Nanocomposites: New Building Blocks for MEMS

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Abstract

Microelectromechanical systems (MEMS) are currently built from silicon, some metals, and a few other materials. Few ceramic materials are available for microfabrication. Contrast this situation with the fact that many revolutionary devices and processes in the macroscopic world involve ceramics and composites. The incorporation of ceramics into microscopic devices would allow the exploitation of novel properties such as increased toughness, high temperature inertness, chemical and biological compatibility, magnetism, piezoelectricity, and photochromism.

In this talk, we will present recent results on the fabrication of functional MEMS microcomponents from ceramic nanocomposites. Our fabrication techniques consist of: 1) micromold fabrication; 2) formulation of a nanocomposite mixture; 3) micromolding. Micromolded components can be produced free standing or assembled on substrates. By using particles a few nanometer in diameters, we are able to mold components with lateral dimensions in the order of a few microns. Microscopy studies indicate that molding of submicron size features should be possible with nanocomposites. This process is compatible with existing integrated circuit manufacturing processes.

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Motivation

Limited number of materials and materials properties currently available for microfabrication

- Silicon and some of its compounds
- Thin (few microns) metal films
- Some polymers
- Thin ceramic films

Research Challenge: To develop microfabrication techniques that introduce materials with novel properties

Answer: Micromolding of ceramic nanocomposites

- Ceramic nanoparticles less than 100 nm in diameter
- Nanoparticles are now readily available
- Variety of materials properties
- Novel properties induced by nanometer dimensions

Ceramic Nanoparticles

Function	Class	Material
Magnetic	Soft	$MnFe_2O_4$
	Hard	$SmCo_5$, NdFeB
Electrical	Insulator	Al_2O_3
	Piezoelectric	$PbZr_{0.5}Ti_{0.5}O_3$
	Ferroelectric	$BaTiO_3$
Optical	Transparent	Al_2O_3
	Photochromic	MoO_3, WO_3
Mechanical	Refractory	Al_2O_3, SiC
	Wear resistant	Al_2O_3, ZrO_2

Ceramic Nanoparticles

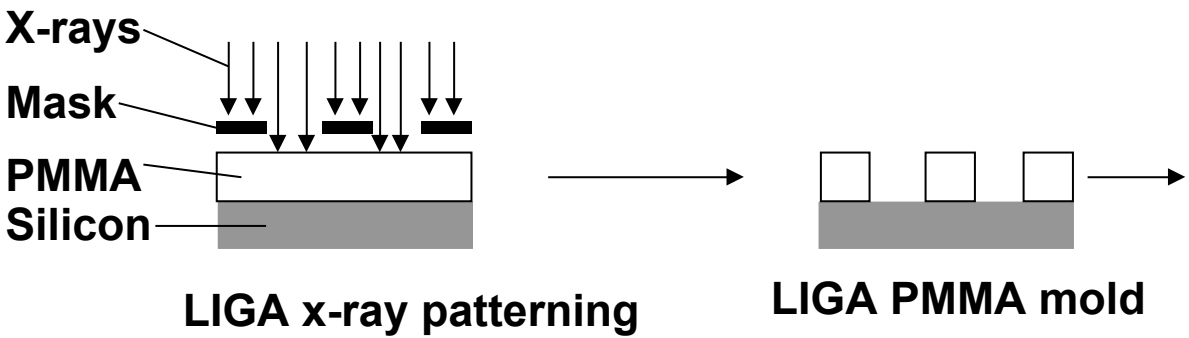
Function	Class	Material
Mechanical	Cutting	Al_2O_3, ZrO_2
	Lubrication	MoS_2
Thermal	Insulation	Al_2O_3, SiO_2
	Radiator	ZrO_2, TiO_2
Chemical	Gas sensor	ZnO, ZrO_2
	Filter	SiO_2, Al_2O_3
Biological	Biocompatible	$Ca_5(PO_4)_3OH$

Experimental Approach

Micromolding of nanocomposites:

