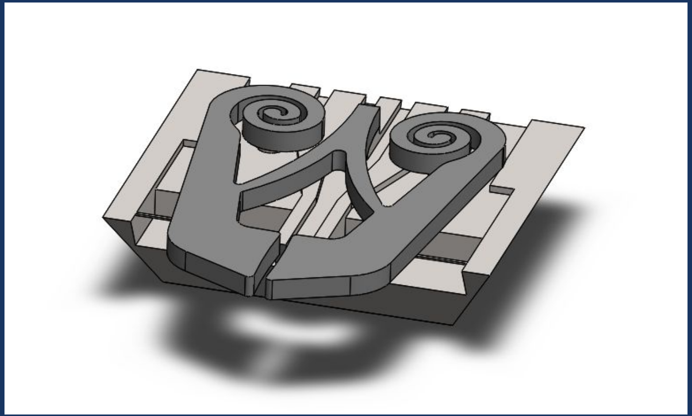
MicroSurgical Suture Device for Targeted Neurovascular Hemostasis with Integrated Hotwire Flow Sensor and Nitinol Actuator

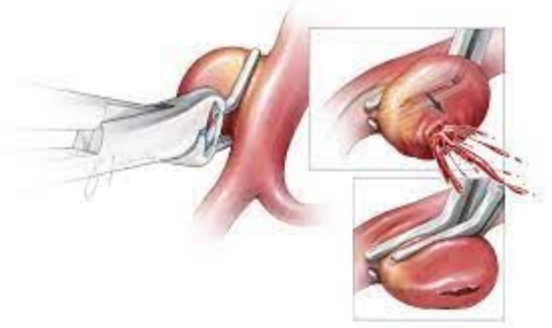
Liam McHugh

Sukhpal Ghotra

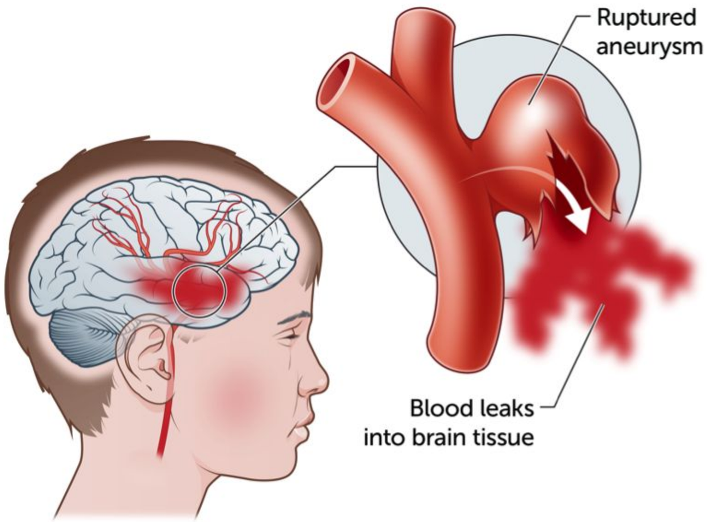
Berkeley
UNIVERSITY OF CALIFORNIA



Problem, System Requirements



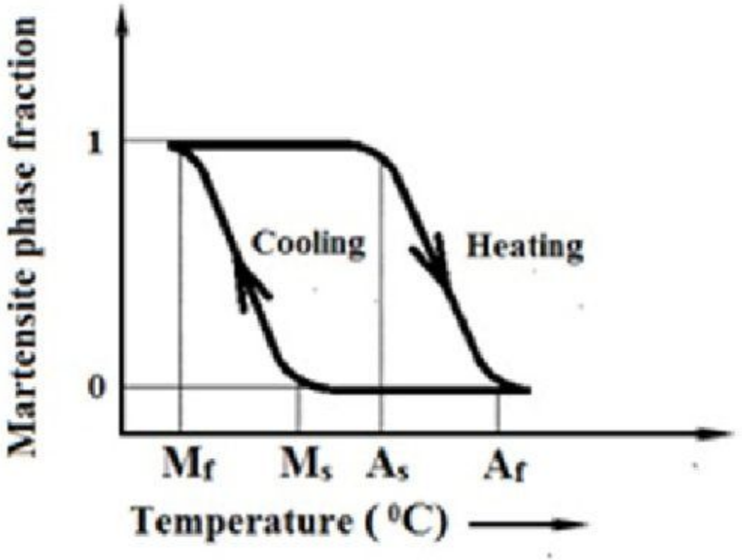
- Prolonged Intracraneal Micro-Hemorrhaging causes brain necrosis
- 795,000 strokes per year in US alone
- Minimally Invasive Surgery, Computational Robotics Developing



