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Fiber-optic tethered microtools actuated with light

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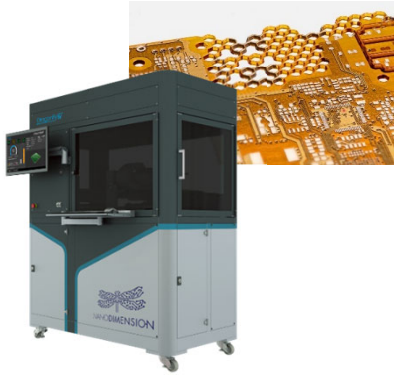
Sandia Materials & Process Science

- ***Fundamental Materials & Process Science***
  - Develop/integrate theoretical insights, computational simulation tools, and experiments to provide foundational, predictive understanding
  - Develop innovative new materials and process technologies
  - Create advanced materials analysis & process diagnostics tools
- ***Materials & Process Advanced Development***
  - Advanced & exploratory materials & process development
  - Production process development & technology transfer
- ***Materials Engineering/Production Support***
  - Materials & process selection/optimization
  - Problem solving, production support
  - Understanding & quantifying the margins
- ***New capabilities!***



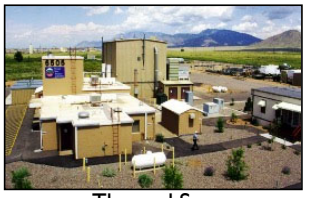
DragonFly IV 3D Printer

Quantum X Align

Multiple Large Materials R&D Facilities

Processing & Environmental Technology Laboratory

Center for Integrated Nano Technologies



Thermal Spray Research Laboratory

Advanced Materials & Processes Laboratory

Ion Beam Laboratory

Integrated Materials Research Laboratory

Microsystems Science & Technology Center

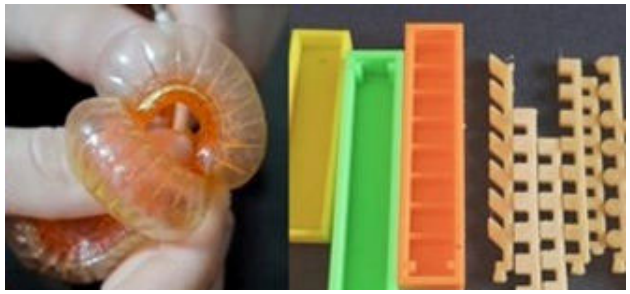
Advanced Materials Laboratory

SUPN
Sandia University Partnerships Network
CINT Summer Research Program
Mini Symposium

CINT Summer Research Program provides undergraduate and graduate students with hands-on exposure to Sandia research and facilities

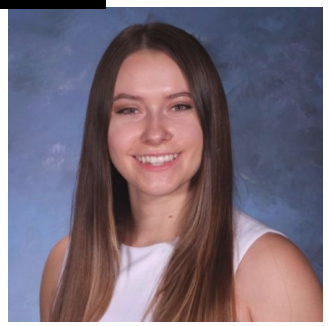
Prof Holly Golecki
UIUC Bioengineering
CINT user project: “Printed Sensing and Control in Soft Robotic Actuators

