National Aeronautics and Space Administration

Micro/Nanofabrication of Bulk Metallic Glass via Thermoplastic Forming

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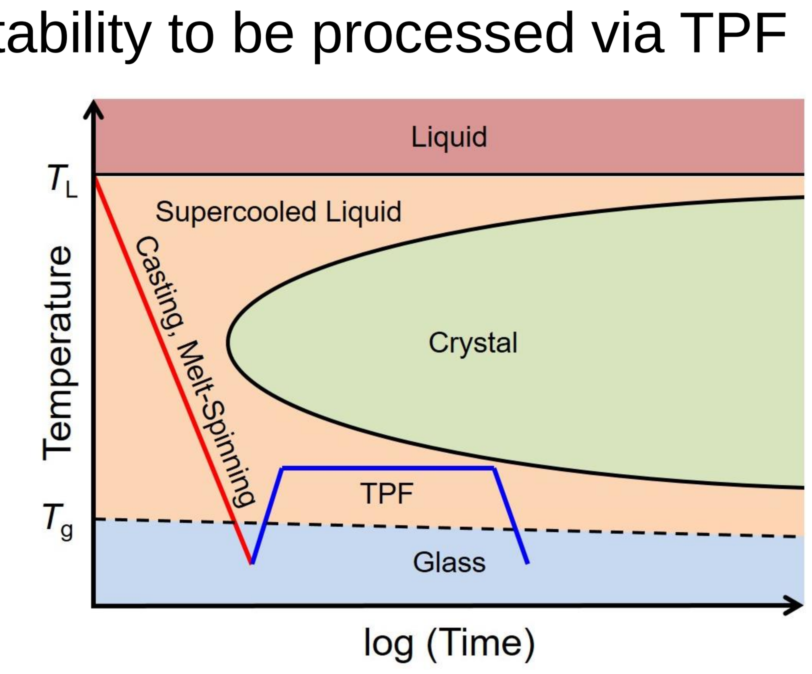
Program: FY 2019 R&TD Spontaneous Concept

Project Objective:

- •JPL has interest in accessing high science return terrain
- •Many of Earths creatures excel at this Current climbing mobility platforms use microspines and Gecko adhesive that are mostly based on polymer systems
- •Flexible polymer compositions are not compatible with space conditions i.e. vacuum, temperature, radiation
- •Mobility platforms based on metallic materials are desired
- •Gecko adhesive structures contain micro and nano-scale features, which are traditionally difficult to manufacture in metal
- •Thermoplastic forming (TPF) of bulk metallic glasses (BMGs) allow for such micro/nanoscale features to be realized
- •Arrays of these structures allow opportunistic perching on surface roughness and beam buckling shares load over many contact points

Background:

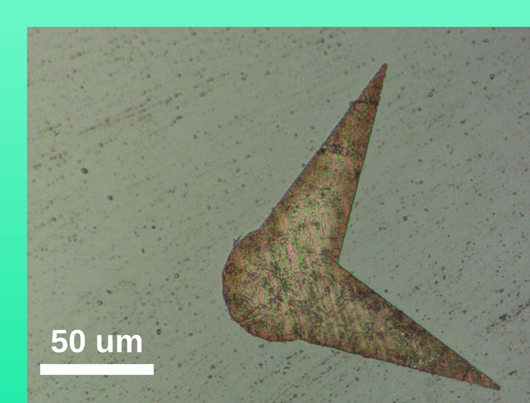
BMGs possess extensive supercooled liquid regions with sufficient thermal stability to be processed via TPF



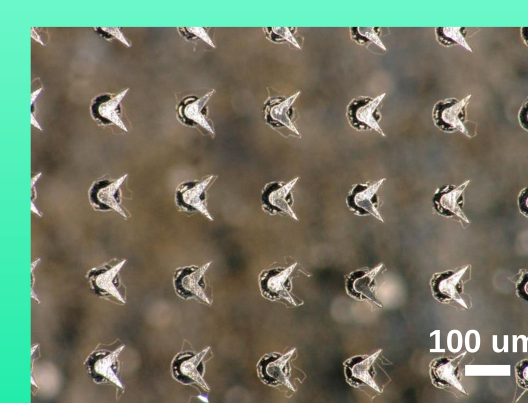
FY18/19 Results:

