PROPRIETARY INFORMATION DO NOT CIRCULATE

COVER SHEET FOR GRANT PROPOSALS

State Board of Education

SBOE PROPOSAL NUMBER: (to be assigned by SBOE)		AMOUNT REQUESTED: **$50,000**	
TITLE OF PROPOSED PROJECT: Biological Testing with MSM Micropump			
SPECIFIC PROJECT FOCUS: Biological testing, Materials Science			
PROJECT START DATE: 07/01/2011		PROJECT END DATE: 06/30/2012	
NAME OF INSTITUTION: Boise State University		DEPARTMENT: Department of Biology	
ADDRESS: 1910 University Drive, Boise, Idaho 83725-1515			
		E-MAIL ADDRESS: greghampikian@boisestate.edu	PI PHONE NUMBER: 208-426-4992

	NAME:	TITLE:	SIGNATURE:
PROJECT DIRECTOR	Greg Hampikian	Professor	[signature]
CO-PRINCIPAL INVESTIGATOR	Peter Mullner	Professor	[signature]
CO-PRINCIPAL INVESTIGATOR			
CO-PRINCIPAL INVESTIGATOR			

	NAME:	SIGNATURE:
Authorized Organizational Representative	Karen Henry	[signature]
	Mary Givens	[signature]

PROPRIETARY INFORMATION DO NOT CIRCULATE

SUMMARY PROPOSAL BUDGET

Name of Institution: Boise State University

Name of Project Director: Greg Hampikian

A. FACULTY AND STAFF

Name/ Title	Rate of Pay	No. of Months CAL	ACA	SUM	Dollar Amount Requested
% OF TOTAL BUDGET:					

B. VISITING PROFESSORS

Name/ Title	Rate of Pay	No. of Months CAL	ACA	SUM	Dollar Amount Requested
Kari Ullakko					26,500
% OF TOTAL BUDGET:				**SUBTOTAL:**	26,500

C. POST DOCTORAL ASSOCIATES / OTHER PROFESSIONALS

Name/ Title	Rate of Pay	No. of Months CAL	ACA	SUM	Dollar Amount Requested
% OF TOTAL BUDGET:				**SUBTOTAL:**	

D. GRADUATE / UNDERGRADUATE STUDENTS

Name/ Title	Rate of Pay	No. of Months CAL	ACA	SUM	Dollar Amount Requested
Aaron Smith					5,000
Doug Kellis					1,500
Laura Wendel					1,500
% OF TOTAL BUDGET:				**SUBTOTAL:**	8,000

PROPRIETARY INFORMATION DO NOT CIRCULATE

E. FRINGE BENEFITS

Rate of Pay (%)	Salary Base	Dollar Amount Requested
29 %	Kari Ullakko	7,613
6 %	Aaron Smith	300
6 %	Doug kellis	95
6 %	Laura Wendel	95
	SUBTOTAL:	8,103

F. EQUIPMENT: (List each item with a cost in excess of $1000.00.)

Item/Description	Dollar Amount Requested
Tools as needed for device design	1,500
SUBTOTAL:	1,500

G. TRAVEL:

Dates of Travel (from/to)	No. of Persons	Total Days	Transportation	Lodging	Per Diem	Dollar Amount Requested
September	2	3	1400	300	300 (total for 2 people)	
					SUBTOTAL:	2,000

H. Participant Support Costs:

	Dollar Amount Requested
1. Stipends	
2. Travel (other than listed in section G)	
3. Subsistence	
4. Other	
SUBTOTAL:	

PROPRIETARY INFORMATION DO NOT CIRCULATE

I. Other Direct Costs:	Dollar Amount Requested
1. Materials and Supplies	1,397
2. Publication Costs/Page Charges	
3. Consultant Services (Include Travel Expenses)	
4. Computer Services	
5. Subcontracts (Fabrication services)	2,500
6. Other (specify nature & breakdown if over $1000)	
SUBTOTAL:	3,850
J. Total Costs: (Add subtotals, sections A through I) TOTAL:	50,000
K. Amount Requested: TOTAL:	50,000
Project Director's Signature:	Date: 5/26/11

INSTITUTIONAL AND OTHER SECTOR SUPPORT
(add additional pages as necessary)

A. INSTITUTIONAL / OTHER SECTOR DOLLARS

Source / Description	Amount

B. FACULTY / STAFF POSITIONS

Description

C. CAPITAL EQUIPMENT

Description

D. FACILITIES & INSTRUMENTATION

Description

HERC PROPOSAL: **Biological Testing with MSM Micropumps**

1. **Name of faculty member directing project:** Greg Hampikian, Ph.D.

2. Name of Idaho public institution: Boise State University

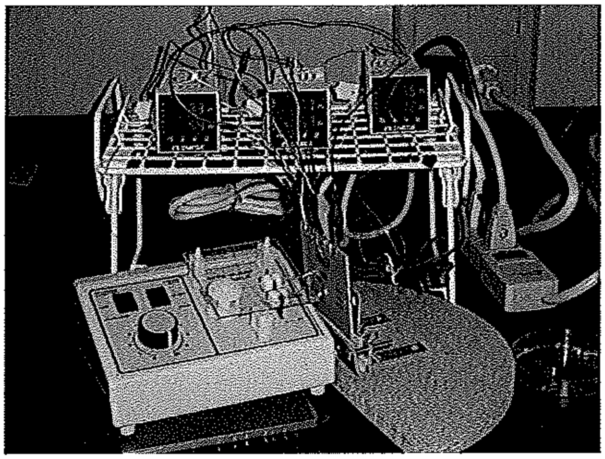


Figure 1. 2007 Miniature DNA Amplification and Bioterror Detection device designed by PI and collaborators in the College of Engineering at BSU (Moeller et al., 2007). The device is the small blue object in the center (about 4 inches square, 1/8 inch thick), the pump is the large white device in the left bottom of the image.

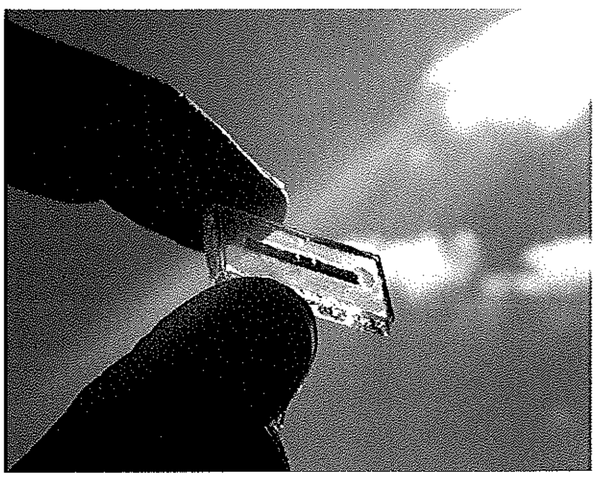


Figure 2. Revolutionary new 2011 MSM pump developed through HERC funding to BSU from March to May, 2011. The actual pump is located between the two dots of light at the rectangle's center, and is powered wirelessly by a surrounding magnetic field.

Executive Summary: Miniaturization of electronic components has revolutionized the field of biological devices. However, building miniature pumps, the most mechanically demanding component of these devices, is proving to be a challenge (figure 1). We have met that challenge by using a remarkable new material, Magnetic shape memory (MSM) elements, that contract and expand in changing magnetic fields. Our wireless micropump (figure 2) mimics biological pumps, and eliminates most of the mechanical elements found in competing technologies.

MSM elements are a new type of crystal that grows in relation to the surrounding magnetic

field, thus providing the expansion and contraction required to move fluids and gases within tiny instruments. Our proposal combines the biotechnology and materials expertise at Boise State University, with the device development strengths of a leading US technology manufacturer, Lockheed Martin. Lockheed Martin, which has signed a NDA with the PI, is developing small biosensors which require micropumps for point of care and portable field analysis. The applicants are preparing a patent application for the general principle of creating local shape-changes in MSM material elements using local magnetic field pulses. This Patent is expected to cover major part of the future micromechanical MSM applications in microfluidics, electronics, and optics. We have also started a new Idaho company, Response Magnetics, Inc. to develop and manufacture MSM devices.

Funds are requested to support a research scientist Dr. Kari Ullakko, an engineering research assistant, and a biological technician. Dr. Ullakko is working with the other investigators to develop more efficient micropumps that will be used in devices such as those made by Lockheed Martin, with initial applications in forensic DNA analysis and drug detection. All of these devices are being developed at BSU, or in collaboration with BSU researchers. Funding of this proposal will establish Idaho as a center of this important emerging technology. Taking into account the large commercial potential of MSM technology (over $20 billion /year), Response Magnetics and its partners national partners have the potential to grow into a remarkable employer in Idaho.

3. "Gap" Project Objective: Design and construct micropumps for biological testing based on MSM materials. **Total Amount Requested: $50,000**

4. Description of how resource commitments reflect the priorities of the home institution

In 2010, Boise State University began an accelerated program to further the expertise of BSU in MSM materials development, and to speed up technology transfer of biological applications of this material. Mary Givens the Director, Office of Technology Transfer at BSU, Hampikian (Professor of Biology) and Mullner (Professor of Materials Science and Engineering) each contributed funds from existing programs to bring Dr. Kari Ullakko from Finland to BSU. Dr. Ullakko discovered MSM materials while at MIT, and had formed the world's fist MSM company. With Dr. Ullakko at Boise State, Idaho is now positioned to become a world leader in product design and production using MSM materials.

The University has dedicated significant resources to facilitate development and industrial partnerships to exploit this technology. Hampikian and Mullner joined the BSU faculty in 2004, and have a patent pending on power generation technology using MSM elements. Mullner has two further MSM-related patents with BSU. These patent application and Dr. Hampikian's work in miniaturizing DNA amplification technology led to the industrial research collaborations which are at the heart of this proposal. The University has been working with Mullner and Hampikian to develop novel uses of MSM materials in biological pumps, power generation, electronic memory and other applications for the past five years.