Soft Robotics



Summer 2021

Alyssa Bradshaw



Alyssa Bradshaw

UIUC ARISE Scholars

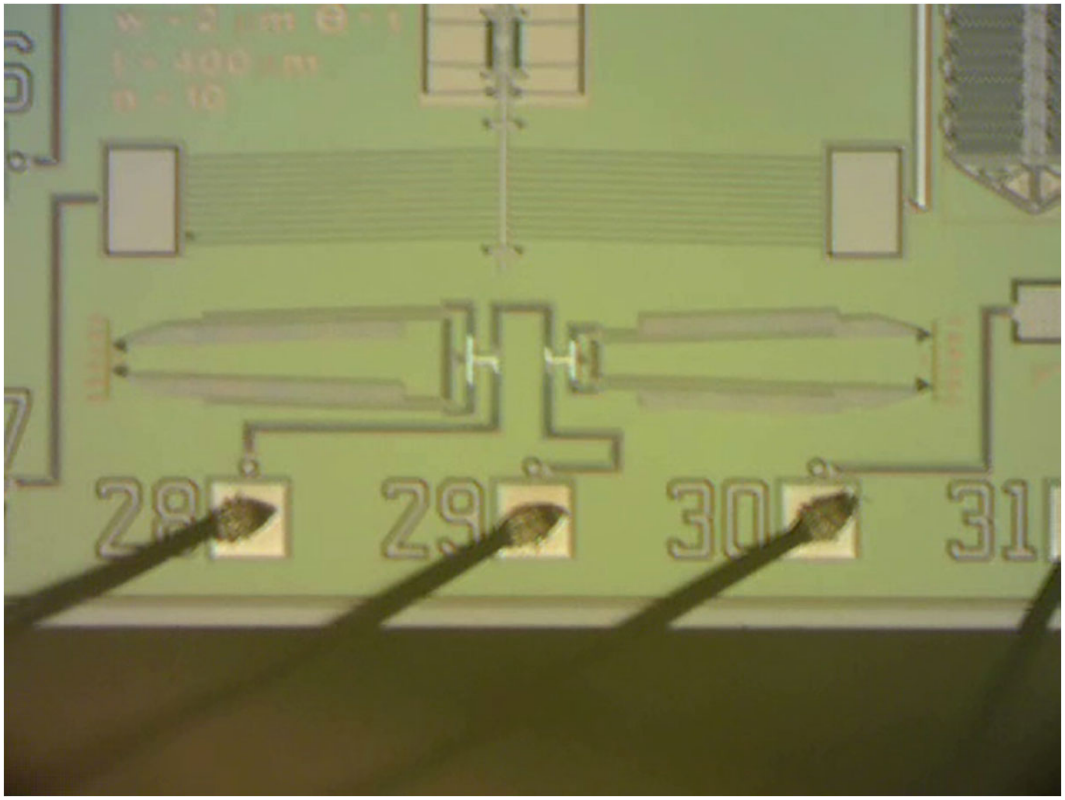
Summer 2022

Jorge Jimenez

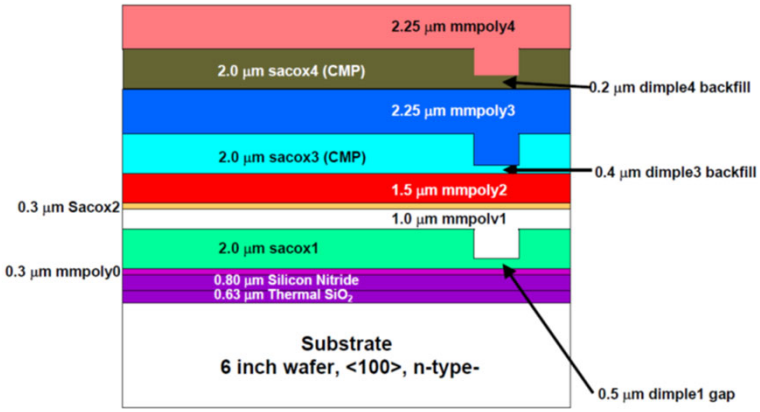
Medical device tools

infoholicresearch.com

Microscale tools example: MEMS microgripper

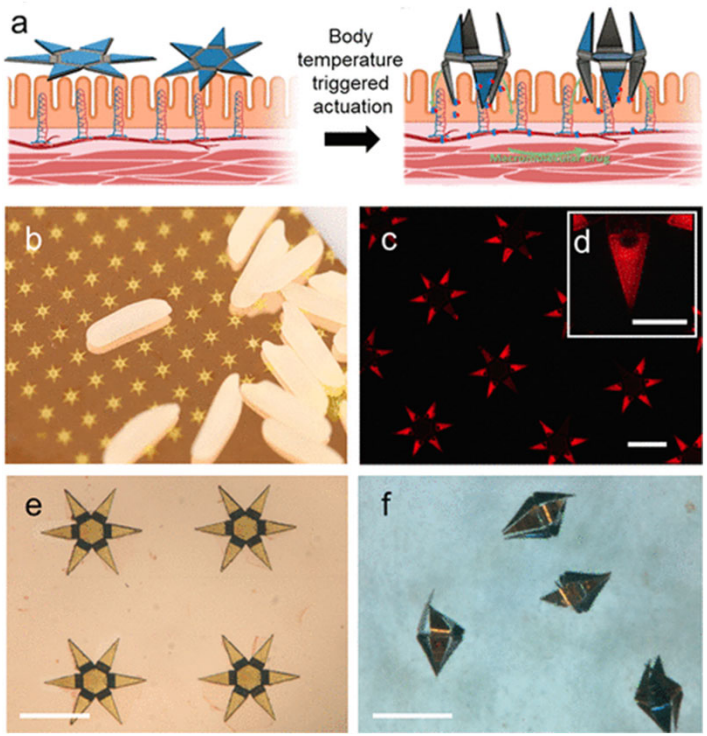


- Prof. Tim Dallas (Texas Tech)
- SUMMiT V™ (Sandia Ultra-planar Multi-level MEMS Technology V)



- Multistep, proprietary, expensive
- CINT user project: Dynamic MEMS Fabrication using Two-Photon Printed Nanostructures

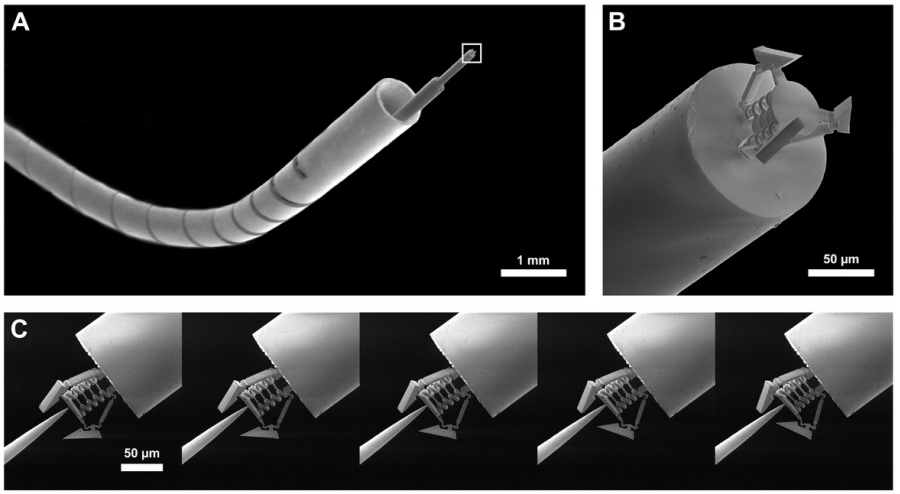
Untethered grippers

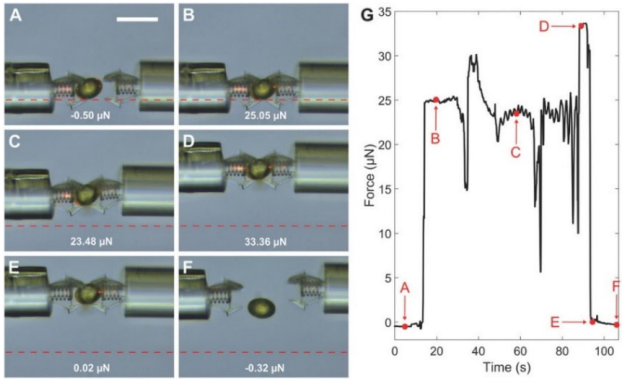


Ghosh, A., Liu, W., Li, L., Pahapale, G.J., Choi, S.Y., Xu, L., Huang, Q., Zhang, R., Zhong, Z., Selaru, F.M. and Gracias, D.H., 2022. Autonomous untethered microinjectors for gastrointestinal delivery of insulin. *ACS nano*, *16*(10), pp.16211-16220.

pH, thermo, magnetic responsive

Tethered grippers

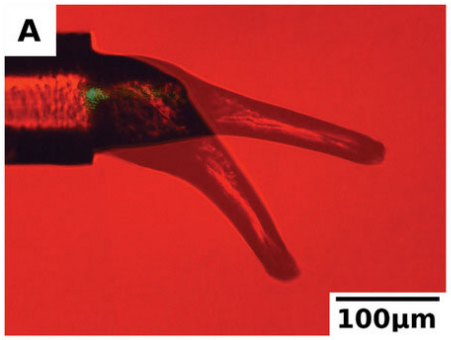


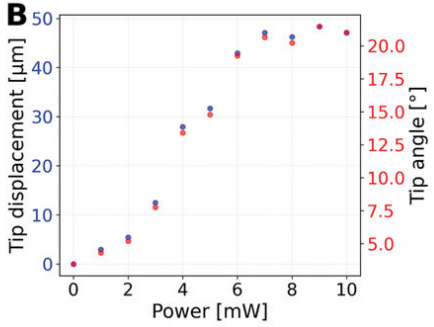


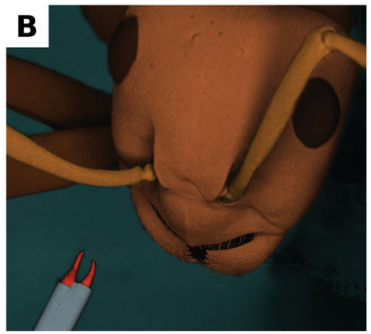
- 3D print on fiber tip
- Tether for guidance and optical feedback (interferometry force measurement).

Power, M., Thompson, A.J., Anastasova, S. and Yang, G.Z., 2018. A monolithic force-sensitive 3D microgripper fabricated on the tip of an optical fiber using 2-photon polymerization. *Small*, *14*(16), p.1703964.