Robust mold making process using photolithography and deep reactive ion etching (DRIE) on silicon on insulator wafers (SOI) was carried out in MDL cleanroom

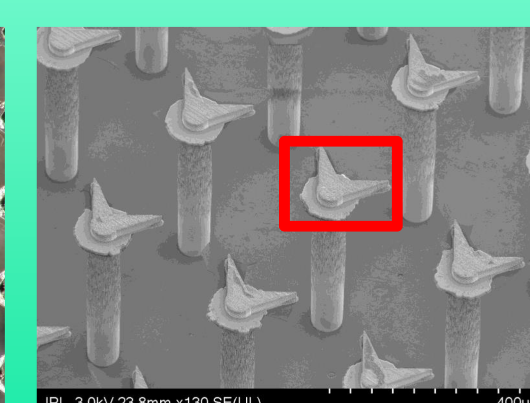
TPF of BMGs have yielded high-fidelity arrays of metallic structures with tips designed to anchor onto surfaces

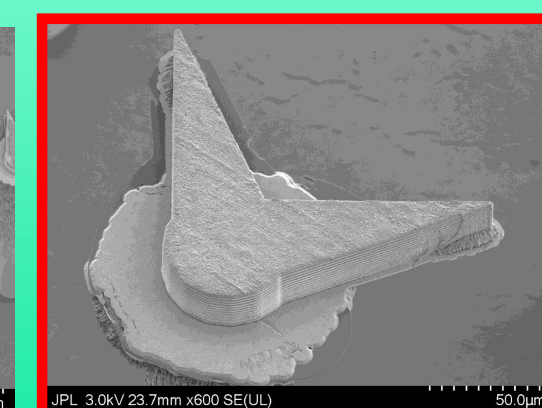


As-molded BMG gripper structure before wafer was dissolved

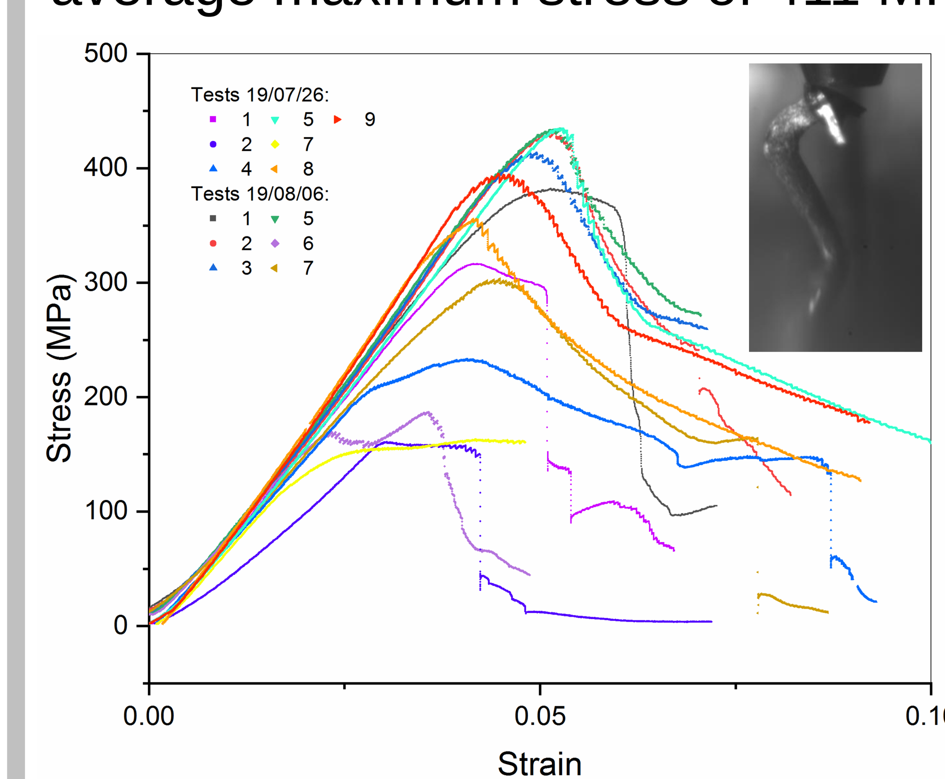


Optical microscope image of the demolded grippers