This proposal would be the first corporate/BSU partnership to fund research aimed at solving a significant industrial problem using MSM technology developed at the university. The groundwork for this collaboration has been laid over the past year, with non-disclosure agreements and meetings between PI Hampikian and researchers from Lockheed Martin corporation, and Idaho based SOS International. Both companies are developing miniaturized biological assays which require micropumps. SOS International has an alcohol sensing anklet (Fig. 3) used by law enforcement that is being currently being considered by Idaho law enforcement agencies, and Lockheed Marin has a forensic DNA profiling device that has been in development for two years and is near production. Current funding for Dr. Ullakko at BSU will run out in July, and funding of this proposal will allow this important work to continue through. After this project has ended Dr. Ullakko will start leading MSM product development in Response magnetics.

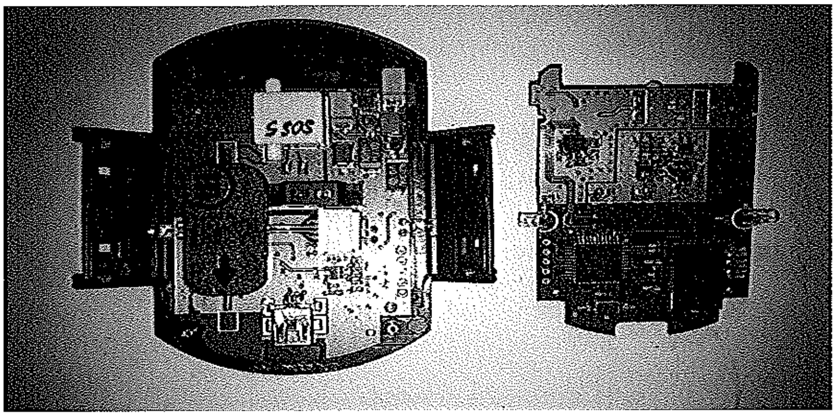


Figure 3. Inside of the SOS International alcohol sensor with GPS monitor. Component labeled M is the current pump which would be miniaturized by the MSM pump element being developed at BSU.

5. Evidence that the project will have a potential impact to the economy of Idaho

Lockheed Martin corporation is one of the largest employers in the United States, and one of the world's largest technology development corporations. Lockheed has recently started to produce portable DNA analysis units, and are developing a new product line featuring portable, point of care diagnostics. Through an NDA with the PI, BSU and Lockheed have begun discussions about incorporating BSU-developed micropump technology in new micro diagnostics.

The PI has also established a collaboration with SOS Inc., which makes monitoring anklets. There are 4 million people in the US alone that are currently on probation, and nearly all of them are required to abstain from drugs and alcohol. There are 1.5 million DUI arrests in the US per year, and there were nearly 11,000 alcohol related traffic deaths in 2010. Strategic Observation Systems Inc (SOS) headquartered in Meridian, Idaho, produces an alcohol sensor with GPS that requires a miniature pump.

SOS uses a piezoelectric based pump imported from Great Britain. Response Magnetics (RM) is a Boise based company formed to facilitate the transfer of technology from Universities to the private sector. This project proposes to complete the design of the MSM micro-pump at BSU, and for RM to use the BSU design to manufacture commercial quantities of the MSM micropump. BSU would earn royalties, and manufacturing jobs would be added to Idaho.

The benefit to the State of Idaho is directly proportional to the number of micro-pumps sold. Approximately 10-20 jobs are expected within the first 2 years. In addition, the production of MSM micropumps would establish the MSM industry in Idaho. Employment in this industry is expected to follow the same pattern as the semiconductor industry of the 1960's and 1970's.

6. Specific Project Plan and Detailed Use of Funds with Timeline

6.1 Identify specifications, tolerances and work expectations of the pumps required for the first commercial applications. We will work with industry partners in the final design of micropumps for their specific applications including:

- dimensions and articulations, to match other components
- dosing accuracy per pumping cycle
- pumped volumes per second, application cycle, and lifetime
- maximum operating and storage temperatures

6.2 Develop high-quality MSM elements: We will grow single crystalline Ni-Mn-Ga alloys and make MSM elements from those crystals. We will characterize the performance of the MSM elements before and after a high number of magnetic field cycles.

6.3 Seal the MSM element: Sealing the MSM element is a key issue for pump success. We will use the polishing facilities used for silicon wafers at BSU. The sides of the MSM element must be sealed with elastic materials to avoid cavitation and turbulent flow. We will test several elastic resins, and select the one which exhibits the highest bonding to the MSM material (Ni-Mn-Ga alloy).

6.4 Coat of the elements for biocompatibility: We will have the MSM elements coated with elastic polymeric and ceramic (TiN, SiC) coatings. Durability and biocompatibility of those coatings will be studied before and after cycling. We select for our pump the coating that is most durable and sufficiently biocompatible. Initial biocompatibility testing will relate directly to the enzymatic processes required by Lockheed's DNA amplification and analysis chip.

6.5 Evaluate pump performance over a large number of cycles: In our pump design, MSM elements are placed between two parallel plates to maintain thin twin structure. These thin twins remain more stable than coarse twins during magnetic cycling (pumping). We will study the stability of the twin structure through a large number of pumping cycles (10^6). Failure will be will be acceptable at ten times the maximum number of cycles planned for the customers' lab-on-a- chip devices.

6.6 Test the pump on Lockheed's and SOS's lab-on-a-chip: The ultimate test of our micropumps will be the successful marriage of our MSM pumps to lab-on-a-chips devices made by Lockheed and SOS.

Timeline:

11.1________
11.2____
11.3__________________
                    11.4_________________
                                        11.5__________________________________
                                                    11.6___________________________

July	August	September	October

2 Budget

2.1 Salaries (Jul 1 – Oct 15)

Kari Ullakko	3.5 x $7500 = $26,500	
Aaron Smith		$5,000
Doug Kellis		$1,500
Laura Wendel		$1,500

Fringe benefits

Kari Ullakko	0.29	$7,613
Aaron Smith	0.06	$300
Doug Kellis	0.06	$95
Laura Wendel	0.06	$95

2.2 Travel

Meeting vendors of fabrication services $2,000

2.3 O&E

Materials and equipment	$2897
Fabrication services	$2,500
Total	**$50,000**

Personnel: Dr. Ullakko will build a working MSM micropump suitable for incorporation into a device for biological testing; funding request is for 3.5 calendar months of full time work. Salary of $5,000 is also requested for an undergraduate assistant with design experience who will work on computer drawing, modeling, MSM element preparation, and assembly of the devices; $1,500 for Doug Kellis in Materials Science and Engineering to perform characterization work on the elements; and $1,500 for biologists Laura Wendel to perform initial biocompatibility studies on the MSM elements. Due to the compressed time period for the proposed work, if personnel modifications are needed they will be made in consultation with the PI and Office of Technology Transfer.

Operating Costs: The balance of the funding request is $2,897 for materials and supplies, and $2,500 for fabrication services.

Travel $2,000 is requested for meetings at corporate partners and vendors of fabrication services.

<u>7. Establishes partnerships with the public or private sector or contribute to new company creation.</u> This project will benefit 3 Idaho entities: Boise State University, SOS Inc., and RM. BSU will receive royalties from research done in their facilities. SOS is a 15 person firm in Meridian that will use this pump to improve their product and achieve market share gains. RM is a recently formed company that has no employees except the founders, but we envision the micropump as the product that will launch the firm. This project will also be the first collaboration between SOS and RM. Theses 2 Idaho companies have complementary competences, and this project could lead RM and SOS to collaborate on other new products, i.e. point of care DNA analysis.

8. The Market Opportunity: The overall annual sales potential of the MSM materials is expected to be around 20 billion USD, which is equivalent to the current sales of piezo actuators. Rapid on-site DNA analysis requires only a micro-pump to become a reality, which is the basis of our collaboration with Lockeheed Martin. The applications for this technology are manifold within forensics, bio-terror, food safety, and medical diagnostics. A market size of 1,000,000 units by 2014 is conservative.

Transdermal alcohol sensors are a fairly small market with an estimated 90,000 units in use today. This number is expected to climb as public sector budget constraints pressure officials to depopulate prisons. An ultimate market size of 300,000 micropumps for alcohol sensors is reasonable. There is currently only one player in this field, SCRAM by AMS. Their website claims that they have monitored 120,000 offenders regarding alcohol consumption/detection.

9. The Technology: Magnetic shape memory (MSM) alloys are multi-functional materials exhibiting coupling between magnetic and structural order which leads to a very large changes in length. The MSM effect arises through the magnetic-field-induced motion of twin boundaries [2; 3]. While the magnetic shape-memory effect is useful for actuation purposes, the inverse effect may be utilized for sensing and energy harvesting applications [4]. Compared to other technologies MSM actuators offer several benefits:

- Up to 100 times longer stroke than piezo materials (stroke up to 10 %)
- Fast response (even 0.1 millisecond)
- Large work output (100 kJ/m^3)
- High position accuracy (nanometers)
- Low power consumption
- Simple and reliable construction

How does the technology contribute to the product and market need and its intellectual

property status? MSM materials are a unique solution for micropumps and other microdevices. The shape changes of the MSM elements generated by a magnetic field source that is placed outside the fluid channel (hermetically isolated from the fluid) pumps the fluid. The whole pump is just a piece of MSM material. This simple construction makes MSM pumps small in size, reliable and low cost. The large stroke of MSM elements (up to 10 %), high positioning accuracy (nanometers), and fast response time (0.1 ms) is a combination that is not possible to achieve with any other technology. These factors make it possible to create micropumps that deliver fluids in nanolitres quantities at a speed of meters per second. No other technology can provide this variety of applications for micropumps.

Theoretical soundness, Maturity and Viability of the technology Our recent HERC progress report (May 30, 2011, see appendix) includes videos of our latest pumps, demonstrating the maturity, viability and soundness of this technology.