Tethered objects built from optical fibers



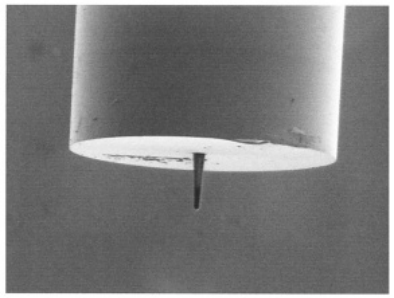




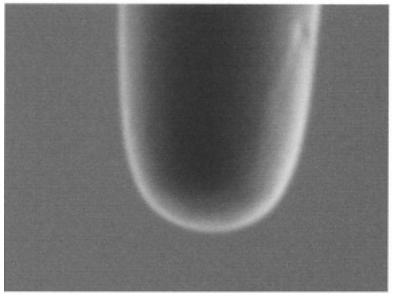
Zmyślony, M., Dradrach, K., Haberko, J., Nałęcz-Jawecki, P., Rogóż, M. and Wasylczyk, P., 2020. Optical Pliers: Micrometer-Scale, Light-Driven Tools Grown on Optical Fibers. *Advanced Materials*, *32*(33), p.2002779.

- Liquid crystal elastomer grown on tip via UV light output
- Actuated with light

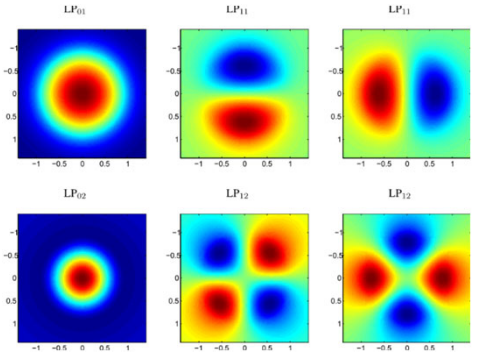
(a)



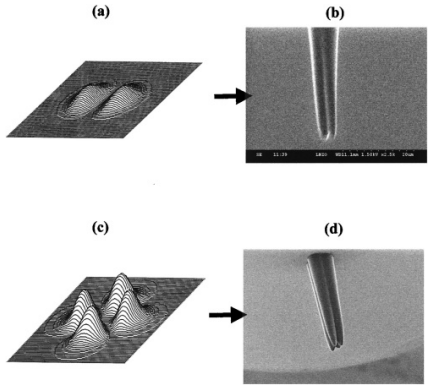
(b)



Bachelot, R., Ecoffet, C., Deloeil, D., Royer, P. and Lougnot, D.J., 2001. Integration of micrometer-sized polymer elements at the end of optical fibers by free-radical photopolymerization. *Applied optics*, *40*(32), pp.5860-5871.

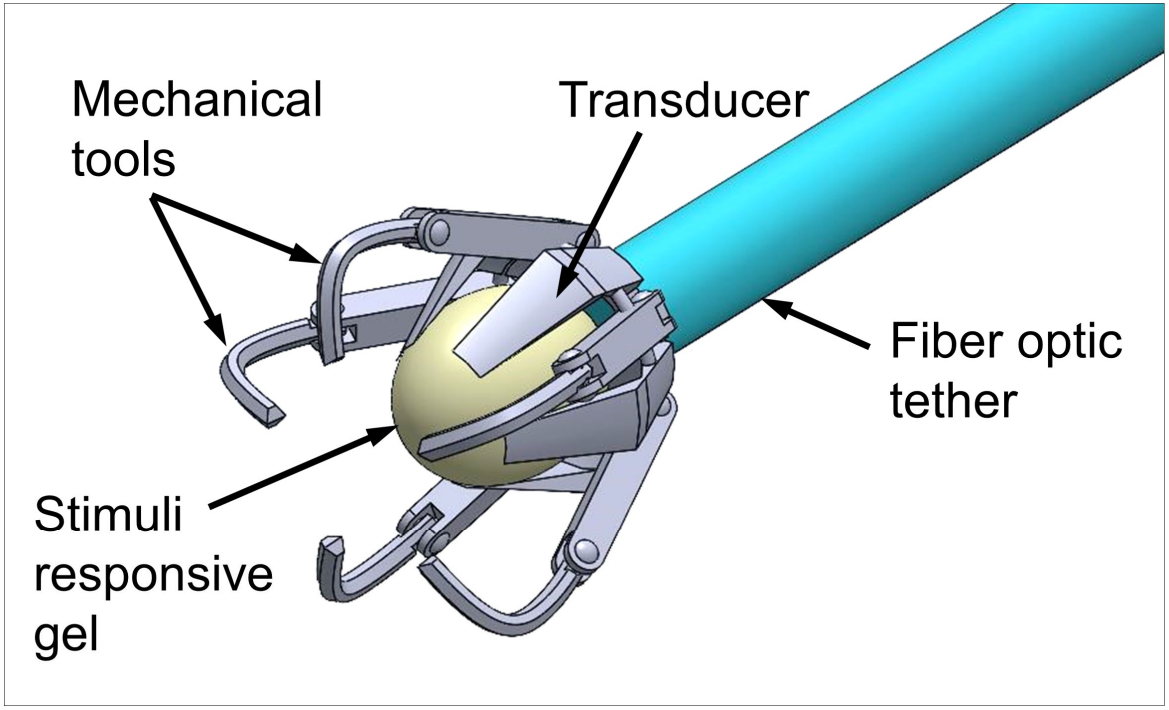


Spatial shape of 6 modes
(wavefrontshaping.net)



Limited complexity of objects

Design concept for a fiber optic tethered actuator

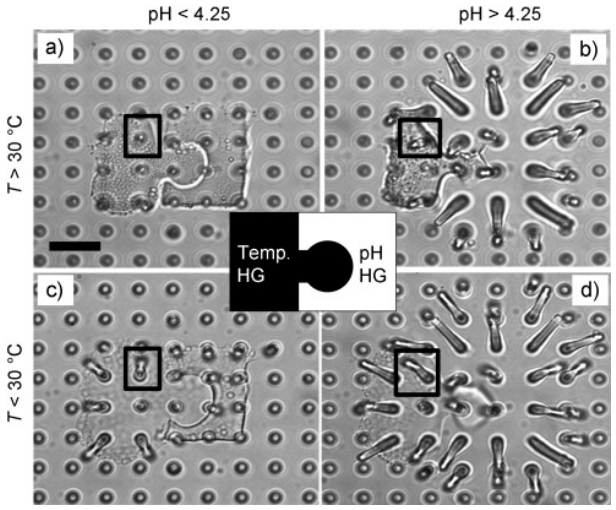


pH/temp responsive microgels

Common gels

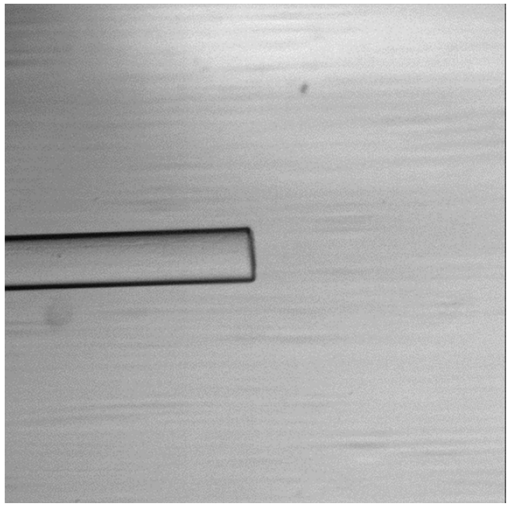
- temperature-responsive:
  - poly(*N*-isopropylacrylamide) (PNIPAAm)
- pH-responsive
  - poly(acrylic acid-*co*-acrylamide) (poly(AAc-*co*-AAm)