Solution Analysis

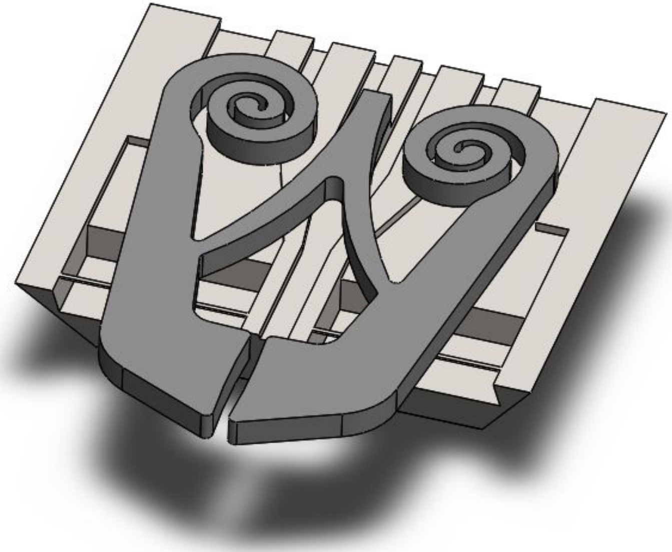
Operating Process:

- Fluid sensor detects precise geometry of blood hemorrhage
- Surgical Harness carries information to Processor, Triggers electrical power to Gripper
- Current flows through actuators > resistive heating > Crystallographic Phase Transition
- Gripper Closes to stitch up the end of the vessel
- Device snaps off at base to disconnect harness/surgical wire



NiTi Transformation Curve (Taha 2015)

Design & Fabrication



Flow Sensor & Nitinol Microgripper

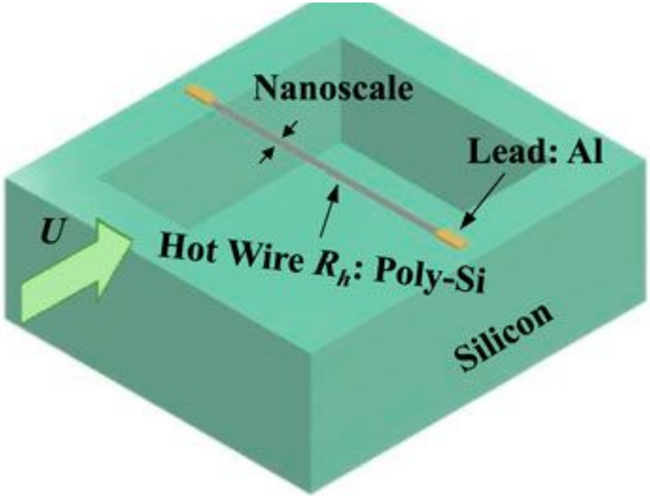
Fabrication Process: CMOS-MEMS

CMOS-MEMS:

- 3 Process - Pre, Intra, Post-CMOS
- Miniaturization and Performance Improvement of structures
- Cost-Effective
    - Sensor and Circuit at same time
- Multiple steps for polysilicon and metal deposition

Post CMOS:

- Nitinol Sputter Deposition
    - Creates the Microgripper
    - Connects it to the surgical harness



Fluid Sensor:
Hot Wire Anemometer

Hot-Wire Flow Sensor Functionality

<u>How Does the Hot-Wire Sensor Work?</u>

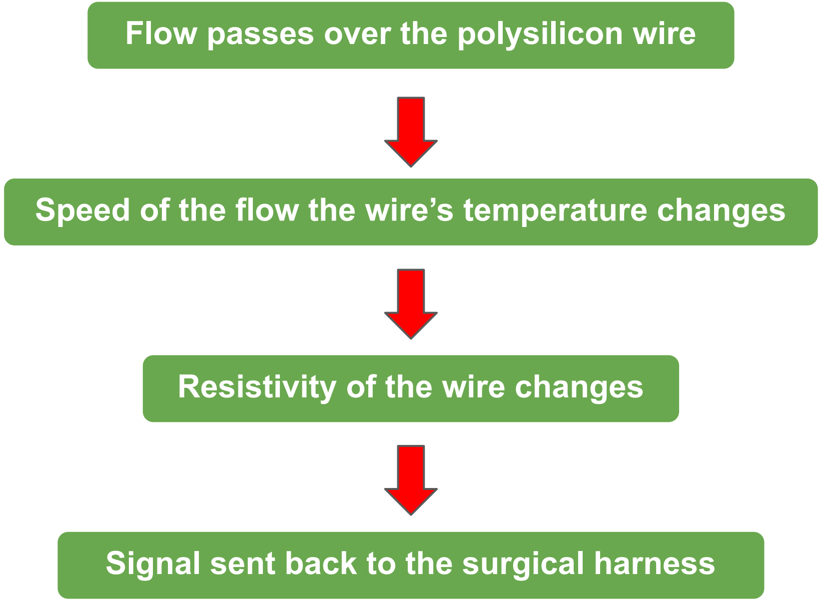
The cooling effect generated by forced convection are used to detect fluid flow

Polysilicon Wire:

- Thermal Coefficient of resistance is high = higher sensitivity
- Higher melting point >800 C
  - Useful when working with deposition of metals with higher melting points

Surgical Harness:

- Connects wheatstone bridge circuit to the nitinol gripper
- Current sent back will trigger current to be sent to the Nitinol gripper



CT Wheatstone Bridge Circuit

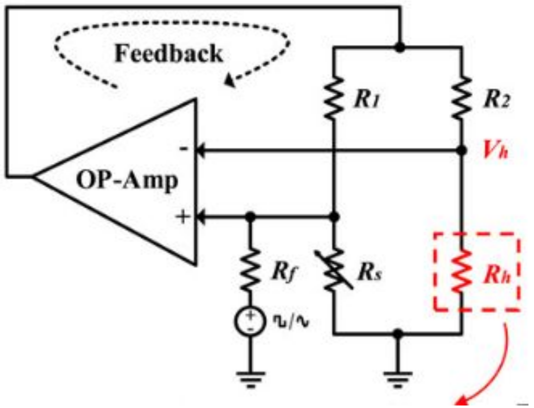
- Fluid flow rate increases over the microheater, the resistance of the hot wire (Rh) decreases due to the cooling effect.

- Changes the voltage difference on input/output ends

- More voltage needs to be fed into the wheatstone bridge, increasing the heating power of the resistor and rebalancing it

- We monitor the power consumption needed to maintain a constant temperature on the hotwire

- Control Temperature (CT):
  - significantly reduce the response time of the flow sensor



- Electrical Configuration:
  - Negative feedback circuit comprising a Wheatstone bridge and an operational amplifier.