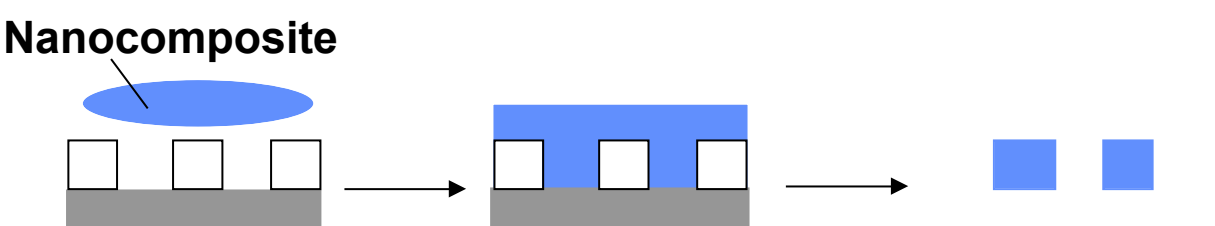
- Fabricate high aspect ratio micromolds with LIGA.
- Develop nanocomposite formulation amenable to micromolding.
- Fabricate micromolds on functional substrates such as silicon and alumina.

Results: High Aspect Ratio Microparts



LIGA x-ray patterning

LIGA PMMA mold

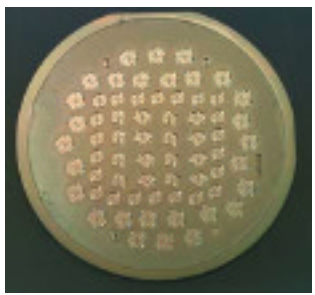


Formulate nanocomposite

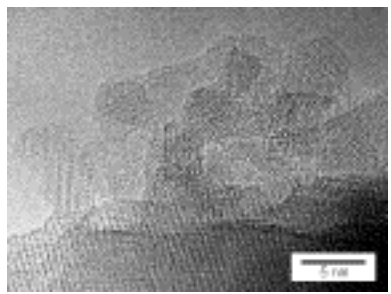
Fill mold and cure

Planarize and demold

Results: High Aspect Ratio Microparts

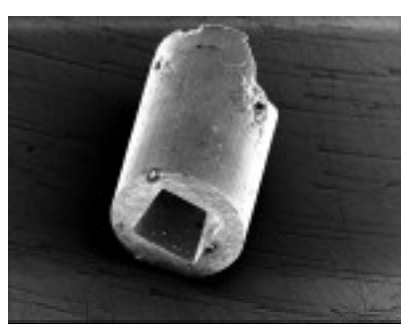


+



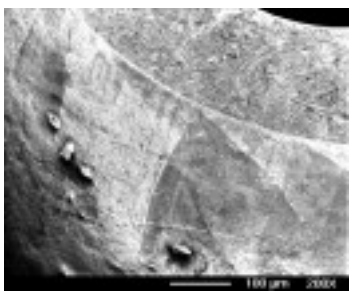
+ 30% w/w Epoxy

LIGA PMMA mold $MnFe_2O_4$ nanoparticles

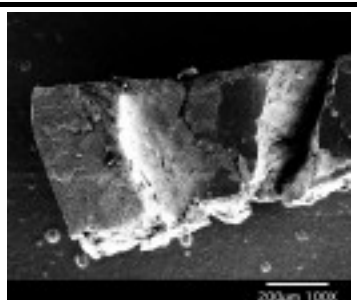


High aspect ratio $MnFe_2O_4$ nanocomposite microparts

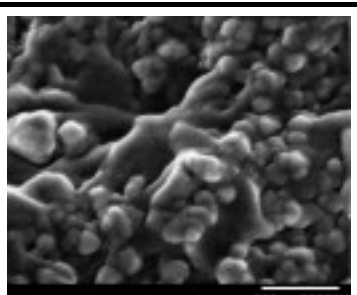
Results: High Aspect Ratio Microparts



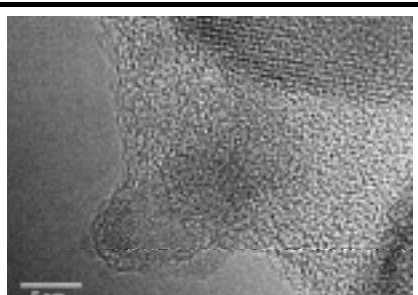
SEM of $MnFe_2O_4$ nanocomposite micropart