Multiphoton lithography of PNIPAAm and poly(AAc-*co*-AAm)

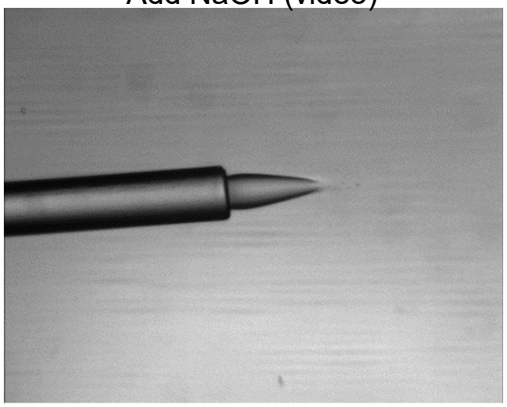


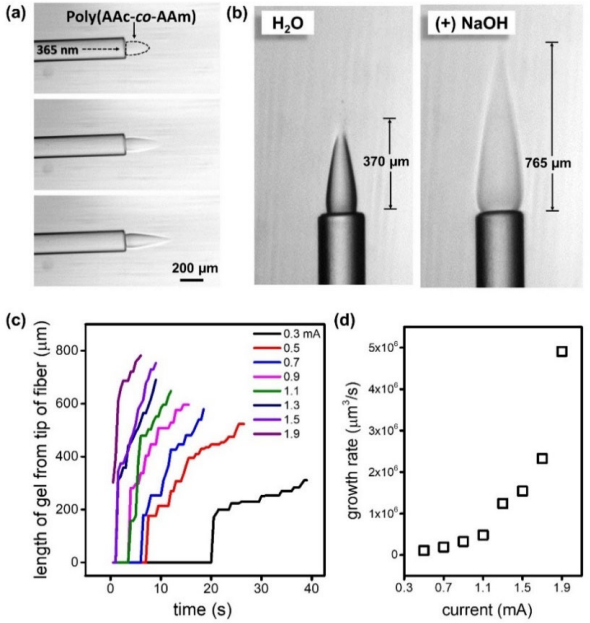
Zarzar, L.D., Kim, P., Kolle, M., Brinker, C.J., Aizenberg, J. and Kaehr, B., 2011. **Direct Writing and Actuation of Three-Dimensionally Patterned Hydrogel Pads on Micropillar Supports.** *Angewandte Chemie*, *123*(40), pp.9528-9532.

UV 'on' (video)

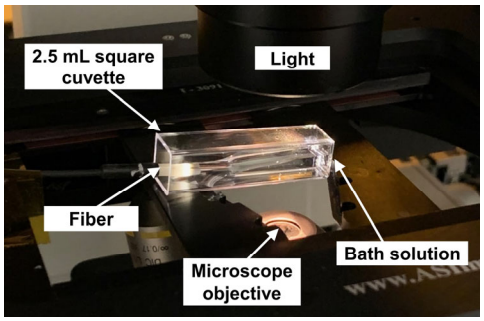


Add NaOH (video)

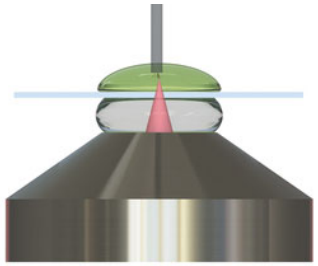




Experimental setup

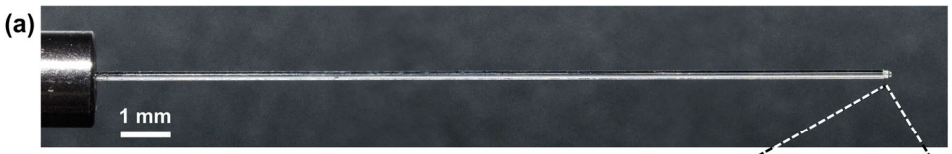


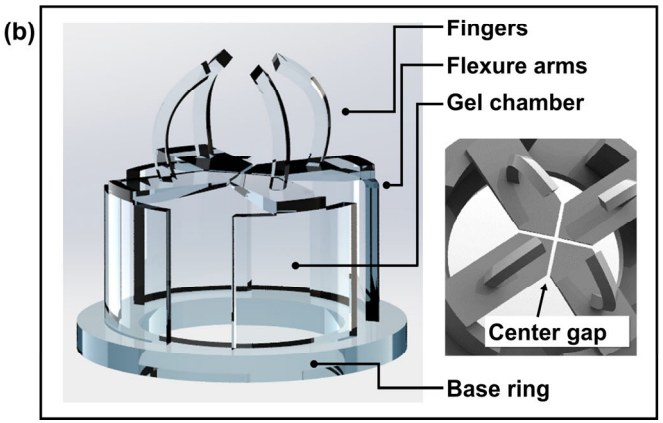
Stiff-soft tethered microgripper

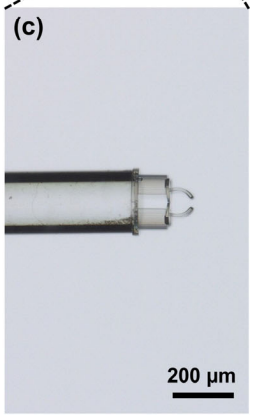


Small, *14*(16), p.1703964.

