COVER SHEET FOR GRANT PROPOSALS
State Board of Education

SBOE PROPOSAL NUMBER: (to be assigned by SBOE)	AMOUNT REQUESTED: $75,000

TITLE OF PROPOSED PROJECT: Solid State Positioning Device

SPECIFIC PROJECT FOCUS:
We will build a prototype for a miniature large-stroke positioning device for medical applications such as real-time imaging of the chamber of the heart.

PROJECT START DATE: July 1, 2015	PROJECT END DATE: June 30, 2016
NAME OF INSTITUTION: Boise State University	DEPARTMENT: Office of Sponsored Programs

ADDRESS: 1910 University Dr., Boise Idaho 83725-1135

E-MAIL ADDRESS: osp@boisestate.edu	PHONE NUMBER: 208-426-4420

	NAME:	TITLE:	SIGNATURE:
PROJECT DIRECTOR/PRINCIPAL INVESTIGATOR	Dr. Peter Mullner	Professor, Chair	[signature]
CO-PRINCIPAL INVESTIGATOR			

NAME OF PARTNERING COMPANY: Acutus Medical	COMPANY REPRESENTATIVE NAME: Randy Werneth

	NAME:	SIGNATURE:
Authorized Organizational Representative	Karen Henry, Executive Director	[signature] 3/30/15

Solid State Positioning Device for Real-Time Imaging of the Heart Chamber

1. Name of Idaho public institution

Boise State University

2. Name of principal investigator directing the project

Dr. Peter Müllner

3. Indicate the technology being proposed

We will build a prototype for a miniature large-stroke positioning device for medical applications. This is the first proposal for this technology.

4. Executive Summary

We propose to demonstrate proof of concept for a fast, high-precision positioning device for applications such as valves, microsurgery, and semiconductor processing; and for economic growth in Idaho. Magnetic shape-memory alloys (MSMAs) exhibit multiple functional properties such as magnetic-field-induced strain and deformation-induced change of magnetization, resistivity, and magnetic susceptibility, making this material "smart." We will utilize the multifunctionality of MSMAs to develop large-stroke actuators consisting of very few parts. Simplicity combined with minimal friction enables miniaturization and light-weight design.

This device will be useful for various applications in the medical and semiconductor sectors and potentially in the automotive sector. For this project, our primary industry partner is Acutus Medical, Inc. who does product development at the Medtec Furnace in Boise, Idaho. We will develop a positioning actuator for a real-time heart chamber imaging device.

5. Gap Projects Objective and Total Amount Requested

The objectives of this project are

a. To develop a long-stroke actuator mechanism based on MSM technology.

b. To develop a MSM *solid state* actuator with long strokes.

c. To develop an actuator prototype for medical applications such as heart surgery.

Objectives (a) through (c) are milestones preparing for the second part of this project to be conducted in the following year, additional funds will be requested for the subsequent year

d. To build and test a technology readiness level (TRL) 9 actuator device for medical applications.

6. Resource commitment and priorities of Boise State University

Boise State University lists five research strengths/priorities [1] including (1) Novel Materials, (2) Sensor Development, (3) Nanoelectronics and integrated systems, (4) Geochemistry and Geophysics, and (5) Health, public and energy policy. The proposed project covers three of these areas of priority by advancing novel materials (area 1), developing an integrated system (area 3), and developing technology for the health sector (area 5). Thus, this project fully aligns with institutional priorities.

Boise State University allocated laboratory space of 1500 sqft to the PI's Magnetic Materials Laboratory.

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

Eleven years of MSMA research at Boise State University, availability of a trained workforce, and access to ongoing international MSMA research suggest the potential for a real impact to Idaho's economy. We believe this project will help to launch a new industry in Idaho.