$MnFe_2O_4$ nanocomposite micropart used for high resolution studies

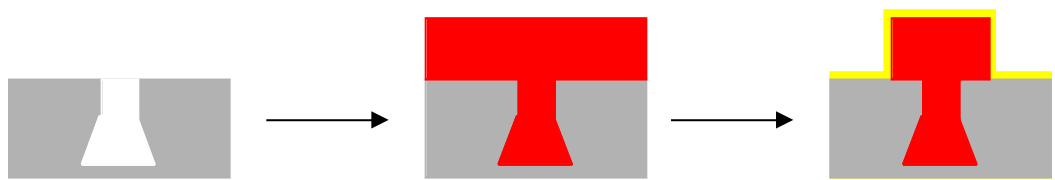


High resolution SEM: nanocomposite aggregates into particles less than 100 nm in diameter



High resolution TEM: $MnFe_2O_4$ nanoparticles embedded in polymer

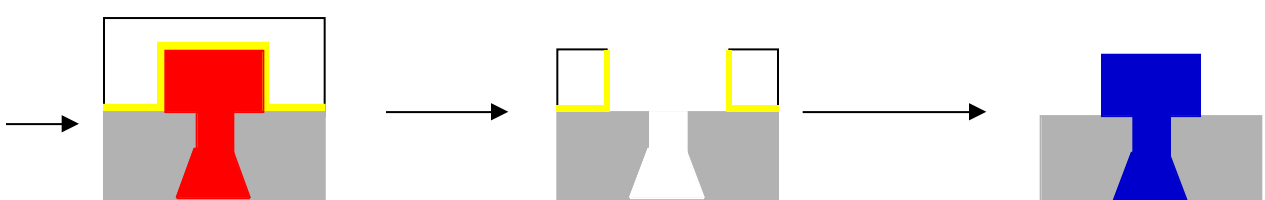
Results: Microparts on Functional Substrates



Etch dovetail into silicon

Cover with photoresist

Pattern micropart in photoresist and seal

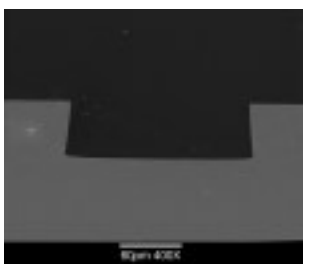


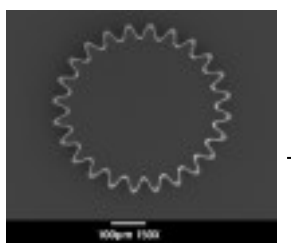
Encase micropart in PMMA

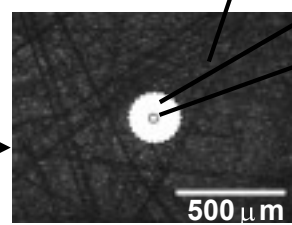
Polish back to reach the top of the photoresist and dissolve photoresist.

Micromold nanocomposite

Results: Microparts on Functional Substrates



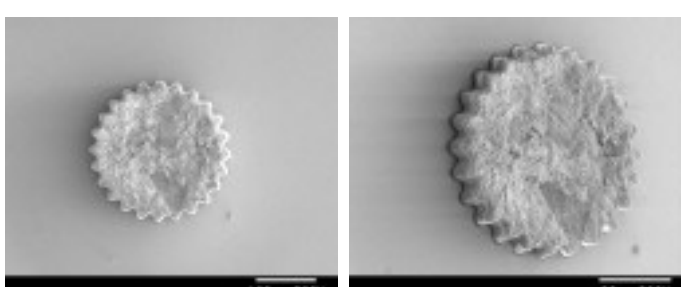




Dovetail in silicon

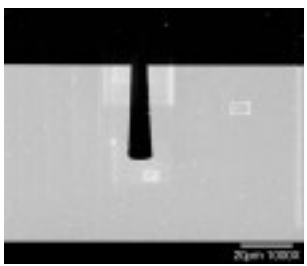
Sealed Photoresist on silicon

Micromold

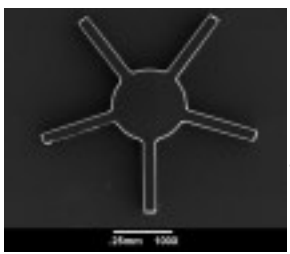


$MnFe_2O_4$ nanocomposite micropart on silicon

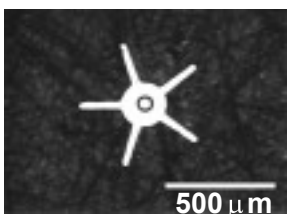
Results: Microparts on Functional Substrates