- 200 µm diameter fiber optic cannulae
- Adhesion to tip by O_2 plasma; silanization in 1% (v/v) 3-(trimethoxysilyl) propyl methacrylate
- Fiber held in a customized device using COTS fiber holder and SLA printed tooling.
- fiber tip was lowered into IP-S photoresin deposited on 25X objective (Nanoscribe GT2)
- Print and develop







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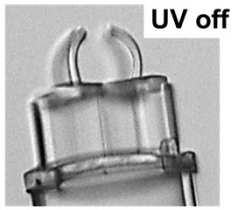
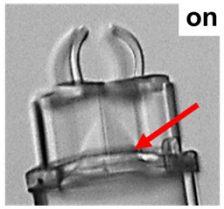
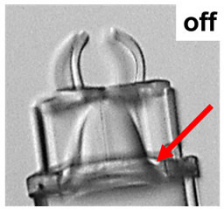
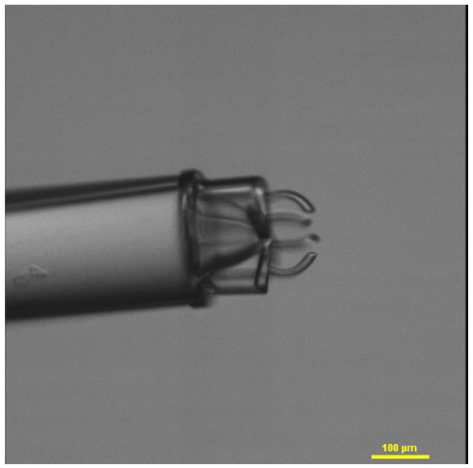


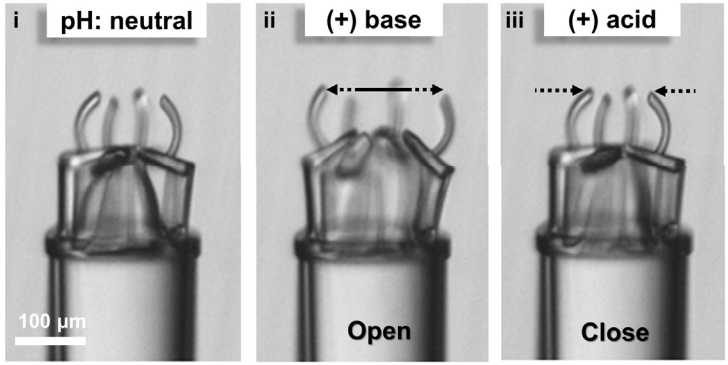




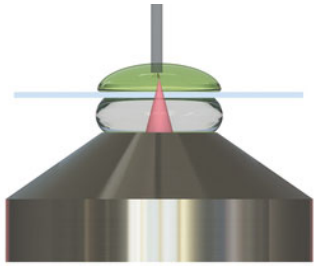
Add NaOH, then HCl (video)



pH induced actuation



Stiff-soft tethered microgripper



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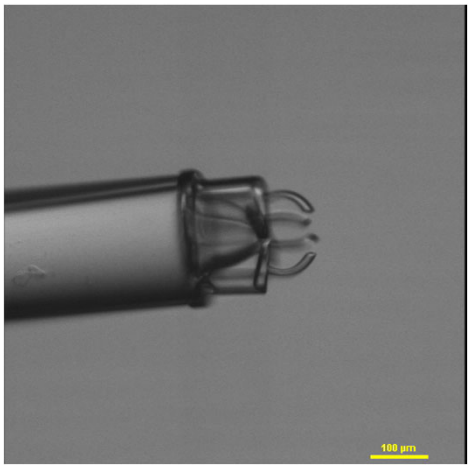
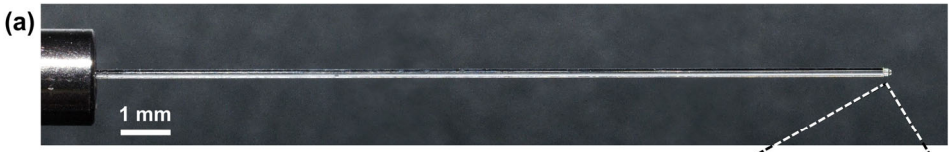
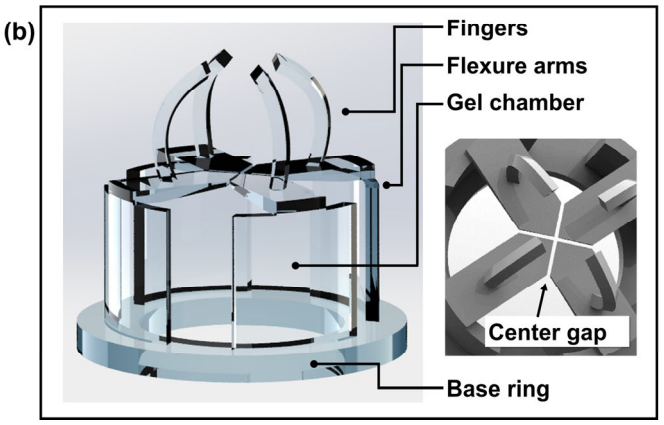
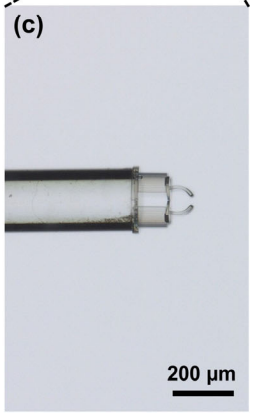
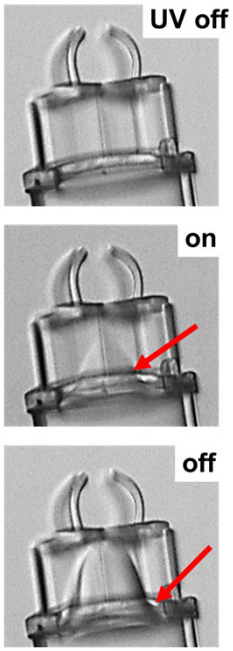