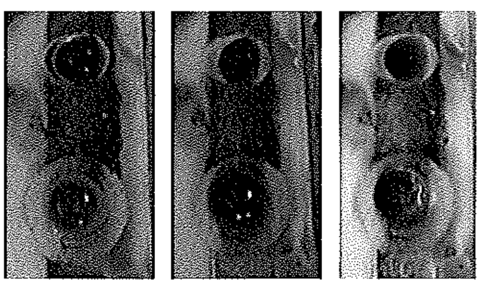
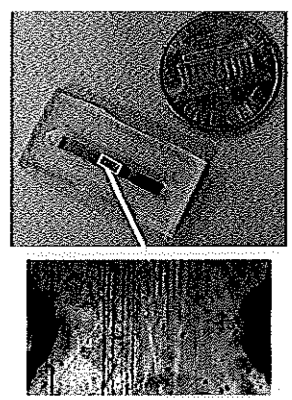


Fig 4

←**Fig 4. MSM Micropump is a reality!** From HERC May 2011 progress report, (See Appendix)
Magnified view:
Initial condition *(Left)*
Fluid pumped down *(Mid)*
Fluid pumped back *(Right)*

Fig 5 Latest actual size wireless pump (within yellow box); magnified view (below).
→



Hardware development and integration risk The hardware of the pump will be made using the silicon lithography technology with which the MEMS devices are currently made. Coils will be made using similar lithography technologies. Attaching the MSM element into the silicon pump is straightforward, and does not include integration risks. The only challenge is the high dimensional accuracy requirements for preventing leaking of the fluid.

10. Commercialization Partners Successful completion of this project will be the creation of an MSM micro-pump that works as part of a lab-on-a-chip device such as Lockheed's DNA profiler or SOS international's transdermal alcohol sensor. RM will then leverage its existing relationships with law enforcement, the U.S. Department of Defense, and the food safety industry to market the DNA analyzer.

12. Education and Outreach In addition to the hired undergraduate student, other student researchers in Hampikian and Mullner's laboratories will be involved in research components of the biological device design, and MSM elements development. In addition, the PIs and Dr. Ullakko will present their results to the Idaho entrepreneurial community though Kickstand and TechConnect. Dr. Hampikian also meets with school groups each month to show Idaho school children the wonders of research. Dr. Ullakko will also present his work during the seminar series in the College of Engineering at BSU.

13. Institutional and Other Sector Support BSU has ardently supported this work through the Office of Technology Transfer. Mary Givens, the Director of the office has worked with Drs. Hampikian and Mullner on MSM technology and biological testing for the past two years, and invested $20,000 of her discretional funds. She has also arranged meetings for the PIs with companies interested in their technology, and has been instrumental in bringing Lockheed Martin and SOSI on board. Ms. Givens coordinated a group of MBA students who assessed the promise of MSM technology in a semester-long study which resulted in a business development plan that served as the launching point for RM. Finally, the Office of Technology Transfer has shown its commitment to this project by paying for three MSM patent applications covering inventions by the PIs.

References

1) K. Moeller, J. Besecker, G. Hampikian, A. Moll, D. Plumlee, J. Youngsman and J.M. Hampikian, "A Prototype Continuous Flow Polymerase Chain Reaction LTCC Device," Materials Science Forum Vols. 539-543 (2007) pp. 523-528

Appendices

Facilities and Equipment:

Biology: Hampikian Laboratory Facilities

The main Hampikian laboratory consists of approximately 800 square feet. The lab is equipped with: ABI 3130 Genetic Analyzer, ABI 310 Genetic Analyzer (shared with Dr. Kevice Ferris), LI-COR 3100 DNA sequencer with dedicated Optiplex GX280 computer, Qiagen BioRobot EZ-1 DNA processor, BioRad Gel Imager, Coulter Counter, NanoDrop spectrophotometer, Eppendorf Real Plex^4 real time PCR cycler, BioRad icycler, MJ Research Minicycler, 4°C and -20°C refrigerators and freezers, NuAire Class II biosafety cabinet, two NUAIRE CO_2 incubators, Beckman LS6500 liquid scintillation counter, BioRad electroporator, and assorted electrophoresis and centrifugation equipment.

A second lab space (80 square feet) is connected to the main lab and contains microscopy equipment including a Zeis fluorescent microscope with Spot RT3 Camera, and an Olympus stereo microscope.

A third space of approximately 90 square feet is being prepared as a post amplification room that will house the 3130, 310, and all thermocyclers. This is essential for forensic applications, in order to prevent contamination with amplified human DNA.

Additional shared resources: the Department of Biology has a number of shared instruments including an Sorvall High Speed Centrifuge, Beckman TL100 Ultracentrifuge, Omni GLH Tissue Homogenizer, Savant SC110A/UVS400 Concentrator/Vacuum System, a Gilson HPLC (including size exclusion and reverse phase chromatography), LC (ion exchange and affinity chromatography) 1-D and 2-D gel electrophoresis systems, protein electroelution system, temperature-controlled chromatography cabinet, and Isothermal microcalorimetry (Microcal), Agfa CP 1000 film processor, Gyromax 737 and 737R incubators, Beckman Coulter Epics XL model flow cytometer, Beckman scintillation counter, Ice machine, and autoclave. ABI 7300 and an I-Core Smart Cycler II Real-Time PCR thermocycler are available for real time quantitative PCR. A LI-COR Global IR2 4200 gel-based automated DNA sequencer, with 64-lane capacity, upgradeable to 96 lanes, housed within the 500 sq ft Sequencing Lab. Large scale sequencing is routinely done at the Molecular Core Facility at Idaho.

Engineering: Most of the equipment is available in the laboratories of the PIs, the Boise State Center for Materials Characterization (BSCMC, located in the College of Engineering http://coen.boisestate.edu/bscmc/index.htm), and the Idaho Mircrofabrication Laboratory (IML, located in the College of Engineering http://coen.boisestate.edu/IMFL/index.html).

The instruments in the laboratory of Dr. Müllner include

1. Induret casting furnace for the fabrication of sputter targets and ingots.
2. Single crystal growth furnace.
3. Tube furnaces (1200 °C).
4. Muffle furnace (1000 °C).
5. High-sensitive Vibrating Sample Magnetometer (VSM) -- ADE model 10 with maximum field 2 T and heating/cooling capabilities for the temperature range from -100 °C to 150 °C.
6. Mechanical test bench Zwick 1445 (Zwick, Ulm, 500 N load cell, displacement resolution 10 nm), equipped with a variable field magnet Multimag 2000 (Magnetic Solutions, Dublin, 2 T).
7. Dynamical magneto-mechanical testing device with constant magnetic field of 0.97 T, field rotation of up to 12,000 revolutions per minute, heating/colling between 10 °C and 50 °C.
8. High-precision wire saw.
9. Diamond saw.
10. Polishing equipment.
11. Multibeam optical system of k-Space for substrate curvature measurements for temperatures up to 1,100 °C. Separate temperature reading system "BandiT" for exact temperature reading up to 600 °C.
12. Electrochemistry for electroplating and electropolishing.
13. Pumping system to evacuate samples in a quartz glass tube and to flush the tube with inert gas such as argon.

Further instruments available at the College of Engineering

14. Sputter deposition system with co-sputter (2 targets) and reactive sputter capability.
15. Two AFM (Veeco Dimension 3100 Atomic Force Microscopy System and Veeco PicoForce Multimode Atomic Force Microscopy System) with dedicated software for analyzing phase, amplitude and height and MFM and nanoindenter functions. The system also includes harmonics imaging and in-situ heating-cooling capabilities.
16. Scanning electron microscope -- LEO 1430VP with energy-dispersive X-ray spectroscopy (EDS) capability, electron beam lithography (EBL), electron backscatter diffraction (EBSD).
17. Transmission electron microscope JEOL 2100 LaB_6, with scanning transmission electron microscopy capabilities, EDS, EELS, and magnetic domain imaging.
18. x-Ray diffractometer Bruker D8 Discover with variable temperature up to 1600°C, texture capabilities, thin film reflectometry, phase analysis, HiStar area detector, and scintillation detector.
19. Optical microscope -- Zeiss Axiovert 200 MAT with CCD camera and software.
20. Variable temperature probe station for electrical measurements between 5.5 K and 450 K.

21. Advanced electrical characterization systems (attoampere and microvolt resolution) -- Keithley 4200 Semiconductor Characterization System Keithley 595 Quasistatic Capacitance-Voltage Meter, HP 4284A LCR meter, Keithley 707A Ultra Low Current-High Frequency Solid State Switching Matrix (2-8X24 I/O cards), Agilent 81110A Pulse/Pattern Generator Unit (2 channels - frequency range up to 330MHz), Agilent Infiniium 54832D 1GHz 4 channel 4GSamples/s Mixed Signal Oscilloscope.

Biographical Sketches and Individual Support:

NAME	POSITION TITLE
Greg Hampikian, Ph.D.	**Professor, Dept. Biology, Boise State University**

INSTITUTION AND LOCATION	DEG.	YEAR (s)	FIELD OF STUDY
University of Connecticut, Storrs, CT	B.S.	1982	Biological Sciences
University of Connecticut, Storrs, CT	M.S.	1986	Genetics
University of Connecticut, Storrs, CT	Ph.D.	1990	Genetics

A- Positions and Honors

1983-84 Research Assistant, Dept. Pediatric Dermatology, Yale Univ. School of Medicine
1990-91 US NSF Postdoctoral Fellow, LaTrobe University, Melbourne, Australia (with Jennifer Graves)
1992 Postdoctoral Associate, Worcester Foundation for Experimental Biology, Worcester, MA (with William Crane)
1993-2004 Assistant, Associate, Full Professor, Dept. Natural Science, Clayton State Univ., Morrow, GA
1994-95 Visiting Scientist, Emory University & The Centers for Disease Control and Prevention (CDC) Atlanta, GA
1997-98 National Science Foundation ROA award. Research Faculty Member, Dept. of Biochemistry, Georgia Institute of Technology, Atlanta, GA
2005- Associate Professor 2005-2006, Full Professor 2007-, Dept. of Biology, Boise State University, Boise, ID

Other Experience and Professional Memberships

2004 Chair, Georgia Academic Advisory Committee for Biological Sciences
2008-2009 Member, presenter, International Society for Forensic Genetics
1999-2009 Member, American Society of Microbiologists: Editor for education Newsletter (1999-2002), Editor for
image archives (1999-2003); Moderator of the Molecular Biology and Biotechnology Education Listserve (1999-2003)
2000-2009 Member, International Society for Computational Biology

B- Selected peer-reviewed publications (in chronological order)

1. F. Deak, Y. Kiss, K. Sparks, S. Argraves, **G. Hampikian** and P. Goetinck, 1986, "Amino acid sequence of chicken cartilage link protein from c-DNA clones," *Proc. Natl. Acad. Sci. USA* 83:3766-3770.
2. J. Foster, F. Brennan, **G. Hampikian**, P.N. Goodfellow, A. Sinclair, R. Lovell-Badge, L. Selwood, M. Renfree, D. Cooper and J. Graves (1992) "Evolution of sex determination and the Y chromosome: *SRY*-related sequences in marsupials," Nature 359: 531-33.
3. J. Graves, J. Foster, **G. Hampikian**, F. Brennan, 1993, "Sex-determination in marsupial mammals," in *Sex chromosomes and sex determining genes,*(Editors, K. Reed and J. Graves) Gordon and Breach, Melbourne.
4. M. Gaudette, **G. Hampikian**, V. Metelev, S. Agrawal and W. Crain, (1993) "Effect on embryos of phosphorothioate modified oligos. into pregnant mice," *Antisense Res. & Dev.*,3:391-397.
5. **G. Hampikian**, J. Graves, D. Cooper, "Sex-determination in the marsupial" in Molecular Genetics of Sex Determination, (Ed. S. Wachtel) Academic Press (1996).
6. P. Henderson, D. Jones, **G. Hampikian**, Y. Kan, and G. Schuster, "Long-distance charge transport in duplex DNA: The polaron-like hopping mechanism," *Proc Natl Acad Sci USA* (1999) 96(15) 8353-8358.