- Components in the CT Mode Configuration:
  - The hot wire (Rh), serves as a heater and a sensor, is placed in a quarter bridge. Off-MEMS resistors (R1, R2, and Rs)

Hot-Wire Flow Sensor Fabrication

Pre-CMOS:

Assumption: Rest of Hot-Wire circuit on surgical harness or created separately in the CMOS process. Focusing only on the creation of the MEMS structure using inspiration from CMOS process by GlobalFoundries and MUMPS design specifications

Step 1: .25 um deposition of thermal Oxide on top of SI

a. Etch stop for DRIE release etch later, prevent undercutting

Step 2: .25 um Deposit low stress LPCVD nitride on top of the Oxide

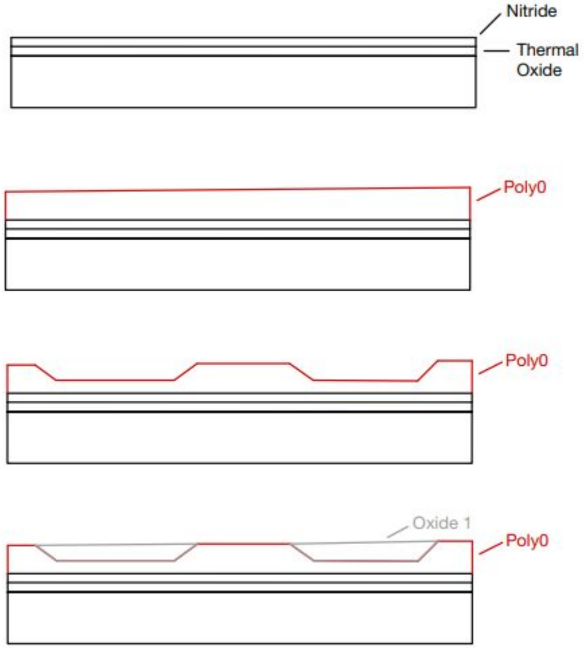
b. Excellent for the high temp electrical passivation and liquid applications

Step 3: 2 um PolySilicon deposition

c. Anisotropic Etching of Poly to get trapezoidal shape
d. Dry etching is fine no need for poly - make it square

Step 4: .75 um Oxide deposition

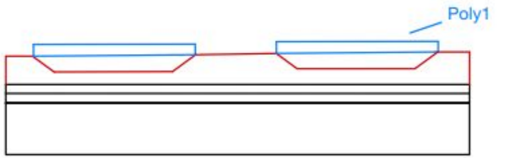
e. Sacrificial layer removed later in HF solution



Hot-Wire Flow Sensor Fabrication

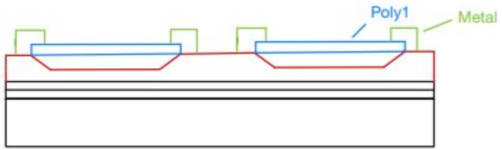
Step 5: .76 um Thin film polysilicon deposition using LPCVD

e. Used as the wire



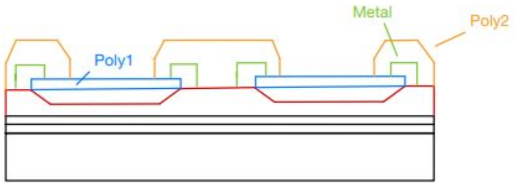
Step 6 : .5 um Metal Layer deposited (Aluminum)

f. Tab the wire, connect it to the rest of circuit



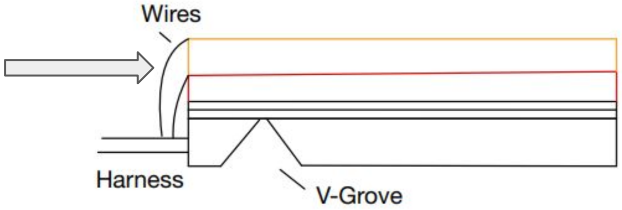
Step 7: 1.5 um Polysilicon Deposition

g. Supports for Nitinol Microgripper



Step 8: Deep Reactive Ion Etching (DRIE) from bottom creating V-Groove up to thermal oxide boundary layer