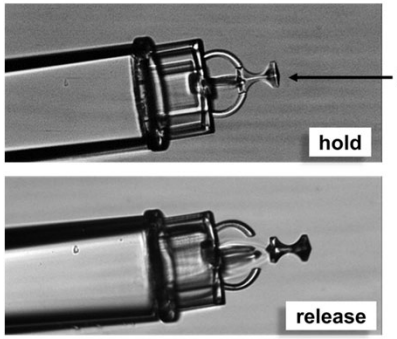


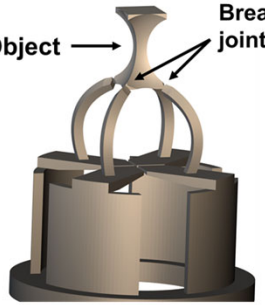






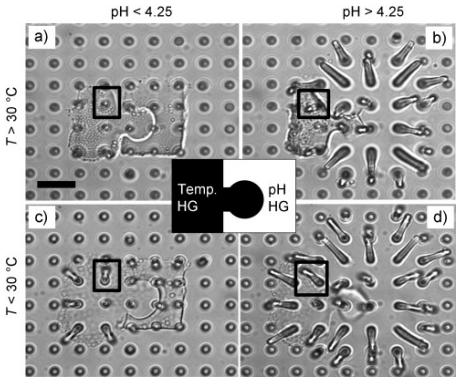
Object manipulation



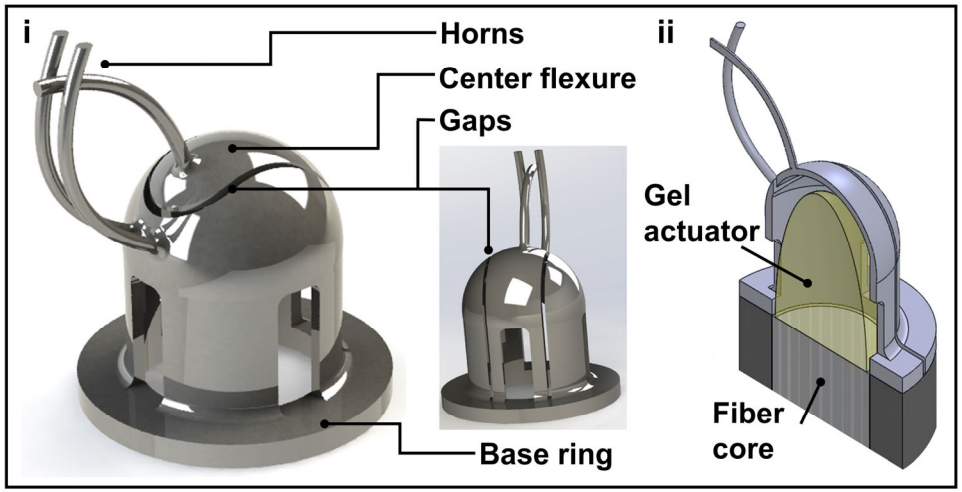


Stiff-soft tethered microgripper (thermal)

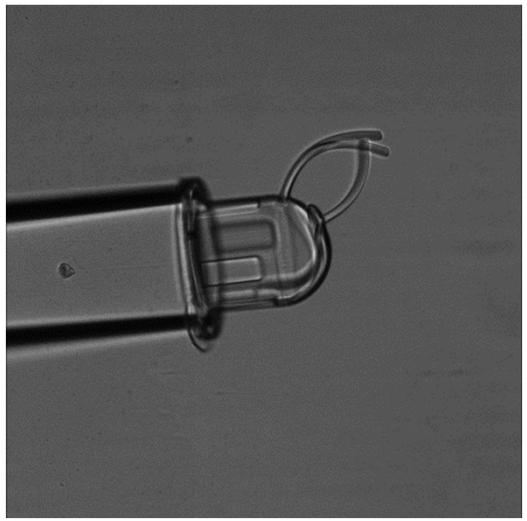
Design considerations for thermal response

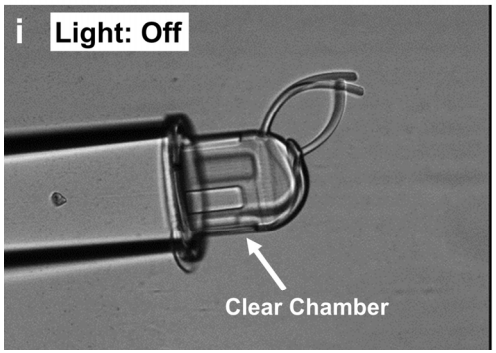


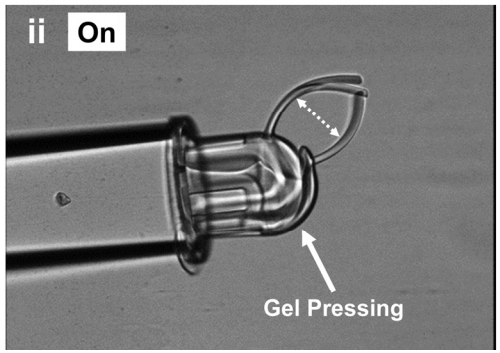
Heat deswells temp HG

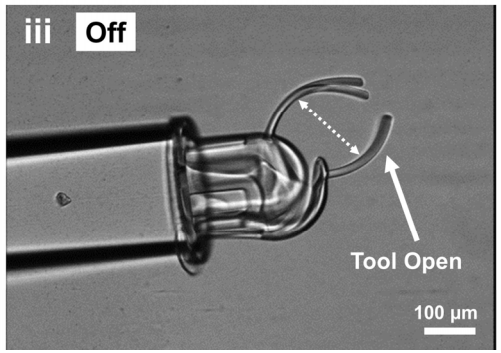


Set gripper span (video)



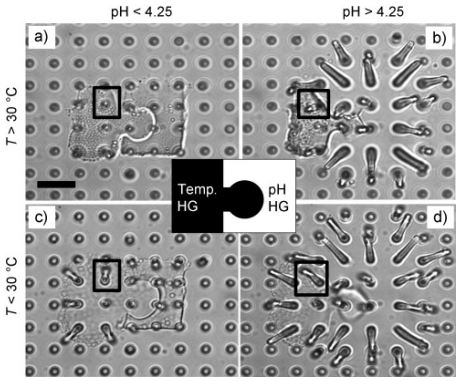




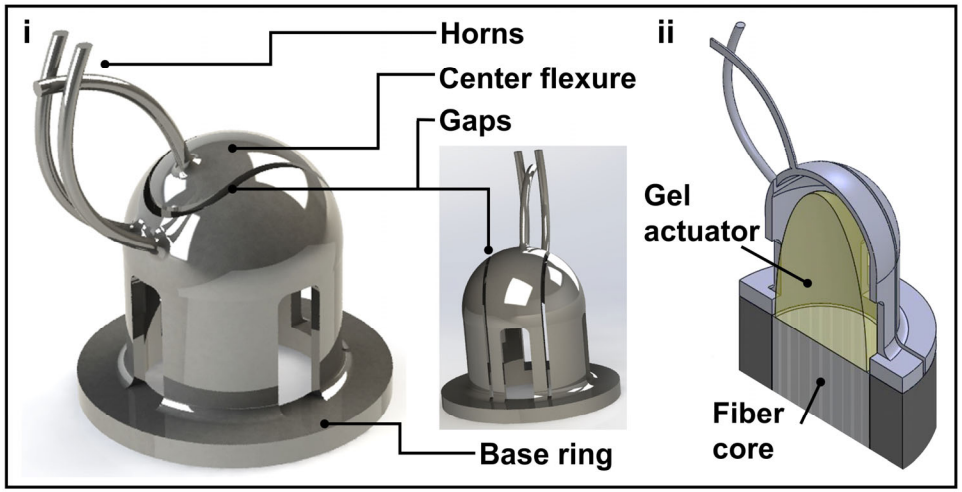


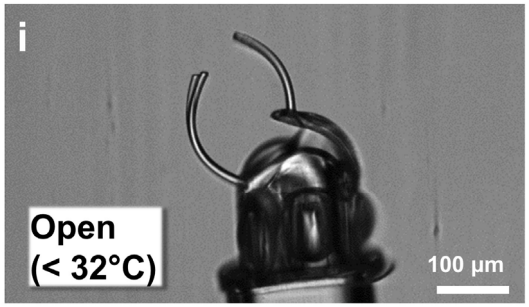
Stiff-soft tethered microgripper (thermal)