7. M. Crayton, C. Ladd , M. Sommer, **G. Hampikian**, L. Strausbaugh, An organizational model of transcription factor binding sites for a histone promoter in D. melanogaster, *In Silico* Biology 4, 0045 (2004).
8. K. Moeller, J. Besecker, **G. Hampikian**, A. Moll, D. Plumlee, J. Youngsman and J.M. Hampikian, "A Prototype Continuous Flow Polymerase Chain Reaction LTCC Device," Materials Science Forum Vols. 539-543 (2007) pp. 523-528.
9. **G. Hampikian** and Tim Andersen; Absent Sequences: Nullomers and Primes, Pacific Symposium on Biocomputing 12:355-366 (2007).
10. L. A. Lucia, L. Adamapoulos, Jason Montegna, **G. Hampikian**, D. S. Argryopoulos, J. Heitmann, "A Simple Method to Tune the Gross Antibacterial Activity of Cellulosic Biomaterials," Carbohydrate Polymers 69 (2007) 805–810.
11. A. Kanu, H. Hill, G. **Hampikian**, S. Brandt, "Ribonucleotide and Ribonucleoside Determination by Ambient Pressure Ion Mobility Spectrometry (IMS)," Analytica Chimica *Acta 658 (2010) 91–97.*
12. Bourland, W., VĎAČNÝ, P, Davis, M., and **Hampikian, G.**, Morphology, Morphometrics and Molecular Characterization of Bryophrya gemmea n.p. (Ciliophora, Colpodea): Implications for the Phylogeny and Evolutionary Scenario for the Formation of Oral Ciliature in Order Colpodida, *Journal of Eukaryotic Microbiology* (in press, 2010)
13. Davis, M., Novak, S., **Hampikian, G.**, Mitochondrial DNA analysis of an immigrant Basque population: loss of diversity due to founder effects, *American Journal of Physical Anthropology* (2010, in press).
14. Bullock, C., Jacob, R., McDougal, O., **Hampikian, G.**, Andersen, T., DockoMatic Automated Ligand Creation and Docking, *BMC Bioinformatics* (2010, in press).

C. Research Support

Current Support

"DNA Safeguard"
Role: PI Agency: Department of Defense ($3,200,000) 2007-2010
Specific Aims:
Aim 1: To identify and rank, rare and absent sequences in amino acid and nucleotide databases.
Aim 2: To develop unique DNA sequences tags to protect DNA samples from contamination.

Overlap: There is no overlap between this grant and any other grant.

Completed Research Support

"Capillary Electrophoresis",PI Equipemnt grant, National Science Foundation, ($21,500)	2005
"Biosensors: LTCC Devices to Detect Biowarfare and Biosafety agents," PI, EPA, ($109,000)	2005
"Li-Cor Sequencer," PI, Li-Cor corportation ($50,000)	2005
"Biosensors: PCR Detection of Biowarfare and Biosafety agents using Novel Material," PI, Agency: EPA ($22,000)	2004

Dr. Peter Müllner concentrated his early work on deformation-induced twinning, characterization of twin structures with transmission electron microscopy, and modeling twin structures and twin-twin interactions in terms of dislocations and disclinations [119-124]. In 1997, he directed his attention to magnetic shape-memory alloys and calculated the magnetic force on a twinning dislocation [21].

After joining the Institute of Applied Physics at ETH Zurich in 1998, Müllner pursued experimental research on magnetic shape-memory alloys and magnetoplasticity of intermetallics. There he constructed testing machines for static and dynamical magneto-mechanical experiments. In 2004, Dr. Müllner moved to Boise, Idaho, where he joined the Department of Materials Science and Engineering at Boise State University (BSU). ETH Zürich donated equipment, which Dr. Müllner had developed at ETH, to his lab in at Boise State University.

In 2007, Müllner started an NSF-supported collaboration with Dr. Dunand at Northwestern University on Ni-Mn-Ga foam. Large MFIS of 0.12% was demonstrated in foam with coarse pores and monomodal pore-size distribution [129]. More recently, the MFIS was increase to 8.7% by tailoring the foam architecture (Fig. 4(a), [118]). These results demonstrate that constraints – imposed by external gripping or by internal grain boundaries – play a critical role because they suppress twin boundary motion and magneto-mechanical properties of MSMA.

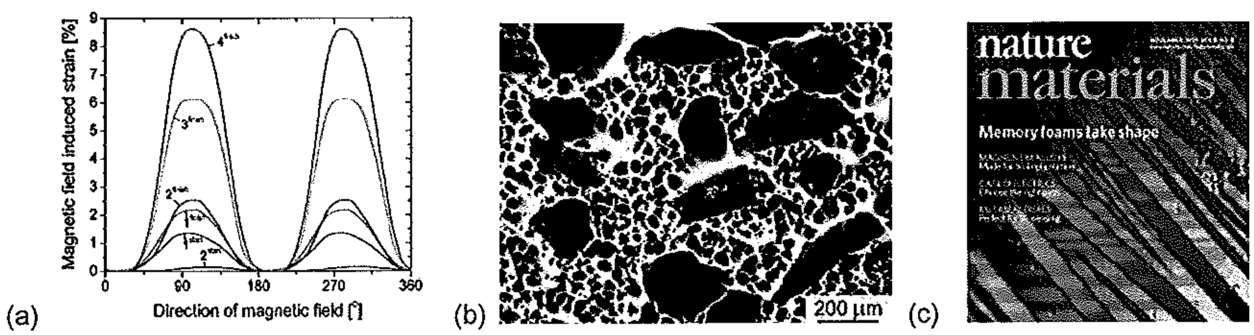
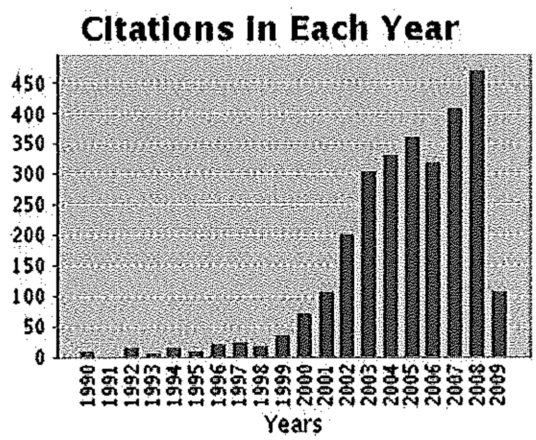


Figure 4: Ni-Mn-Ga foam with bimodal pore size distribution. (a) Magnetic-field-induced strain (MFIS) during one full rotation of a magnetic field of 0.97 T before and after the first four heating/cooling cycles. (b) Optical micrograph of a polished cross section showing two populations of pores (black) in Ni-Mn-Ga metal (white). (c) Optical micrograph with polarized light shows twins and decorates the cover of the November 2009 issue of Nature Materials [118].

By developing a cutting edge research laboratory focusing on the characterization of magnetic shape memory alloys, Dr. Peter Müllner has positioned himself among the leaders in the field. His research group grew quickly and currently has 15 members and his activities are spread worldwide through active collaborations with colleagues in Germany, Finland, Austria, Switzerland, Spain, Italy, China, Japan, and America. He gave more than 20 invited conference lectures and invited seminar presentations in the last three years. He has published 87 scientific publications (Hirsch index is 18 based on ISI Web of Science), and is the holder of one patent. He has three additional patents pending.

Examples of related research articles by key personnel (Dr. Peter Mullner):
Chmielus M., Mullner P. *et al.*, Nature Materials 8 (2009) 863-866.
Mullner P, *et al.*, Scripta Mater. 49, (2003) 129-133.
Chmielus M., Mullner P. *et al.*, Eur. Phys. J. Special Topics 158, 79-85 (2008).
Chmielus M., Mullner P. *et al.*, Acta Materialia, Acta Mater. 58 (2010) 3952-3962.

Dr. Kari Ullakko is a Visiting Research Professor in Boise State University. His current contract will end by June 30, 2011. Dr. Ullakko has worked in several university laboratories in different countries and led a number of development projects (Finnish, European Commission and US). Dr. Ullakko discovered the MSM effect in Ni-Mn-Ga in 1995 at MIT, and has studied and developed MSM materials and devices since then. He has been a research director and a president of high tech companies. In 1996 he started Adaptamat Ltd. (in Finland) to develop and commercialize MSM technology. Ullakko is a member of several advisory committees and professional organizations, and author or co-author of more than 220 publications, and a holder of 6 patents. One publication (Sozinov, Likhachev, Lanska, Ullakko, Appl. Phys. Lett. 80, 10, 2002) was selected in 2003 as the most fast breaking article in whole physics. The number of citations to his publications is over 3000, and the Hirsch index is 22 (i.e., 22 publications that have been cited at least 22 times). Figure 1 shows the number of citations as a function of time (According to Web of Science).