FIX - Showcase the poly not going over wire

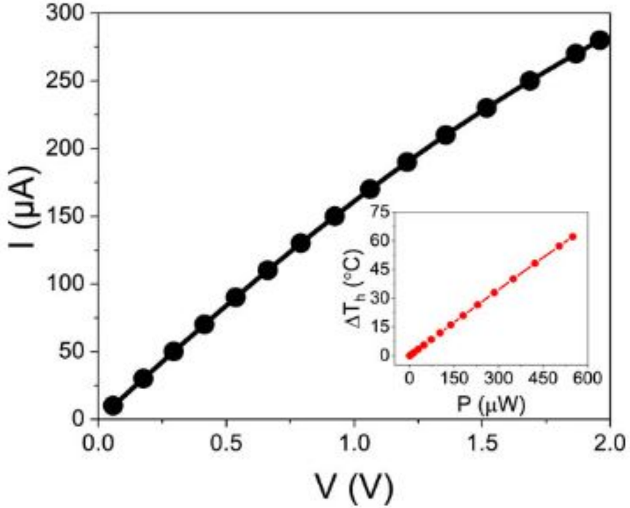


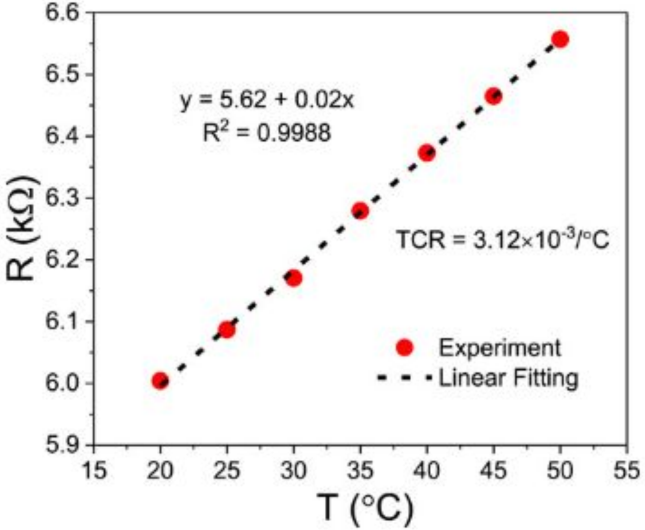
Hot-Wire Joule Heating - Resistivity Feedback Analysis

- Power Exchange between Joule Heating and Wire in Crossflow
- Model: Stable Finite Difference Analysis - @0.8V, 0.75m/s ~85C

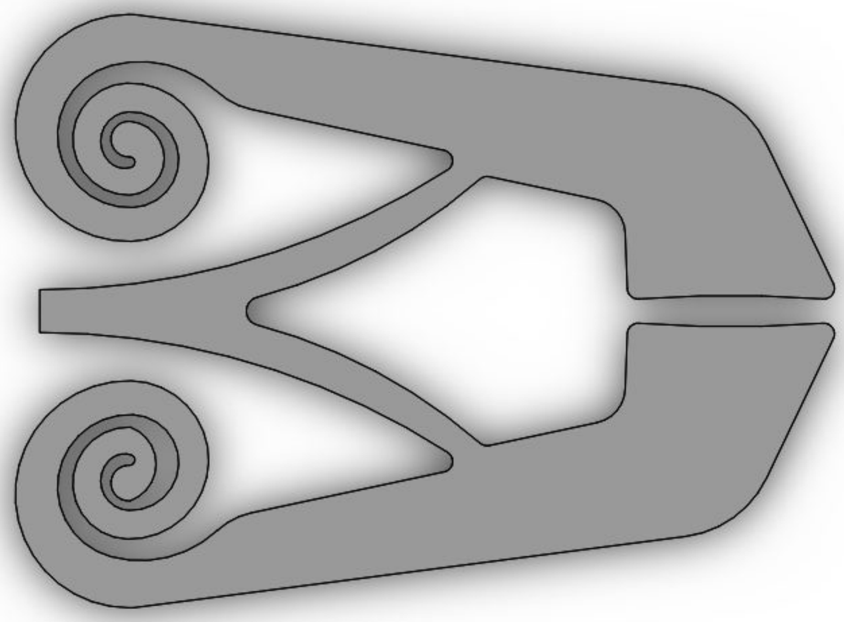
$$\overline{\mathrm{Nu}}_D = 0.3 + \frac{0.62\, \mathrm{Re}_D^{1/2}\, \mathrm{Pr}^{1/3}}{\left[1 + (0.4/\mathrm{Pr})^{2/3}\right]^{1/4}} \left[1 + \left(\frac{\mathrm{Re}_D}{282{,}000}\right)^{5/8}\right]^{4/5}$$