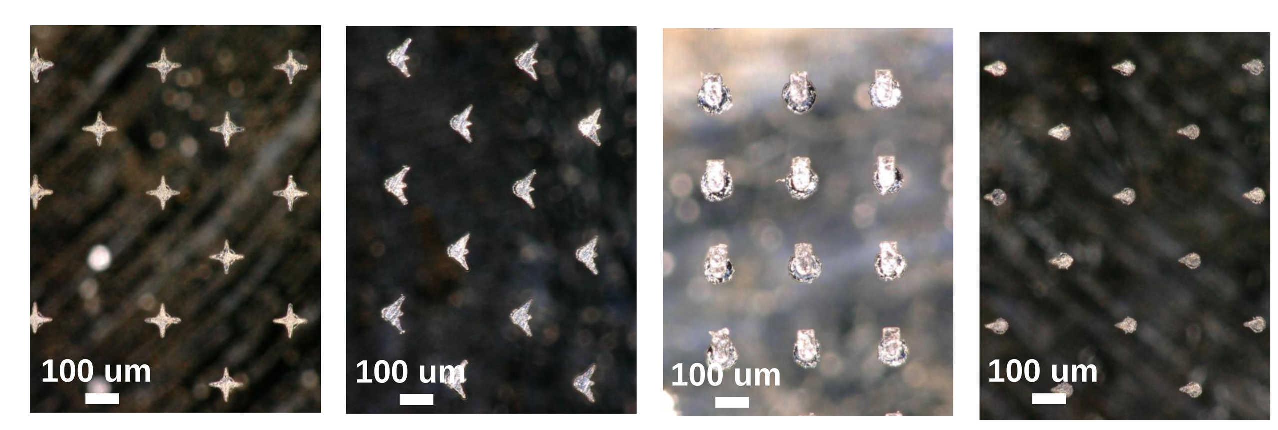

SEM of the molded grippers


Higher magnification SEM showing mold replication resolution

Mechanical testing on individual rods indicated that under compression, the structures fail by buckling with average maximum stress of 411 MPa

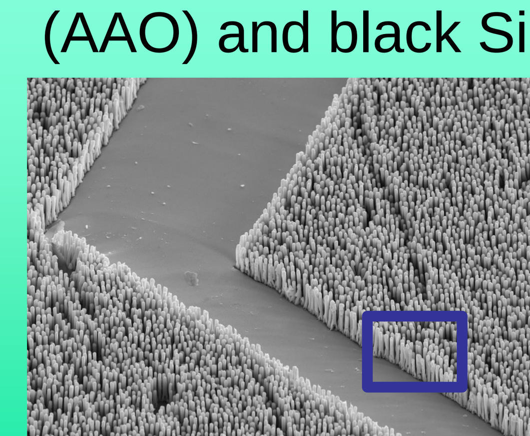


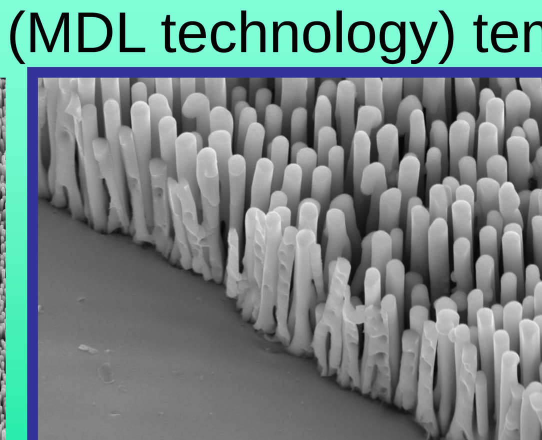
Versatility of silicon micromachining technology allows various gripper tip shapes and packing densities to be fabricated