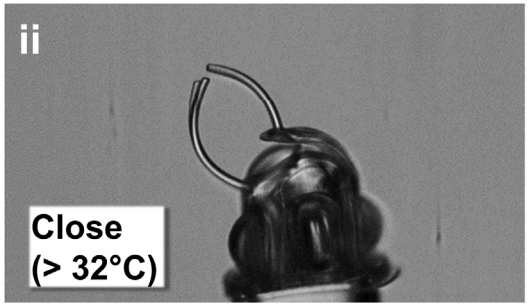
Design considerations for thermal response

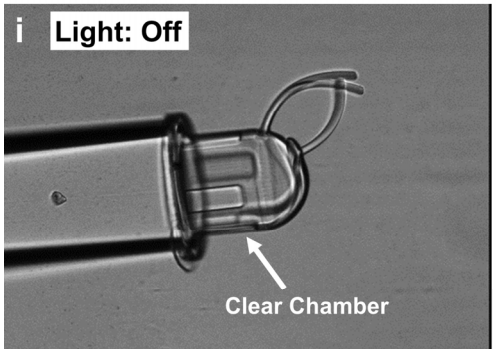


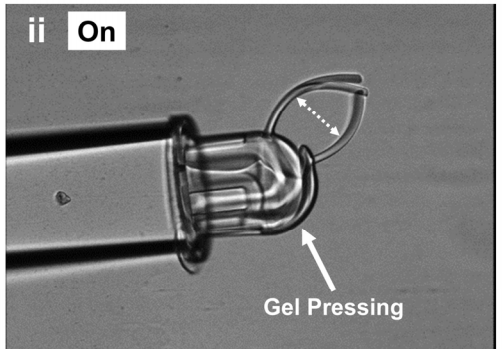
Heat deswells temp HG

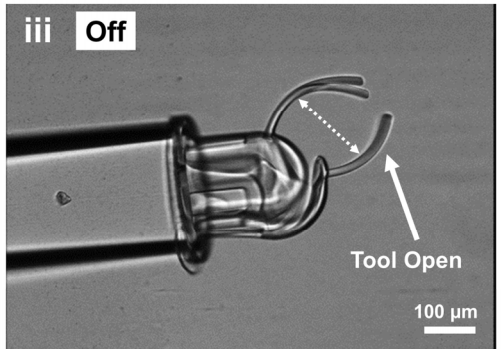






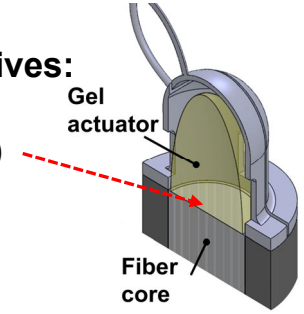


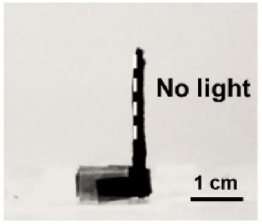


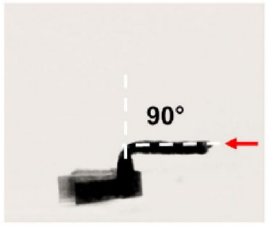


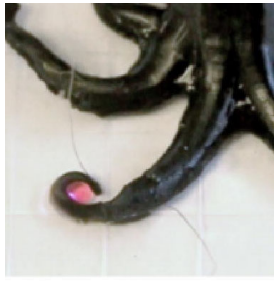
Stiff-soft tethered microgripper (photothermal)

Photothermal gel additives:
Pigments, dyes,
NPs (metal, carbon, etc.)



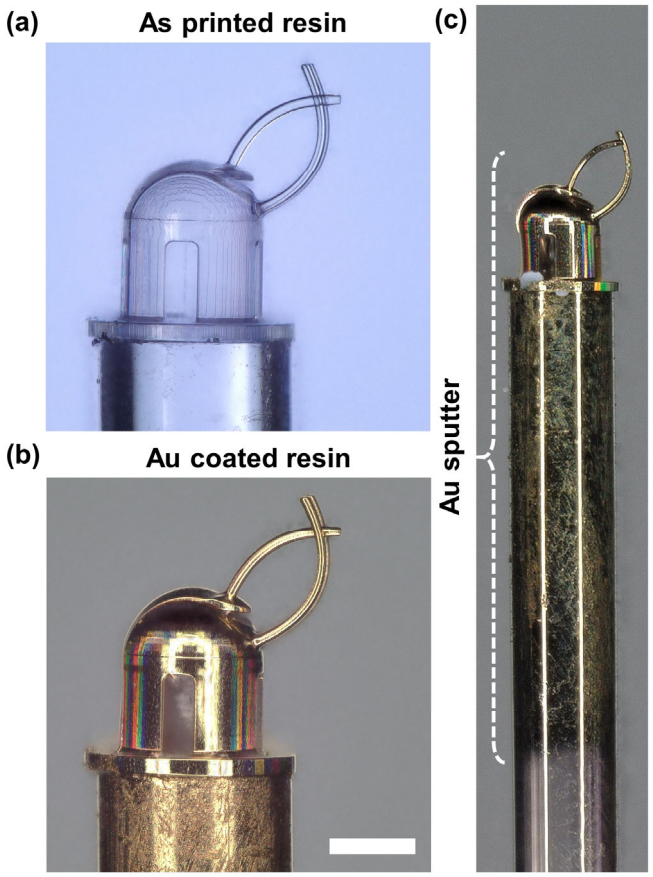


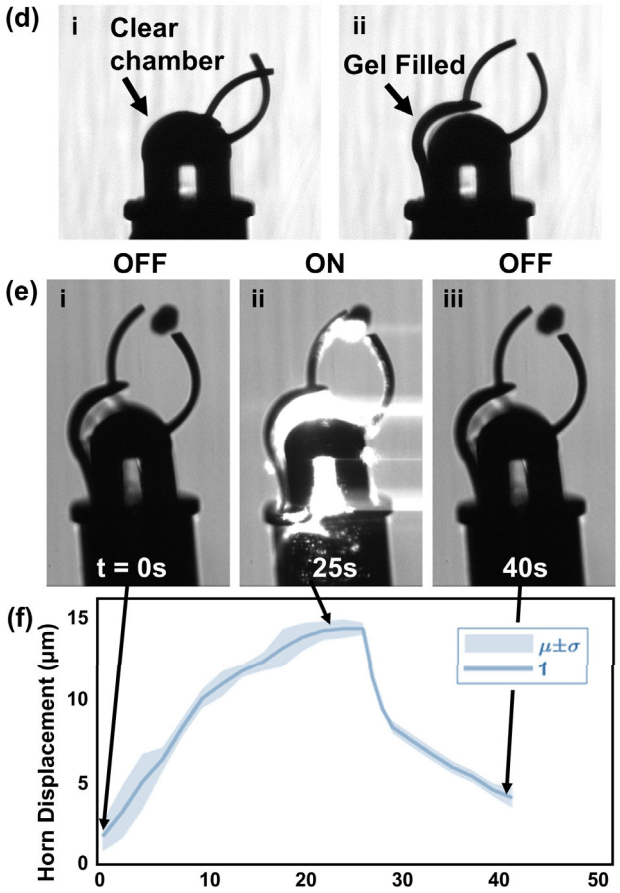




Lo, C. Y., Zhao, Y., Kim, C., Alsaid, Y., Khodambashi, R., Peet, M., ... & **He, X.** (2021). Highly stretchable self-sensing actuator based on conductive photothermally-responsive hydrogel. *Materials Today*, *50*, 35-43.