7.a International Leadership at BSU

Dr. Müllner collaborates with many international leading scientists in the field in countries such as Germany, England, Spain, Italy, Switzerland, Austria, China, and Japan. With these contacts, he can ensure sustaining new developments with cutting edge know-how. Dr. Müllner organized the first MSMA Business Development Event at the 4th International Conference on Ferromagnetic Shape Memory Alloys (ICFSMA'13) in Boise, ID, June 3-7, 2013. As a result of this event, Dr. Müllner and ETO Magnetic GmbH (Stockach, Germany) created the interest group MSM Net with the goal to advance MSM technology transfer. Bringing ICFSMA to Boise (previous host countries include India, Spain, and Germany) demonstrates the recognition of Boise State University as a leading institution in the field.

7.b Why Southwest Idaho?

During the past eleven years, more than forty (40) undergraduate and graduate students have worked in the Magnetic Materials Laboratory with Dr. Müllner and received in-depth training on Magnetic Shape Memory Alloys. Many Materials Science and Engineering graduates prefer employment in the Treasure Valley over other places in the US and stay in the region.

With such a large number of experienced students and graduates, the Treasure Valley presents one of the largest – if not the largest - concentration of MSMA expertise worldwide. Boise is thus the right place to start a business on MSMA technology.

In recent years, Idaho grew expertise in the medicine technology sector. The CORE of Idaho is a coalition for innovation and promotes new industry in this sector [2]. Our industry partner Acutus Medical (section 10.1) [3] develops real-time imaging hardware in the Medtech Furnace incubator in Boise, Idaho, less than a mile from the PI's lab at Boise State University. This project will promote the success of Acutus Medical. In turn, partnering with Acutus Medical ensures market entry for the proposed technology.

Finally, this project will attract venture capitalists to invest in the Treasure Valley. This is the first technology project initiating a series of further technology development efforts including an MSM based pump for micro-fluidics applications (lab-on-the-chip, insulin pump), four-state memory and more. Thus, this project will initiate a new industry located in Idaho. Future industry partners may include car manufacturers, 3M, Lockheed Martin to name a few.

7.c Recent business developments in Idaho related to MSM technology

PI Müllner holds six patents. In 2014, he has submitted four proposals jointly with the BSU

College of Business and Economics to federal agencies including the NSF and EDA for technology development projects involving industry partners. Steps towards business development for the proposed technology are listed in the following ***Table 1***.

Table 1: Recent steps towards commercialization of proposed technology

DATE	ACTION
November, 2014	Conceived invention: Long stroke actuator
November 17, 2014	Disclosed invention to Boise State Office of University and Industry Venture
January 2015	Patent "Magnetic Shape Memory Apparatus with Long Stroke" (file 169) in preparation
January 20, 2015	Shaw Mountain Technology LLC registered with State of Idaho
March 17, 2015	Collaboration established with Acutus Medical Inc.

8. The Market Opportunity

8.a Need addressed by the project

Minimal invasive surgery, microfluidic systems such as the lab-on-a-chip, and positioning devices on micro-satellites, are but a few examples of industries which rely on the miniaturization of linear actuators. Many contemporary actuators make use of a conventional electromotor and a crankshaft mechanism to produce linear motion. Such technology bears sever limitations towards miniaturization. Particularly friction associated with rotational motion increases with decreasing size and obstructs motion at very small scale. A technology is needed for building friction-free actuators. Such technology must avoid rotational motion.

8.b Applications and markets for the technology

Minimally invasive surgery is a rapidly growing multi-billion dollar market with the forecast to double within the next five years exceeding $14 billion in 2019 [4]. The proposed Solid State Positioning Device is an enabling technology for instruments such as the real-time imaging apparatus of Acutus Medical. The solid state positioning device is but one example of solid state devices which can be built with Boise State University's MSM technology. Another example is Boise State University's MSM micro-pump which gives access to the equally fast growing multi-billion dollar micro-fluidics market.

8.c Product, market audience, competition, and barriers to market entry.