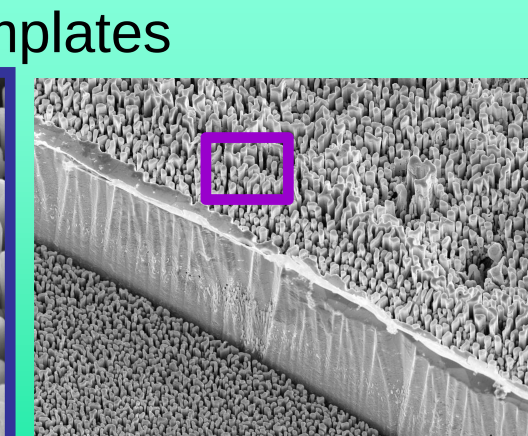


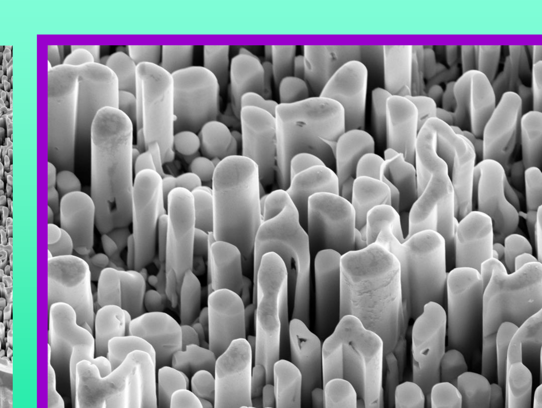
Thin beam features could be fabricated using EDM to machine molds

Nano-scale fabrication was demonstrated using COTS anodized aluminum oxide (AAO) and black Si (MDL technology) templates


SEM of BMG molded into COTS AAO template


Higher magnification SEM of COTS AAO template structures

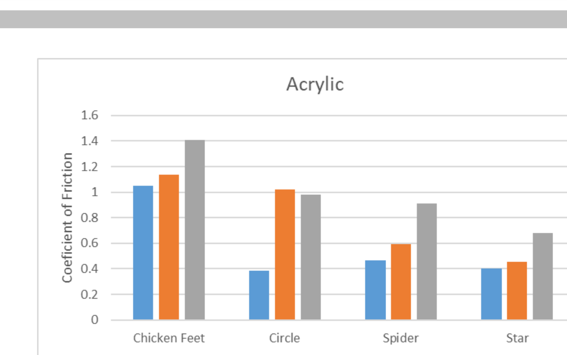

SEM of BMG molded into black Si template, fabricated by MDL

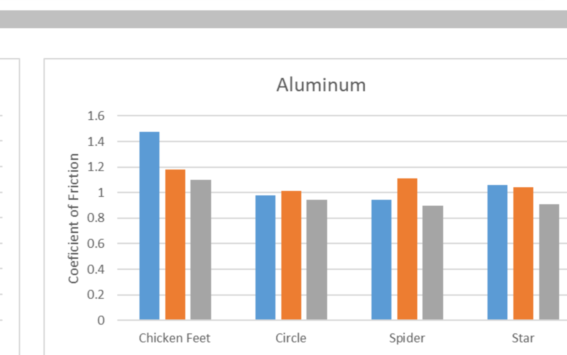

Higher magnification SEM of BMG molded into black Si

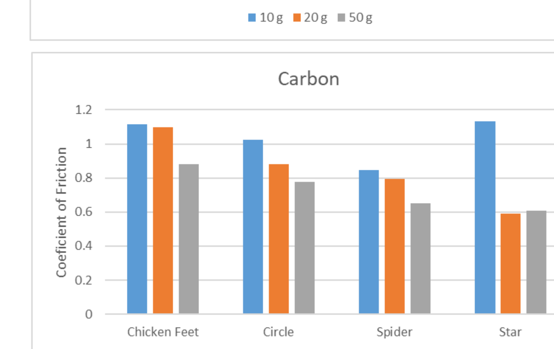
Benefits to NASA and JPL (or significance of results):

The results on the right show up to 1.4 coefficient of friction. This is double a tire on a dry road. While friction is not really an equivalent to this method of resisting slip it give us a common frame of reference to judge it by. that the resistance to slip is more a function of the tip geometry and the beam width then a material or surface dependence. This is demonstrated by the trend of reduced coefficient of friction to increased normal load. Also the similar results across the materials per geometry support this.

If these trends hold, an optimized gripping geometry tip, coupled with the right beam width and length for an array, could yield a perching/gripping mechanism with similar performance across smooth to rough surfaces. This will allow a general solution to a wide variety of problems.







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