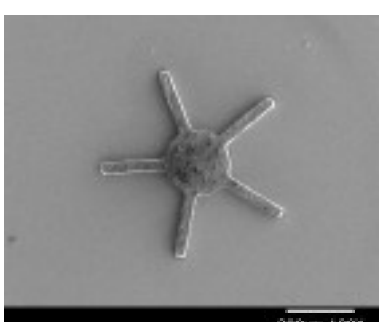
Dovetail in silicon

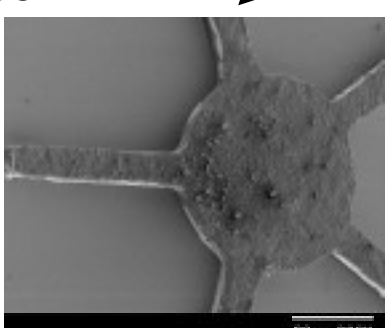


Sealed photoresist on silicon



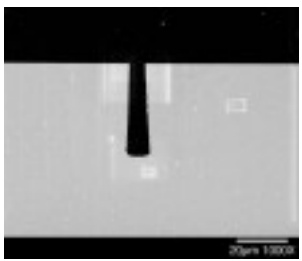
Micromold



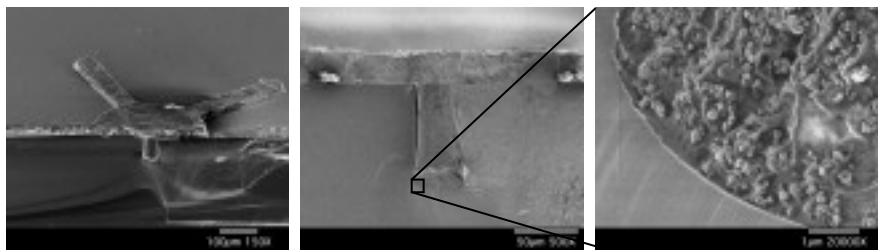


$MnFe_2O_4$ nanocomposite micropart on silicon

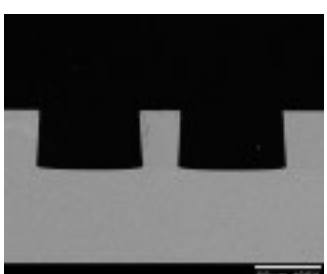
Results: Microparts on Functional Substrates



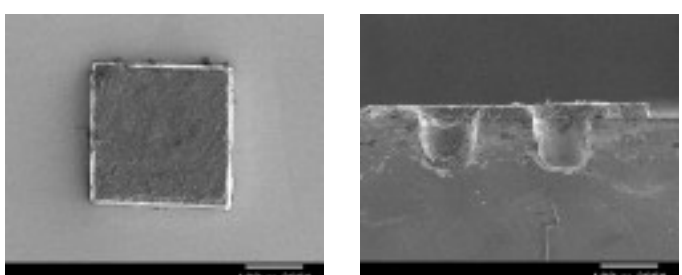
Dovetail in silicon



$MnFe_2O_4$ nanocomposite micropart anchored with dovetail into silicon



Dovetails in silicon



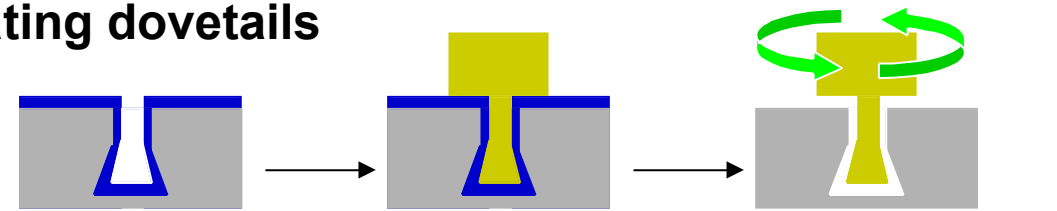
$MnFe_2O_4$ nanocomposite micropart anchored with four dovetails into silicon

Conclusions

- Combined LIGA and micromolding to produce free standing high aspect ratio ceramic nanocomposite microparts
- Combined silicon etching, lithography, and micromolding to produce ceramic nanocomposite microparts on silicon
- Microscopy studies indicate molding of submicron features should be possible with ceramic nanocomposites.

Work in Progress

- Rotating dovetails



- Micromolding other nanocomposites
- Sintered ceramic parts (no binder)
- Characterization
- Looking for collaborators interested in making devices

Thanks to

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Silicon etching carried out at the

UC Berkeley Microlab