The product is a fast and precise long-stroke actuator. There are many target audiences (market audiences) such as patients undergoing surgery (minimally invasive surgery), patients in need of off-the-shelf disease tests (lab-on-a-chip), car owners (engine valves), operators of robots, and upper middle class home owners (surveillance cameras).

The novelty of the MSM technology presents a barrier to the market. To overcome this barrier, we selected an application in minimally invasive surgery, particularly the real-time imaging of the heart chamber. This is a high-value, high margin product market conducive for a disruptive innovation such as MSM technology and capable of overcoming and leveraging great novelty.

The following anecdote illustrates the lack of competitive solutions. Dr. Martin Vreugdenhil, a neurologist at the University of Birmingham, England, studies brain functions of rats related to epilepsy and schizophrenia. Only, he had a research problem; he wanted to maintain very small but consistent drug delivery to the brains of live rats under study. Further, he wanted a pump small and light enough for a rat to carry on its own. Vreugdenhil's search for commercial micropumps did not yield a solution. His search of the scientific literature identified our 2012 paper [5] on the MSMA micropump, and he contacted us in September, 2013.

9. The Technology and Path to Commercialization

9.a Describe the technology and the current state of the technology

In April 2014, Müllner collaborated with TechHelp to develop a working product for Vreugdenhil. Undergraduates contributed to develop the pump, and Idaho TechHelp applied rapid prototyping capabilities to produce components including a 3D-printed pump housing. In May 2014, the team produced eight micropumps. A Boise State engineering undergraduate

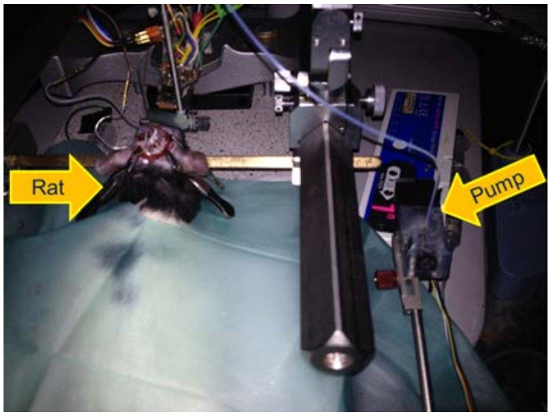

Fig. 1: First drug-delivery pump experiment performed at the University of Birmingham, England.

student assisted Vreugdenhil in the first experimental use of the pump on a rat (***Fig. 1***), and the pump delivered drugs at the required 0.3 µl/min flow rate [6]. This micro-pump is the first MSM device that successfully uses MSM technology to solve a problem.

Since we are describing a technology you do not see in today's products, it may help to use familiar science fiction to explain how it works. In the movie *Terminator 2* (1991), Arnold Schwarzenegger starred as the hero, the T-800 robot sent back from the future to save the world. Although advanced by our standards, Schwarzenegger's robot was built out of numerous interlinking electro-mechanical parts. His nemesis, however, was a more advanced T-1000 robot, fabricated from a single material. Its "liquid metal" structure allowed it to fluidly morph into new shapes, something the T-800 could not do.

MSMA technology is similar in concept to the "liquid metal" robot. Although not humanoid, MSMA does shape-shift in response to magnetic fields. Apply a magnetic field, and the material responds with a shape change. Remove the field, and the new shape remains. Apply a different magnetic field and the material re-forms into a new shape. Do this quickly and with purpose and you have linear motion, aka a small motor or pump.

9.b Contribution of the technology to the product and market need and its intellectual property status.

The MSM solid state positioning device transforms electrical energy via miniature electromagnets and pole pieces into linear motion thereby avoiding rotational motion. The apparatus works similar to the motion pattern of a caterpillar walking along a stick. If the caterpillar were laying on its back and balanced the stick on its feet, it could move the stick a long distance. The MSM solid state positioning devise works like this caterpillar laying on its back and moving a stick except that it is much faster. The MSM solid state positioning device can move a stick at the speed of sound.