Graph at left shows the number of citations to Ullakko's publications in recent years (as of March 2009).

Examples of related research articles by key personnel (Dr. Kari Ullakko):
Ullakko, *et al.*, Appl. Phys. Lett. 69, 13, 1996; (about 1000 citations)
Ullakko, J. Mater. Eng. and Performance, Vol 5 (3), pp. 405-409, June 1996; (1st MSM paper published).
Sozinov, Likhachev, Lanska, Ullakko, Appl. Phys. Lett. 80, 10, 2002; (most fast breaking article in Physics in 3rd quarter in 2003).
I. Suorsa, J. Tellinen, E. Pagounis, I. Aaltio and K. Ullakko, Applications of Magnetic Shape Memory Alloys, Proc. of the Int. Conf. Actuator 2002, 10-12 June 2002, Bremen, Germany, p.158-161
Straka, Lanska, Ullakko, Sozinov, Appl. Phys. Lett. 96, 2010, 131903

In summary, Dr. Ullakko and Dr. Müllner combined have 30 years of experience with magnetic shape memory alloys, including extensive experience with the Ni-Mn-Ga system, both in regard to material synthesis and material characterization. They are, thus, well prepared to perform the proposed study.

PROPRIETARY INFORMATION DO NOT CIRCULATE

Provide documentation of other sector resource commitments.

SOS INTERNATIONAL

To whom it may concern: November 26, 2010

SOS International is an Idaho company headquartered in Meridian, Idaho. We develop, engineer and then market state of the art GPS tracking devices for law enforcement and judicial services, as well as for private companies and individuals. We have been working for the last 12 months on a transdermal alcohol sensing device which detects consumed alcohol in humans by sampling transdermal gases (perspiration). One of the key requirements for this technology is keep the overall package that is attached to a person's leg as small as possible. We are currently working with Dr. Greg Hampikian at Boise State University and several researchers there with regards to this emerging technology. The ultimate goal is to have the smallest micro pump possible inside of the device so that we can accurately sample these transdermal gases, evaluate what the sample contains, and then in real time send this data over cell phone frequency radios to the monitoring agency. Dr. Kari Ullakko of the Material Science and Engineering Department is working with our team on some key technology called Magnetic Shaped Memory (MSM) which when perfected will be the perfect solution for a high volume micro diaphragm pump which as I have mentioned is a critical part of our transdermal alcohol sensing technology.

I would highly recommend that the Higher Education Research Council (HERC) fund at whatever level possible the micropump design and MSM research being done by Hampikian, Ullakko and Mullner at Boise State University. Their successful completion of this technology is an essential step towards our future success in bringing the world the first micro real-time transdermal fuel cell alcohol sensor.

Best regards,

Paul Thomas
President—SOS International

BILATERAL NON-DISCLOSURE AGREEMENT
Boise State University
NDA No. 10-070-BG

This Agreement, effective as of the date of last signature of a party hereto, is made by and between Lockheed Martin Corporation, acting by and through its Information Systems & Global Services business area (hereinafter sometimes referred to as "IS&GS-Civil"), having a place of business at 700 North Frederick Ave., Gaithersburg, MD 20879 and **Boise State University** (hereinafter sometimes referred to as the "Company"), having a principal place of business at Biology 1910 University Drive Boise, ID, 83725-1515 and sets forth the terms and conditions for the protection, use and disclosure of confidential Proprietary Information by either Party to the other.

1. For purposes of this Agreement, IS&GS-Civil and the Company may be collectively referred to as the "Parties" or individually referred to as a "Party", "Disclosing Party", "Receiving Party" or "Recipient". For purposes of this Agreement the term "Affiliates" is that which is defined in Subpart 2.1 of the FAR. "Proprietary Information" shall include, but is not limited to, technical, business or financial information which: (a) is originated by or otherwise peculiarly within the knowledge of the one Party; (b) is currently protected against unrestricted disclosure to others; and (c) pertains to the Subject Program. "Subject Program" refers to data and information relating to the **Microfluidics**, and any and all task orders/follow-on work, if any, associated therewith.

2. In consideration for the disclosure of Proprietary Information, the Receiving Party agrees: (a) to hold Proprietary Information in trust and confidence and to only disclose or otherwise provide access to the same to those of its employees, directors, officers or consultants, ("Individuals") or its Affiliates with a bona fide need to know, provided that said Individuals or Affiliates have been made aware of their obligations hereunder, agree to be bound by the same and have entered into confidentiality agreements with its company which are no less restrictive than this one. In any event, the Receiving Party shall be responsible for the actions and inactions of its Individuals or Affiliates, and agrees, at its expense, to take all reasonable measures to restrain those Individuals or Affiliates from the unauthorized disclosure or use of the Proprietary Information; and (b) to refrain from using the same except for the purposes of Subject Program related proposal(s) and contractual effort, and all task order(s) associated therewith, if any, without prior approval of the Disclosing Party.

3. All financial information exchanged between the Parties is hereby deemed to be Proprietary Information and shall need no legend to be protected. All other Proprietary Information disclosed hereunder shall be protected under the terms of this Agreement: (a) if it is disclosed in writing, and is marked with the legend "PROPRIETARY INFORMATION" or an equivalent conspicuous legend; or (b) if it is disclosed orally or visually, and is identified as Proprietary at the time of disclosure and is subsequently reduced to a writing specifically identifying the items of a Proprietary nature and is furnished to Recipient within fifteen (15) days of disclosure; or (c) if it is disclosed by electronic transmission (e.g. facsimile, electronic mail, etc.) in either human readable form or machine readable form, and is marked electronically as proprietary within the electronic transmission, such marking to be displayed in readable form along with the any display of the Proprietary Information; or (d) if it is disclosed by delivery of an electronic storage medium or memory device itself as containing Proprietary Information and the storage medium or memory device itself is marked as containing Proprietary Information and such stored information is electronically marked as Proprietary Information.

4. A Recipient of Proprietary Information hereunder further agrees: (a) to preserve and protect such information for three (3) years from the date of disclosure; and (b) to exercise the same degree of care it uses to preserve and protect its own Proprietary Information and in no event shall less than a reasonable degree of care be utilized.

5. A Recipient of Proprietary Information hereunder will have no obligation or restriction and shall not be liable to a Party claiming a proprietary interest for disclosure of Proprietary Information if the same is: (a) in the public domain at the time of disclosure, or subsequently falls into the public domain without restriction through no wrongful act or omission on the part of the Receiving Party; (b) to the best of Recipient's knowledge, information and belief, lawfully known to the Receiving Party at the time of disclosure without restrictions on its use, as evidenced by competent proof; (c) independently developed by the Receiving Party, as evidenced by competent proof; (d) used or disclosed inadvertently or accidentally despite the exercise of the same degree of care, but not less than reasonable care, that each Party takes to preserve or safeguard its own Proprietary Information, provided Receiving Party notifies Disclosing Party forthwith and subsequently exerts reasonable efforts to prevent any further inadvertent or accidental disclosure or use; (e) used or disclosed with the prior written approval of the

to the expiration of such term, may be terminated at any time by either Party giving thirty (30) days prior written notice to the other Party; provided, however, the obligations to protect Proprietary Information contained herein shall survive such expiration or termination for the time period set forth in section 4 herein.

14. No rights or obligations other than those expressly recited herein are to be implied from this Agreement. Neither the execution of this Agreement, nor the furnishing of any information hereunder shall be construed as granting, either expressly or by implication, or otherwise, any license under any invention or patent or other intellectual property now or hereafter owned by or controlled by the Disclosing Party. No license, express or implied, shall inure to the benefit of the other participating Party as a result of a patent being granted to one of the Parties for inventions made exclusively by its employees. None of the information which may be submitted or exchanged by the respective Parties shall constitute any representation, warranty, assurance, guaranty, or inducement by either Party to the other with respect to the infringement of patents, copyrights, trademarks, trade secrets, or any other rights of others.

15. The validity and interpretation of this Agreement shall be governed by the laws of the State of New Jersey.

16. This Agreement is effective as of the date of last signature hereto and is the entire understanding and agreement of the Parties relating to protection of Proprietary Information. Neither Party shall be bound by any additional or other representation, condition, or promise except as subsequently set forth in writing signed by the Party to be bound. This Agreement shall apply in lieu of and notwithstanding any specific legend or statement associated with any Proprietary Information exchanged and the rights and obligations of the Parties shall be determined exclusively by this Agreement. If any portion of this Agreement is held to be invalid, such decision shall not affect the validity of the remaining portions. Each person executing this Agreement represents and warrants that each has full authority to bind his/her company hereunder. Each Party also hereby agrees that a facsimile copy or copies of one or both signatures hereto shall have the full force and effect as an original.