Lienhard (2020)

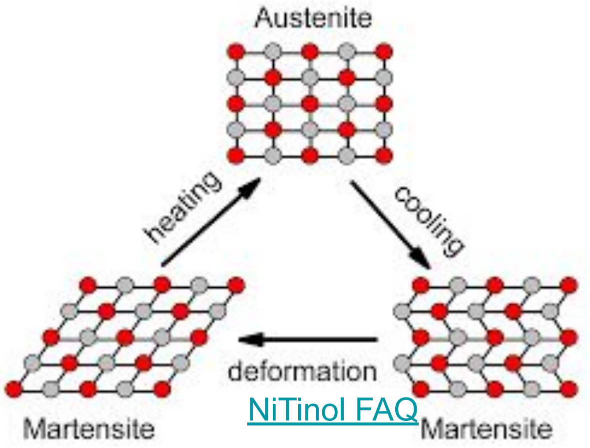




Nitinol-Actuated Clamp



Nitinol Layer Design, Fabrication



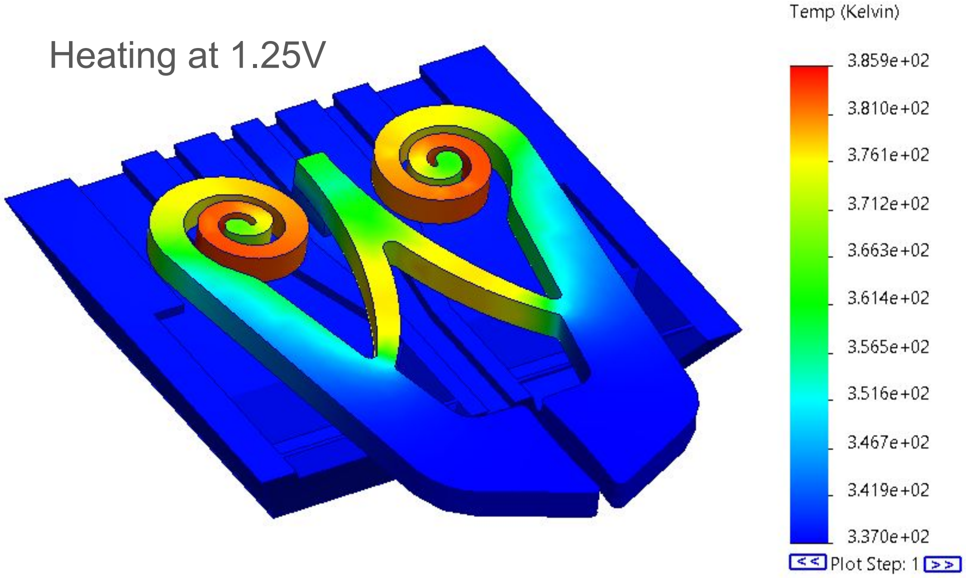
[NiTinol FAQ]

