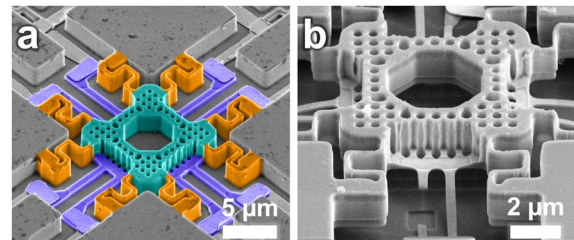


Fig. 1 a) SEM image of the sensor shows  $10 \times 10\ \mu\text{m}^2$  MEMS shuttle (teal), anchors connected by springs (orange) and SiNW piezoresistors (purple) of length  $5\ \mu\text{m}$ , b) SEM image after FIB cut exposing the SiNW cross-section (width  $\times$  height =  $500 \times 280\ \text{nm}^2$ ).

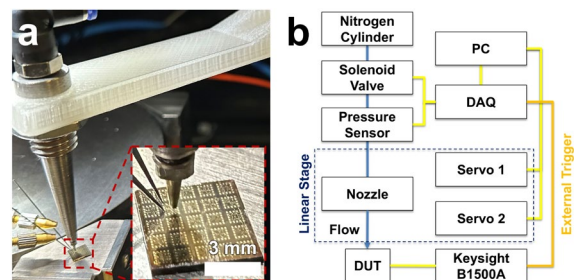


Fig. 2. a) Picture of the experimental setup showing the DUT, probe tips, and nozzle (inset: DUT–nozzle close-up). b) Block diagram of the experimental setup.

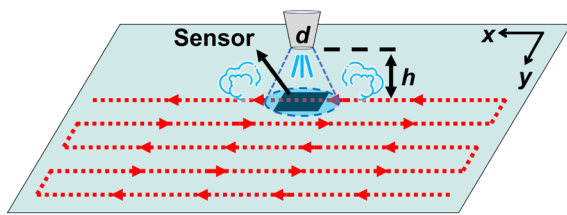


Fig. 3 Measurement workflow schematic showing the chip (cyan) with on-chip sensor (black) and nozzle positioning for centered characterization and raster mapping (red arrows indicate the scan trajectory).

## Results

With the sensor biased at 50 nA ( $R_0 = 190.4 \text{ k}\Omega$ ,  $<0.5 \text{ nW}$ ), the response surface increases with  $J$  and decreases with  $h/d$  (Fig. 4). The fit yields local sensitivities of  $-7.35 \times 10^{-4} (h/d)^{-1}$  and  $1.22 \times 10^{-3} \text{ mN}^{-1}$ . The raster scan at  $h/d = 7.5$  (Fig. 5a) shows a clear  $\Delta R/R_0$  maximum at  $y/d = 0$  decaying with lateral displacement. Across each map, the 95th percentile  $\Delta R/R_0$  reaches 1.54%, 1.23%, and 1.14% at  $h/d = 2.5$ , 7.5, and 10 respectively. While  $J$  primarily scales response magnitude, increasing stand-off narrows the peak response region while weaker loading persists across the field (Fig. 5b). The platform resolves these patterns with sub-nW power in a  $10 \times 10 \text{ }\mu\text{m}^2$  pixel, supporting in-situ mapping across a wide stand-off operating range. This framework opens direct wall-referenced characterization to applications in microscale cooling, additive manufacturing, and needle-free injection where near-field loading governs process outcomes.