LOCKHEED MARTIN CORPORATION
Information Systems & Global Services - Civil

By:

Name: Drew Dotta

Title: Manager of Subcontracts – IS&GS - GSCM

Date:

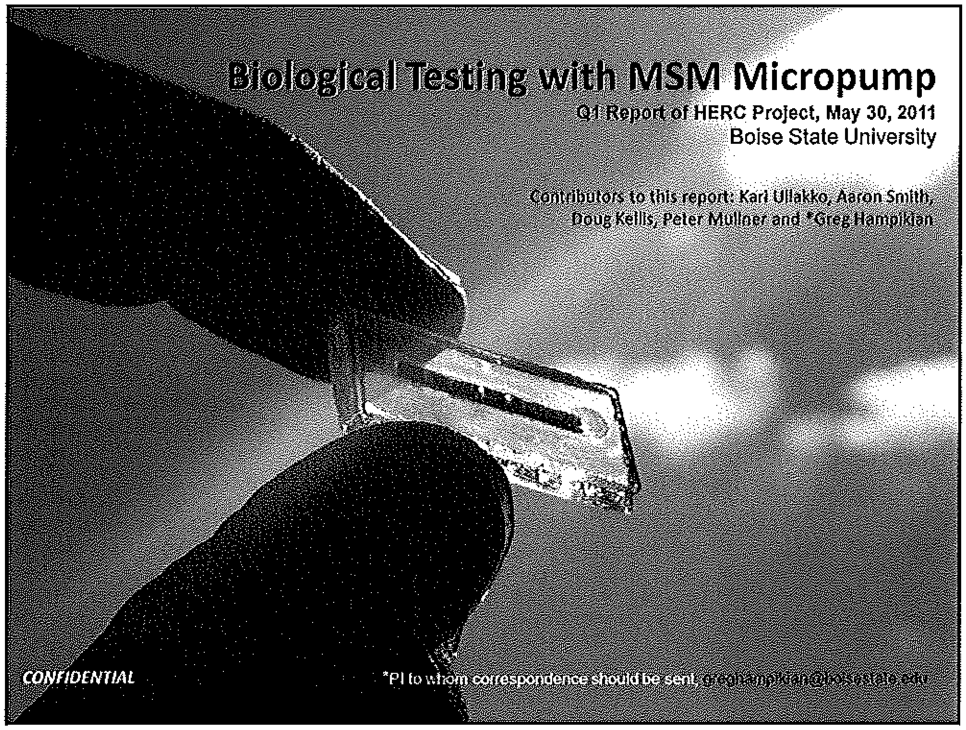
Boise State University

By: [signature]

Name: Mary Givens

Title: Director Office of Technology Transfer

Date: 4/6/2010



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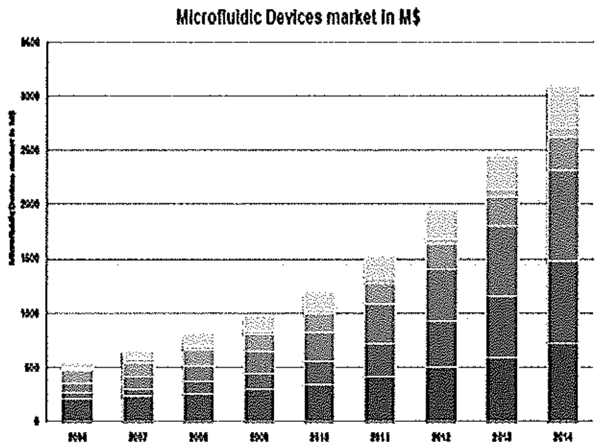
Microfluidics Markets

Microfluidic components are increasingly used in diagnostic and biomedical research devices. These devices improve effectiveness at many levels:
- Analysis automation through
  - high parallelization
  - multiplex analysis
- Reduced volume of reagents
- Faster analysis
- Higher accuracy in fluid dispensing.

In 2014, the market for microfluidic devices will exceed $3 billion. Drug discovery remains the largest microfluidics market, and will continue to grow. **However, the largest growth is expected in the field of Point of Care diagnostics.**



Source: *Emerging Markets for Microfluidic Applications in Life Sciences and In-Vitro Diagnostics, EMMA Report 2009, Yole Developments*
http://www.i-micronews.com/upload/Rapports/yole_rapport_flyer_emma_2009_web.pdf

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MSM pumps for microfluids devices

Current pumps are large devices placed outside the microfluidic lab-on-a-chip devices. There is a big need in the market for small pumps that can be integrated with lab-on-chip designs. Presently, no satisfactory pumping technology has been developed.

Magnetic Shape Memory[1] (MSM) materials provide an excellent pump solution for lab-on-chip devices, because

- MSM materials produce large (up to 10 % of the length of the sample) and fast (rise time less than 0. 1 ms) strains with high position accuracy in an applied magnetic field.
- An external magnetic field powers the MSM pump. Therefore, the device is wireless and contact-free, so the entire pump and lab-on-a-chip are inexpensive and disposable.
- MSM pumps are simple. A single piece of MSM material is placed in a microfluidic channel and acts as the pumping mechanism (See section 2).

These pumps achieve a high dosing accuracy, and volumes can be scaled from nanoliters to milliliters. This is due to the high position accuracy of the MSM materials, and the high cycling frequency the MSM pumps. This large dynamic range is not possible to achieve with any other technology.

[1] Invented and reduced to practice by one of the authors (K.U.) at MIT in 1996

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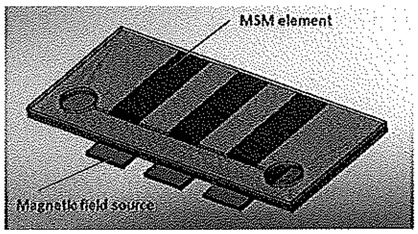
Project Goal

The primary goal of this project is to create a new business in Idaho based on MSM micropumps. The pumps are powered by a magnetic field source placed outside the pump, and are ideal for Biological testing devices.

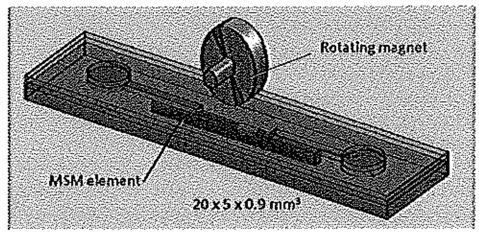
1. A three-element plunge pump (Section 1)



Programmed strokes of the three plunges made of MSM elements perform pumping

Target specifications:
- Dosing accuracy 10 nl
- Maximum flow 1 ml/min

2. Biomimetic "Swallow pump" (Section 2)



Swallow wave travels along the element, allowing the magnetic field to pump the fluid.

Target specifications:
- Dosing accuracy 1 nl – 10 nl
- Maximum flow 50 – 500 μl/min

Section 1 presents the three-element plunge pump. Experimental and modeling evidence is shown for its workability. In section 2 we show the "swallow pump". Demonstrators will be made of the swallow pump.

Pumps can also be powered by magnetic field pulses generated by small coils, but we demonstrate the use of only rotating permanent magnets in this project.

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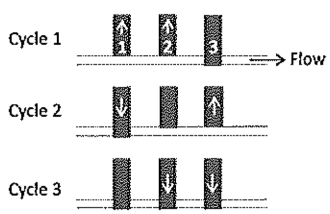
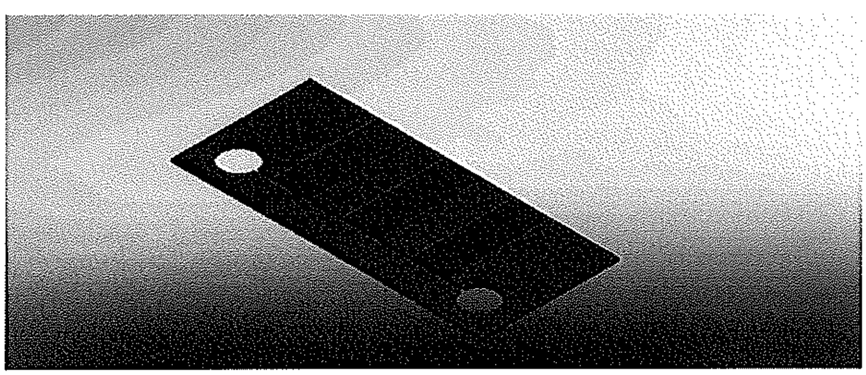
1 A three-element MSM pump



A three-element micropump is composed of three glass plates of 0.2 mm in thickness welded together using laser. The fluid channel (0.2 mm wide) and three pumping elements (blue rectangles in the figures) are placed in between two glass plates. The pumping elements are MSM material pieces (0.2 x 2 x 6 mm³) that elongate 6 % of their length in a magnetic field (perpendicular to the plate), and shrink 6 % in a magnetic field directed parallel to the long dimension of the element.



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1.1 Magnetic field generation

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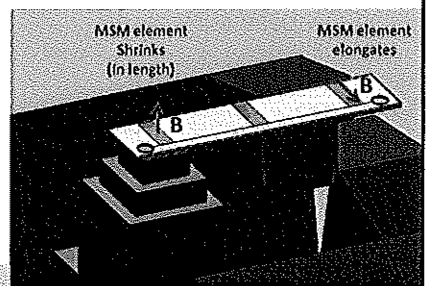
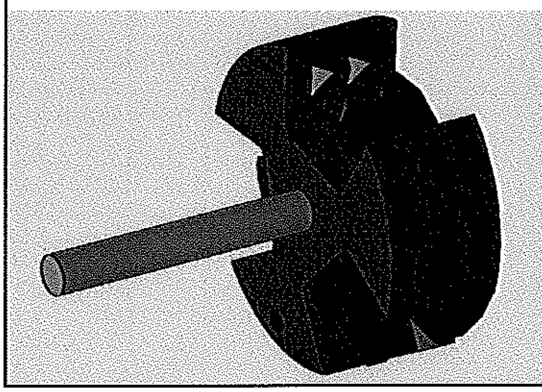
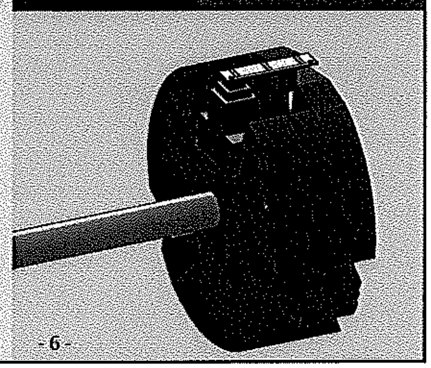
The wheel rotates underneath the fixed pump. The wheel contains three sets of magnets that generate magnetic fields **parallel** and **perpendicular** to the long dimension of the MSM elements. Parallel fields elongate the elements, and perpendicular fields shrink the elements, thus generating the pumping cycles shown in slide 4. (appendix 2 illustrates other field generators that we have modeled.)







1.2 Magnetic circuit: design and testing

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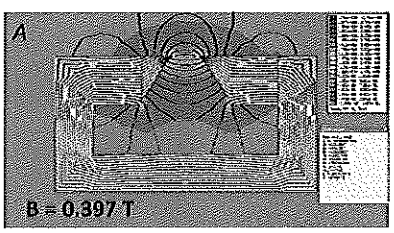
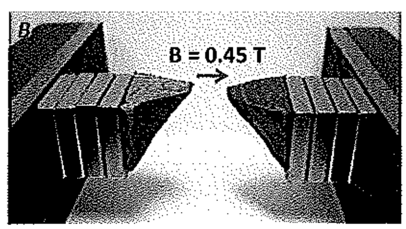
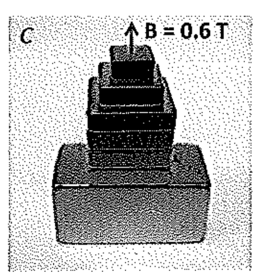
The shapes and sizes of the magnetic circuits that generate the parallel and perpendicular magnetic fields in the rotating wheel were optimized by modeling (see figure *A*) and measured experimentally (figures *B* and *C*).