Post-CMOS Sputter Deposition (6um) - Alloying control

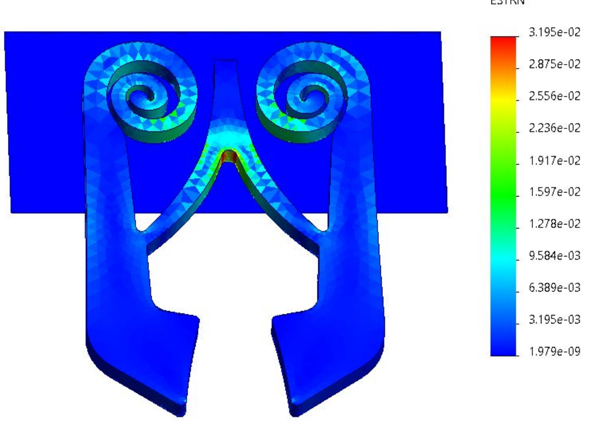
400C Heat Treatment in Closed Position - Phase Behavior Control

Twinned Martensite Structure on Cooling

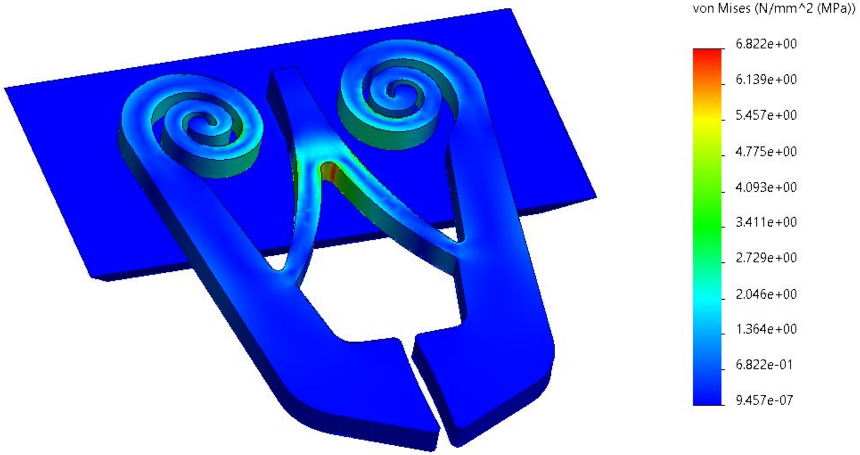
Assumption: Flow Sensor signals the harness to send current directly to the Nitinol, resulting in self-heating and closure