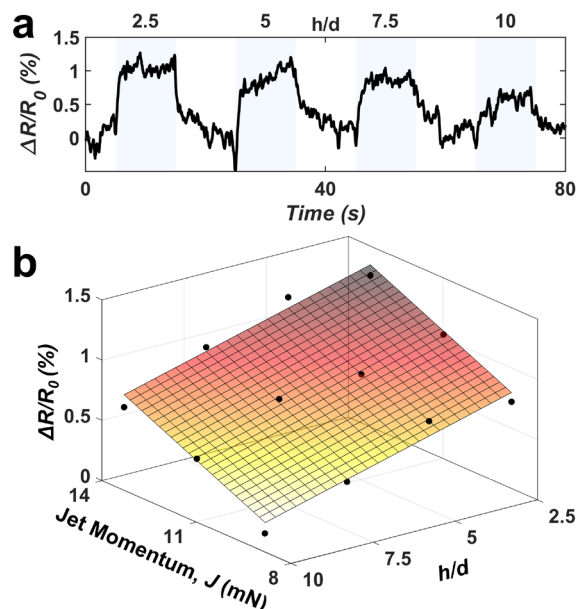


Fig. 4. a)  $\Delta R/R_0$  vs. time at  $J \approx 11 \text{ mN}$  for  $h/d = 2.5$ – $10$ ; shaded intervals indicate flow-on periods. b) Response surface (bilinear fit) to 12-cycle averages from three independent tests in  $(J, h/d)$ ;  $R^2 = 0.93$ .

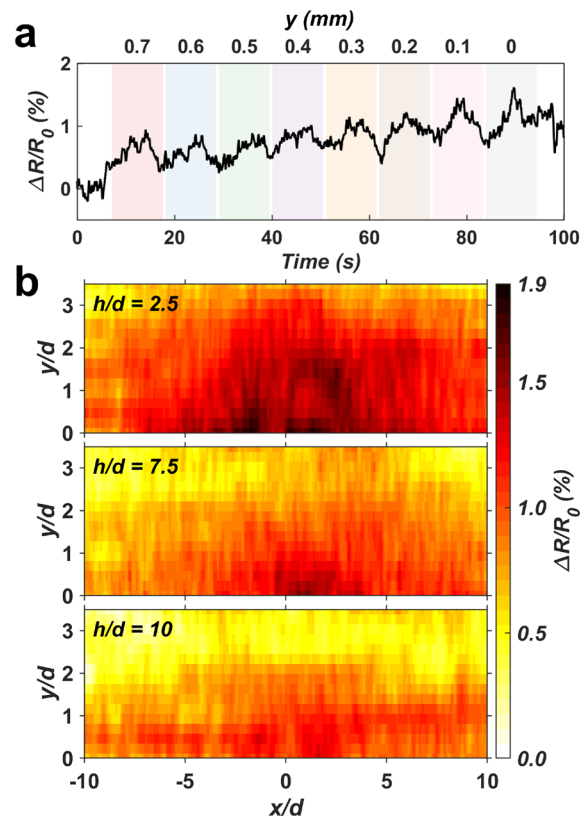


Fig. 5. a) Eight-pass raster scan at  $J = 11.8 \text{ mN}$ ,  $h/d = 7.5$ .  $\Delta R/R_0$  is plotted against time and corresponding  $y$  position. b)  $\Delta R/R_0$  maps at  $h/d = 2.5$ , 7.5, and 10 on a common color scale.

## References

- [1] C. Ngalande, T. Lilly, M. Killingsworth, et al., Nozzle Plume Impingement on Spacecraft Surfaces: Effects of Surface Roughness, *Journal of Spacecraft and Rockets* 43, 1013-1018 (2006); doi: 10.2514/1.19321
- [2] R. Lindken, M. Rossi, S. Große, et al., Micro-Particle Image Velocimetry ( $\mu\text{PIV}$ ): Recent developments, applications, and guidelines, *Lab on a Chip* 9, 2551 (2009); doi: 10.1039/b906558j
- [3] A. Bottega, C. Dongiovanni, A new sensor for the analysis of jet momentum spatial distribution, *Sensors and Actuators A: Physical* 269, 283-293 (2018); doi: 10.1016/j.sna.2017.11.041
- [4] L. Demirkazik, U. Kerimzade, M. Jedari Ghourichaei, et al., Gas Flow Sensing with a Piezoresistive Silicon Nanowire-Based MEMS Force Sensor, 2025 IEEE 38th International Conference on Micro Electro Mechanical Systems (MEMS), 809-812 (2025); doi: 10.1109/MEMS61431.2025.10917650
- [5] M. Jedari Ghourichaei, U. Kerimzade, L. Demirkazik, et al., Multiscale Fabrication and Characterization of a NEMS Force Sensor, *Advanced Materials Technologies* 10, 2400022 (2025); doi: 10.1002/admt.202400022

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