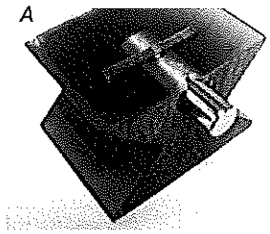
Result: The flux densities in the perpendicular and parallel directions are high enough for straining the MSM elements whose twinning stress is **0.7 MPa up to 4 % strain** (See Appendix 3). That was verified experimentally.



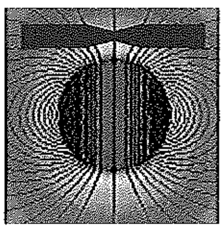
1.3 Straining the MSM element by a rotating cylindrical magnet

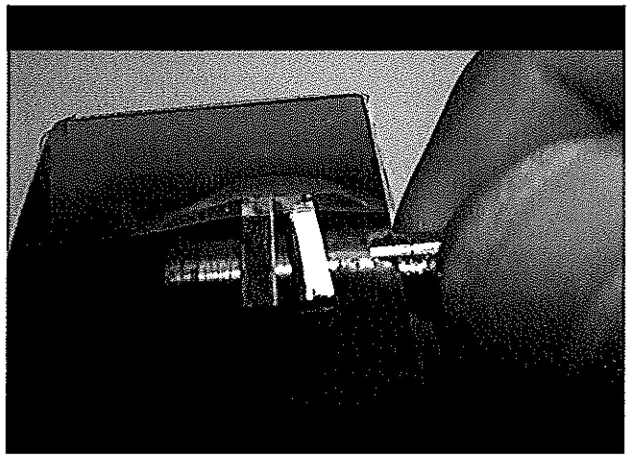
Figure *A* shows a jig on which an MSM sample sits. A diametrically magnetized cylindrical magnet (diameter ¼ ") is rotated beneath the MSM element, alternatingly elongating and shrinking the MSM element (see magnetic flux lines in the figure *B*). The video shows two parallel MSM elements straining in the rotating field (turn up the audio to hear the sound of twins.) Appendix 1 shows how several MSM elements can be driven in different phases by a rotating cylindrical magnet.

A

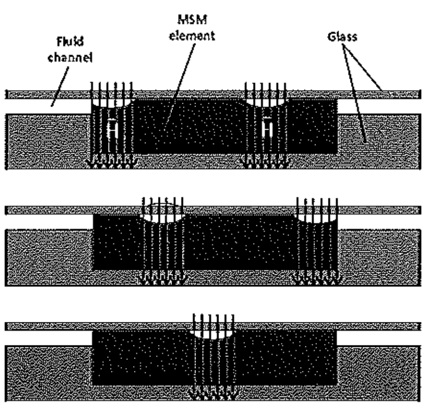


B





2 "Swallow pump"



The swallow pump is based on biological models of movement. Our MSM elements shrink locally in the direction of the applied magnetic field. Just as in muscular contraction, the element shrinks locally in one direction (gets thinner), and grows in the other (gets longer).

A traveling local magnetic field moves along the MSM element from left to right in this illustration. The moving field carries the shrinkage that transfers fluid. Figure shows three snapshots, steps 1 to 3, of the pumping process.

2.1 Proof of concept

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MSM swallow pump that is powered by a rotating magnet placed in a jig (Fig 1.). The MSM element was strained 2 %, and fixed at both ends. Then the element was sealed on all sides using an elastic silicone-type paste. A transparent acrylic plate was pressed against the MSM element. The plate contains two holes for a fluid inlet and outlet.

The pump was first tested by rotating the magnet by hand. After 200 cycles, the pumped volume was about one microliter (see figure 2, *A* and *B*), indicating a volume transfer of about 5 nanoliters per cycle. When the rotation was reversed, the pumping direction was also reversed (figure 2, *C*). The video demonstrates pumping with a frequency of about 500 Hz. Magnetic flux calculations of the pump are shown in Appendix 4.

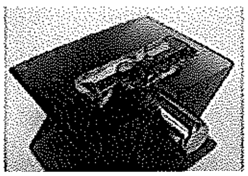


Fig. 1 Swallow pump

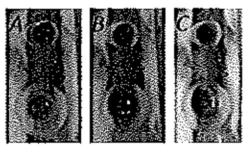
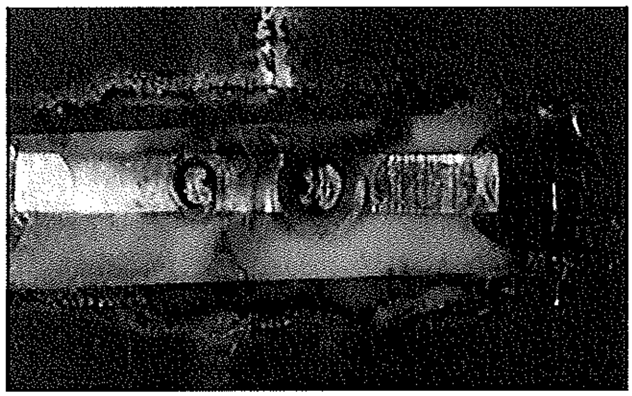


Fig. 2 Initial condition *(A)*,
Fluid pumped forward *(B)*,
Fluid pumped back *(C)*



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2.2 The first prototype

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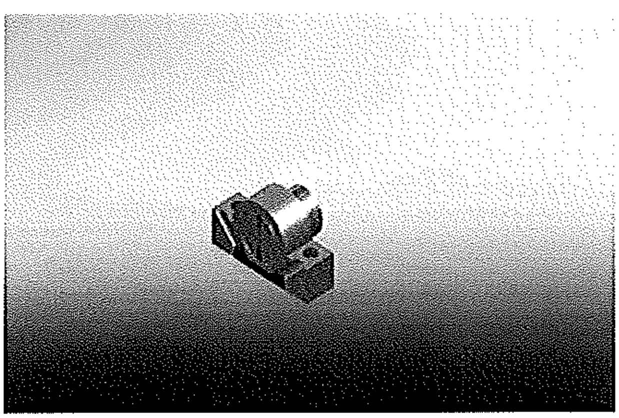
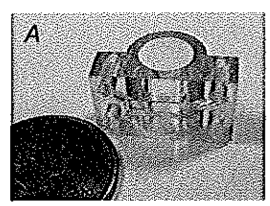
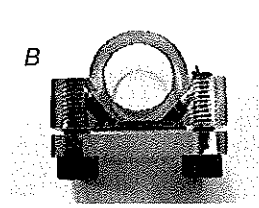
The animation below shows the structure and working principle of the swallow pump prototype that was made in this project. The rotating magnetic field transfers a shrinkage along the MSM element (shown as 9 x 2.3 x 0.9 mm^3) carrying the liquid. Below is a cross section view of the working parts of the swallow pump. Figure *A* shows the pump made from plastics using rapid prototyping. We pumped liquid from one container to another, as shown in figure *B*.







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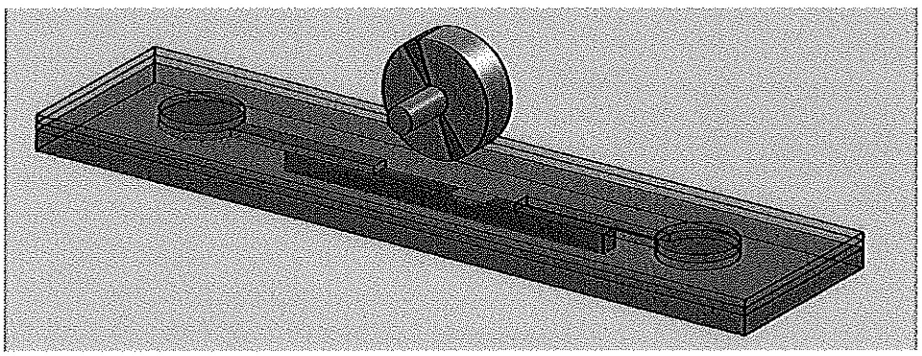
2.3 A thin swallow pump

Our final goal in this project is to make a thin swallow pump that can be placed inside a microfluidic lab-on-a-chip device. The demonstrator pump will be 0.9 mm thick, and the MSM element 0.5 mm thick. The fluidic channel shown below is 0.5 mm wide and 0.2 mm deep. The pump is powered by a rotating magnet placed above the pump. The design is shown in the figure below. The pump has no contact with the magnetic or any electrical source.



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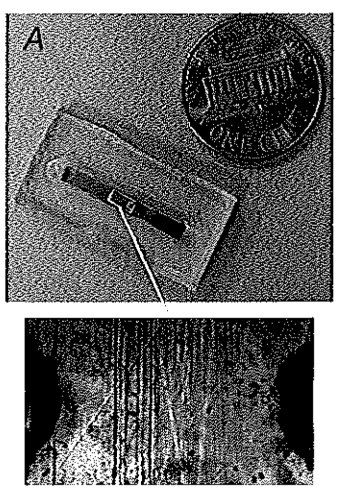
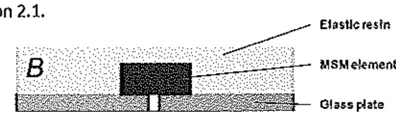
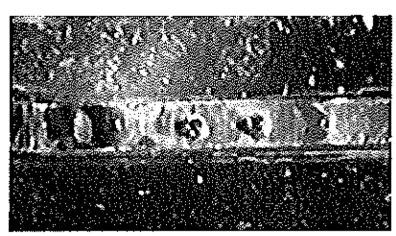
2.3.1 MSM element cast in elastomer

We developed and tested pumps in which the MSM element was placed on a glass plate and cast in an elastic resin. The glass plate contains holes for the liquid inlet and outlet. The pump is shown in Fig. A, and its cross section view in Fig. B. The inset of Fig. A shows the twins transferring the fluid from the inlet hole to the outlet hole. Also note that the inset shows the entire working mechanism of the pump. A rotating cylindrical magnet is placed beneath the MSM element in the same way as was shown in Section 2.1.