Structural, Operational Analysis

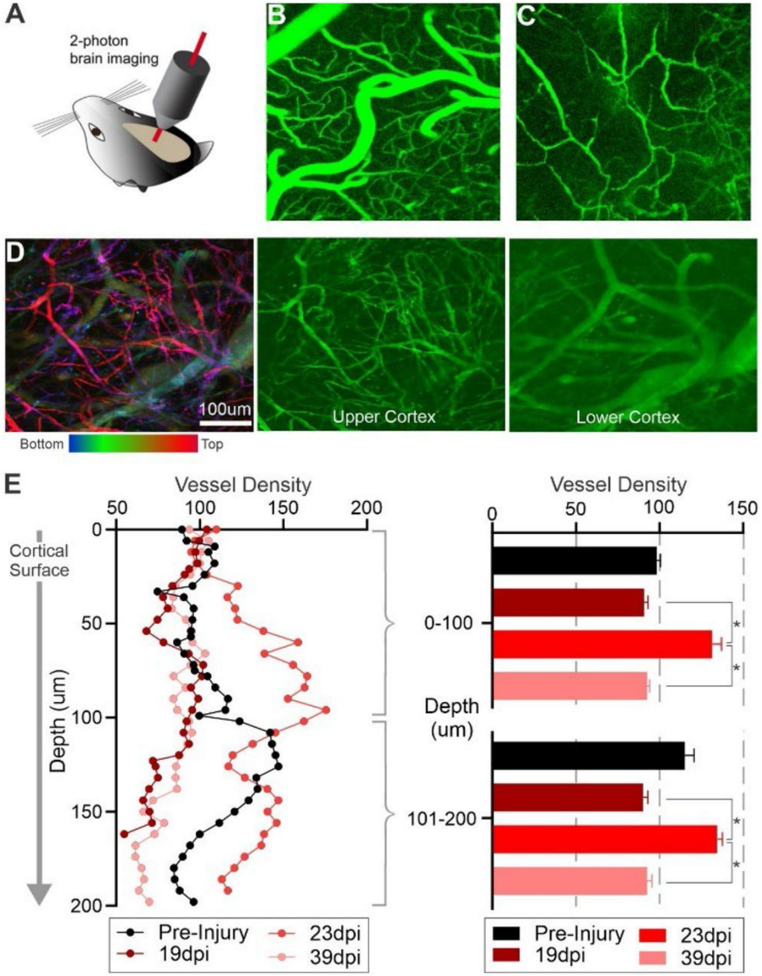


- Martensitic Phase Plastically Deforms below 6% strain
- Easily Withstands Closure Pressures for vessels in the 10-50µm range (10-25kPa)



Further Improvements

- Rigorous Vessel / Aneurysm Operational Analysis
- Coupled Joule Heating - Structural Analysis of Microgripper
- Detailed Hotwire FEM for geometric prediction and transient response



XiaoXiao

Conclusion & Resources

- Wang, Xiaoyi, et al. “A Nanoscale Hot-Wire Flow Sensor Based on CMOS-MEMS Technology.” Frontiers, Frontiers, 28 Mar. 2022, www.frontiersin.org/articles/10.3389/fmech.2022.877754/full.
- Z. Miao, C. Y. H. Chao, Y. Chiu, C. -W. Lin and Y. -K. Lee, "Design and fabrication of micro hot-wire flow sensor using 0.35 μm CMOS MEMS technology," The 9th IEEE International Conference on Nano/Micro Engineered and Molecular Systems (NEMS), Waikiki Beach, HI, USA, 2014, pp. 289-293, doi: 10.1109/NEMS.2014.6908810.
- Qu, H. (2016). CMOS MEMS Fabrication Technologies and Devices. Micromachines 7 (1), 14. doi:10.3390/mi7010014
- Rainer Buchner, Christoph Sosna, Marcus Maiwald, Wolfgang Benecke, Walter Lang, A high-temperature thermopile fabrication process for thermal flow sensors, Sensors and Actuators A: Physical, Volumes 130–131, 2006, Pages 262-266,
- Wang, X., Fang, Z., Song, X., & Xu, W. (2022). A Nanoscale Hot-Wire Flow Sensor Based on CMOS-MEMS Technology. Frontiers in Mechanical Engineering, 8, 877754. doi: 10.3389/fmech.2022.877754
- Khan, L. A., McCarthy, E., Muilwijk, C., Ul Ahad, I., & Brabazon, D. (2023). Analysis of Nitinol actuator response under controlled conductive heating regimes. Results in Engineering, 18, 101047. doi: 10.1016/j.rineng.2023.101047
- Shayan, Mahdis, and Youngjae Chun. (2015). An overview of thin film Nitinol endovascular devices. Acta Biomaterialia, 21, 20-34. doi: 10.1016/j.actbio.2015.03.025
- Pelton, A. R., et al. (2008). Fatigue and durability of Nitinol stents. Journal of the Mechanical Behavior of Biomedical Materials, 1(2), 153-64. doi: 10.1016/j.jmbbm.2007.08.001
- Taha, O.M.A., Bahrom, M.B., Taha, Obai, & Aris, M.S. (2015). Experimental study on two-way shape memory effect training procedure for NiTiNOL shape memory alloy. doi: 10. 7847-7851.
- Mehrpouya, M., and Bidsorkhi, H. C. (2016). MEMS applications of NiTi based shape memory alloys: A review. Micro and Nanosystems, 8(2), 79-91. doi: 10.2174/1876402908666161102151453