…or sputter the whole thing

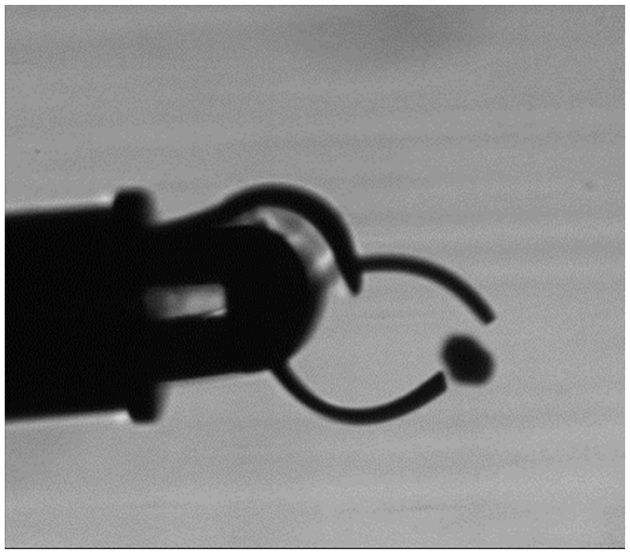


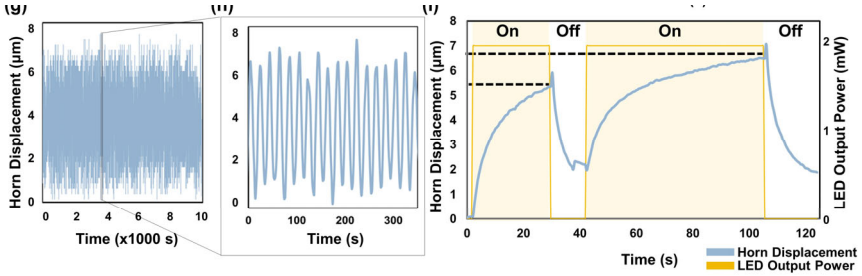


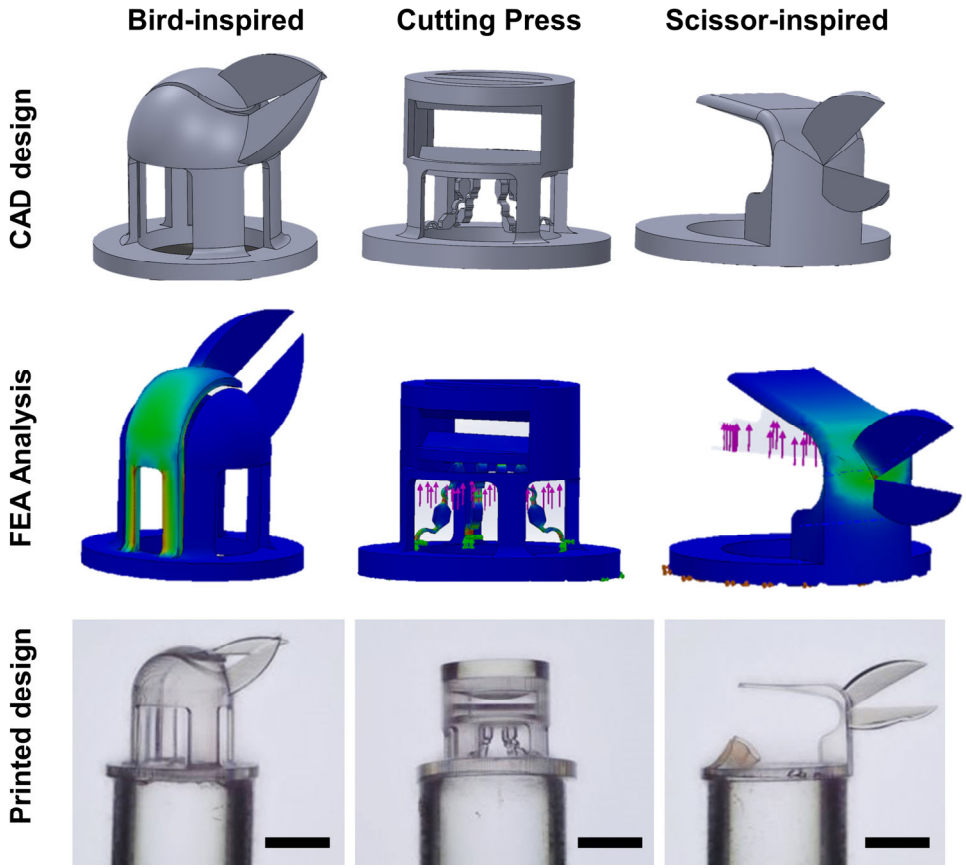
8 mW 4000K correlated color temperature LED

Stiff/soft tethered microgripper: a modular platform

Light induced pinching (video)







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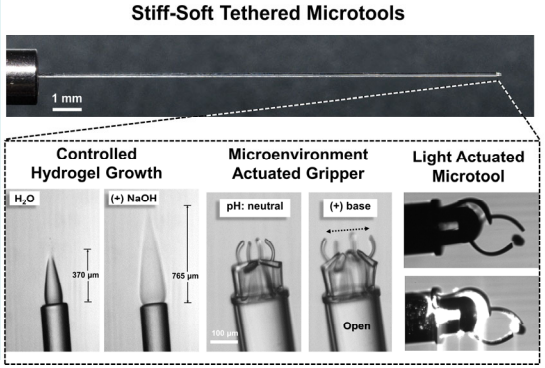
G. Kaufman, J. Jimenez, A. Radecka, A. Bradshaw, M. Gallegos, B. Kaehr, H.M. Golecki, “A Stiff-Soft Composite Fabrication Strategy for Fiber Optic Tethered Micro-Tools”, Advanced Materials Technologies, *Accepted in press,* 2023,



Poster award! (nominee)
Georgia Kaufman and Jorge Jimenez

Sandia National Laboratories

Advanced Materials Laboratory

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