The video below shows pumping in both forward and reverse directions.



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2.3.2 Liquid flow driven by twins

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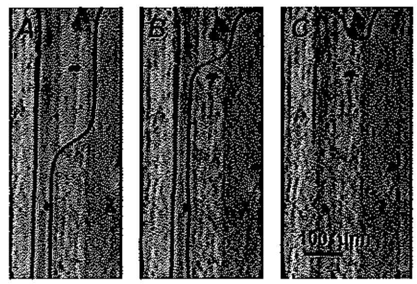
The video below shows twins (vertical lines) transferring the fluid (pink color) from the right hole to the left hole. Darker pink color means a thicker liquid layer. The video was recorded in a microscope. The distance between the holes (black areas) is 4 mm.

We demonstrated that individual twins can be fluid channels. The volume restricted by the twin surface and the glass plate can be as small as a picoliter. This finding is expected to exhibit applications in microfluidics. The snapshots below show liquid moving along the channels formed by twins. Fig. *A* shows an initial state, Fig. *B* shows the intermediate state after the liquid has partially moved along the twin, and Fig. *C* shows the final state when nearly all liquid has left the twin.



Plans for Next Quarter

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May

- Make the swallow pump shown in the animation in section 2.2 by stereo lithography (rapid prototyping) from transparent plastics
- Design and make the thin swallow pump (shown in section 2.3)
- Study our single crystal elements: strain, durability, fatigue, etc.
- Preliminary performance testing of the pumps (2.2 and 2.3)
- Discuss newest design with lab-on-a-chip team at Lockheed and other potential partners
- Begin design of lab on chip applications

June and July

- Performance test the pumps: accuracy, pumping volumes, max number of cycles before failure
- Make a series of 20 pumps for failure testing, and demonstration for corporate partners
- Travel to Lockheed to demonstrate pumps for biological testing
- Characterization and fatigue testing of our MSM elements
- Second report for HERC

Acknowledgements

Higher Education Research Council is acknowledged for their support. We thank Dr. Juhani Tellinen for performing the magnetic field calculations and wheel designs, Mary Givens for technology transfer advice and assistance, the Department of Defense for support of the initial pump research and design through a grant to the PI, and the Department of Energy, Office of Basic Energy Science for support of initial research for MSM element development through a grant to the Co-PI.

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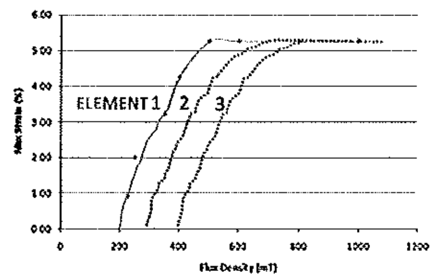
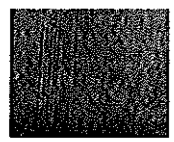
Appendix 1: A method for straining several MSM elements in different phases by a rotating cylindrical magnet

A rotating diametrically magnetized cylindrical magnet produces a gradually increasing and decreasing magnetic field when the cylinder rotates. We introduce a method that shows how several MSM elements can experience different strains at different, controlled time intervals.

Figure on right shows three strain vs. magnetic flux density curves. The blue curve 1 was measured on the MSM element made from our material. The material starts straining at 200 mT. Let us assume that element 1 of the pump shown on slide 4 were made from this material. Let us assume further that elements 2 and 3 of the pump were made from materials that correspond to curves 2 and 3 in the plot at the right. When the cylindrical magnet rotates underneath the three MSM elements, element 1 strains first, once the flux density reaches 200 mT. After that, element 2 strains when the flux density is 300 mT. Element 3 strains last when the flux density has reached 400 mT. Difference in the critical flux densities (switching fields) of the MSM elements makes the intervals of straining of the elements. The time difference of the two element strokes is shown on video in slide 10.



There are several ways to increase switching field, for instance, by coating the surfaces of the MSM elements with titanium nitride TiN (see figure on right). Element 1 could be uncoated, and element 2 coated with a 50 nm thick TiN layer, and element 3 with a 200 nm thick TiN layer. Coating increases twinning stress and switching field.



Optical micrograph of an MSM element coated with 1 µm layer of TiN

Other ways to increase switching field are surface deformations or other treatments, heat treatments, compositional changes and spring loading of the elements. If we want to change the order of strokes in parallel fields as compared to perpendicular fields, we can place elements in bias magnetic fields of different fields strengths. Bias field decreases switching field when the applied field is along switching field, but increases switching field in perpendicular direction. Using bias magnets we can also make opposite directions of the magnetic fields unsymmetrical. For instance, the field in north direction can strain the sample, but south direction does not strain, if the bias magnet increases the field in the north direction.

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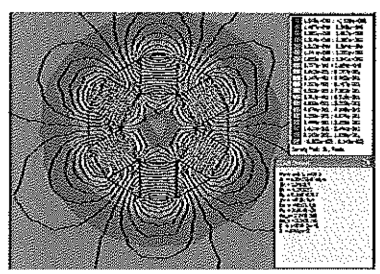
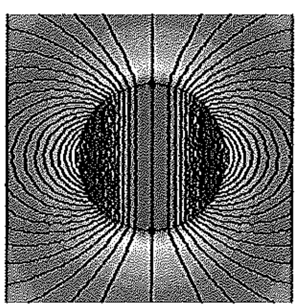
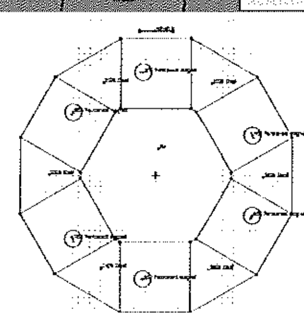
Appendix 2.1: Other rotating wheel designs

In order to simplify the rotating wheel, several wheel designs were made to create perpendicular and parallel magnetic fields in the MSM elements.

Figure below shows magnetic flux lines of a solid cylindrical magnet that is magnetized in diametric direction. Figures on right show a wheel composed of permanent magnet cubes and triangle-shaped low carbon steel pieces.







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Appendix 2.2: Other rotating wheel designs

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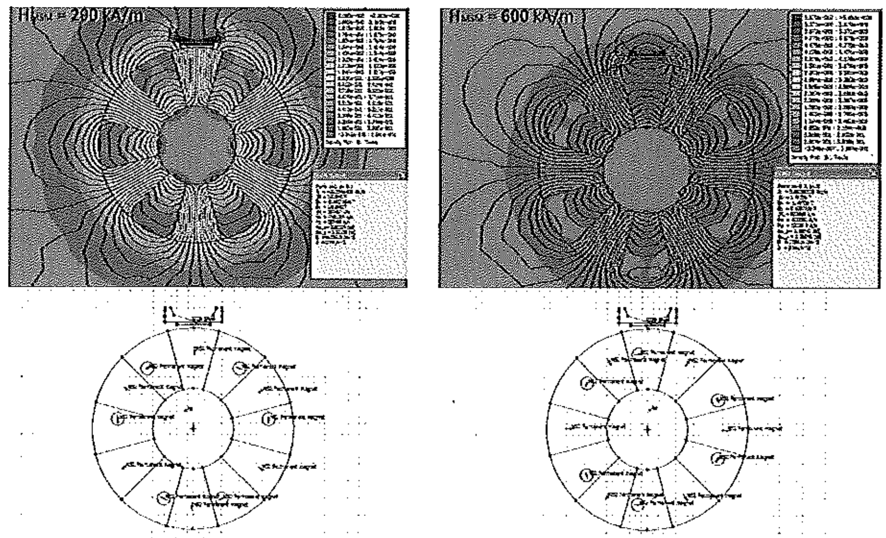
A Halbach rotor combined with a steel focuser placed above the micropump produces homogeneous perpendicular and parallel magnetic fields on the MSM elements, as shown in the figures below.



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Appendix 3: MSM elements

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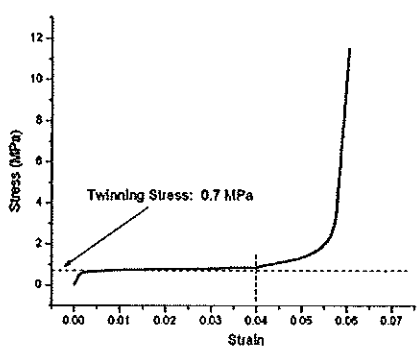
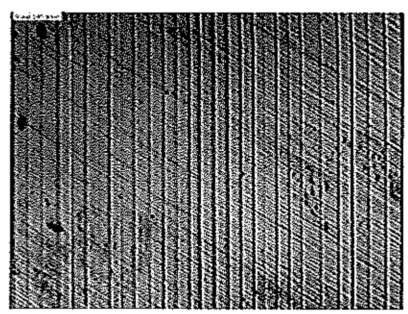
We have manufactured MSM elements whose twinning stress is about **0.7 MPa up to 4 % strain from our single crystals.**



Twinning stress measurements



Our MSM elements exhibit a regular twin structure

We have tested the MSM components of the **three-element MSM pump**, and proven that they work properly.

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Appendix 4: Magnetic flux density in the proof-of-concept pump

Figure below shows magnetic flux lines of the proof-of-concept pump shown in section 2.1. The length of the shrinkage is 1 mm (In the side view the shrinkage is in 45 degrees angle following the twin plane direction). Figure shows that perpendicular flux lines are concentrated (0.85 Tesla) in the shrinkage area. Parallel flux lines (density about 0.9 T) cover several millimeters along the MSM element in both sides of the shrinkage. Magnetic field directions are shown as white arrows in the figure. The flux density calculations confirm our experimental results of the operation of the pump. Magnetic flux density in perpendicular direction is high enough to make the shrinkage. And aside the shrinkage the flux density in parallel direction is high enough to resist shrinking. When the magnet rotates, the shrinkage moves along the MSM element, as shown in section 2.1