Advancing On-Chip Micromotor Fabrication Through Electrochemical Micromachining of Silicon

Farbod Abazar, Salvatore Surdo, Chiara Cozzi, Giovanni Polito, Giuseppe Barillaro
Department of Information Engineering, University of Pisa, via G. Caruso 16, 56122, Pisa, Italy
giuseppe.barillaro@unipi.it

Microscale mechanical systems are increasingly critical in integrated devices for lab-on-chip applications. However, fabricating movable microstructures such as interlocked microgears directly in silicon remains challenging. Electrochemical micromachining (ECM) offers a promising alternative to conventional methods like deep reactive ion etching (DRIE) or LIGA, which either suffer from surface roughness or process complexity [1–2]. Recent advancements in ECM have shown its ability to produce complex, freestanding silicon microstructures with high aspect ratios and nanoscale surface quality, making it ideal for such applications [3–4].

In this work, we demonstrate the fabrication of freestanding, interlocked silicon microgears using ECM. The process involves four main steps: surface patterning, nucleation seeding, anisotropic etching for deep feature definition, and isotropic ECM to release movable parts (Figure 1). By dynamically alternating between anisotropic and isotropic regimes, we achieve high aspect-ratio structures (AR ~50) with sub-micrometric precision and ultra-smooth surfaces (<10 nm).

SEM images confirm the successful etching of gear structures with 20–40 involute teeth, diameters ranging from 68 µm to 136 µm, and precise gear ratios of 1:2. These gears are integrated into a microfluidic channel, enabling fluid-to-mechanical energy conversion without electrical actuation. The gear teeth design enables smooth rotational transmission while serving as distributed Bragg reflectors for optical monitoring (Figure 2).

This approach paves the way for the integration of silicon-based micromotors in microfluidic and MEMS systems, offering improved efficiency, miniaturization, and robustness.

References

[1] M. S. Huang, et al., J Mater Process Technol, vol. 209, no. 15–16, (2009), pp. 5690–5701
[2] G. Vizsnyiczai, et al., Nat Commun, vol. 8, (2017), pp. 15974
[3] M. Bassu, et al., Adv Funct Mater, vol. 22, no. 6, (2012), pp. 1222–1228
[4] S. Surdo et al., Lab Chip, vol. 12, no. 21, (2012), pp. 4403–4415

Figures

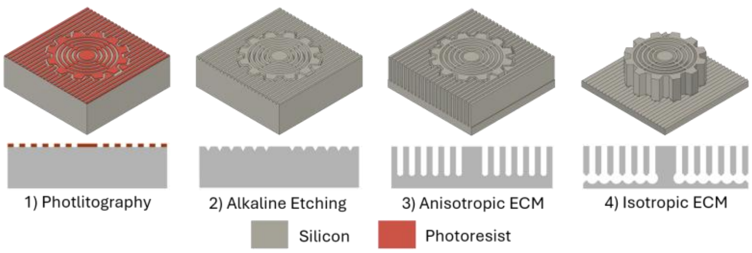

Figure 1: Schematic of the fabrication steps used for silicon microgear electrochemical machining

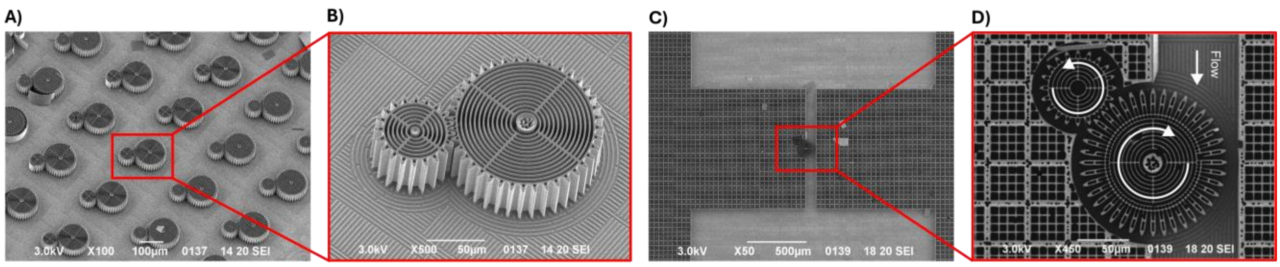

Figure 2: A) Scanning electron microscopy (SEM) images of an array of interlocked microgears. B) Magnified image of one of the microgear pair in the array. C) SEM (top view) image of a silicon microfluidic system integrating two freestanding interlocked microgears integrated with a microfluidic channel. D) Magnification of the microgears integrated into the microchannel for fluid-mechanical actuation