The MSM solid state positioning device will actuate the catheter of Acutus Medical's instrument for real-time imaging of the heart chamber.

The patent "Electrically driven magnetic shape memory apparatus" (BSU file 158) is pending and the patent "Magnetic shape memory apparatus with long stroke" (BSU file 169) is in preparation.

9.c Who developed the technology and with what funding

Dr. Müllner has developed MSM technology at Boise State University since 2004 with funding of $3.4 million from federal agencies (NSF, DOE), state agencies (HERC), and private sources.

9.d Concrete steps to bring technology to market

The steps to bring the technology to market include

i. demonstrating a long-stroke actuator mechanism based on MSM technology as described in BSU file 169,

ii. demonstrating a MSM *solid state* actuator with long strokes as described in BSU files 158 and 169,

iii. demonstrating an actuator prototype for medical applications such as heart surgery in partnership with Acutus Medical,

iv. demonstrating a TRL 9 actuator device for medical application in partnership with Acutus Medical.

10. Commercialization Partners

10.1 Acutus Medical Inc.

Acutus Medical [3] is committed to pioneering a breakthrough technology to optimize strategies for complex cardiac arrhythmias such as Atrial Fibrillation by developing innovative, safe, efficacious, and cost-effective solutions for individuals suffering from these complex cardiac arrhythmias. Acutus Medical’s mission is to develop and market a new leap-frog platform technology which will take the treatment from a strategy based approach to a medical evidence based approach. This will completely revolutionized the way Electrophysiologist operate on these patients. Acutus Medical’s platform is a real-time imaging of the heart chamber (CT Scan Quality), then overlaid on the heart chamber is the real-time electroactivation map of the entire heart chamber, beat by beat. In September 2014, Acutus Medical secured additional $26.2 million to develop a complete product portfolio [3].

Acutus Medical provides in-kind support consisting of (i) establishing parameters for a linear positioning device, (ii) helping to transition the project from bench-top testing to practival use, and (iii) providing trials of the device integrated in a prototype surgical machine.

Shaw Mountain Technology LLC

Peter Müllner established Shaw Mountain Technology LLC in January 2015 in Boise, Idaho and manufactures high-quality high-tech devices in Idaho. Initially, SMT will focus on devices utilizing magnetic shape memory alloys.

Shaw Mountain Technology will not participate in this project. Upon completion of this project, Shaw Mountain Technology will license and commercialize the technology in collaboration with Acutus Medical.

11 Specific Project Plan and Detailed Use of Funds

11.a Budget

The requested amount totals $75,000 as detailed in the following ***Table 2***.

Table 2: Budget by category

Budget Category	Amount ($)
Salary (PI, research engineer, post-doctoral researcher, UG students) plus fringe benefits	61,200
Materials and supplies (crucibles, gasses, raw materials Ni, Mn, Ga, lab supply, data acquisition cards, computer dedicated to the SSLSP device, soft iron for magnet cores, copper wire for windings, electronic parts)	8,500
Rapid prototyping in New Product Development Lab (Idaho TechHelp)	2,000
Material characterization, Boise State Center for Materials Characterization	2,300
Travel domestic (development of industry partners)	1,000
Total	**75,000**

11.b The project team and responsibilities

Table 3 outlines the project team members and their responsibilities.

Table 3: Team members, functions, and responsibilities

Team member	Function	Responsibilities
Dr. P. Müllner	PI, team lead	project oversight, coordination, industry cont.
Dr. P. Lindquist	research engineer (20%)	electrical components
Dr. A. Smith	post-doct. res. (25%)	design and building of micro devices
E. Rhoads	undergraduate student	crystal growth and sample preparation
TBD	undergraduate student	programming and electrical control

11.2 Project tasks

Project tasks include (1) demonstrating the long-stroke MSM actuation mechanism actuated by a diametrically magnetized rod magnet similar to the MSM micro-pump [5]; (2) demonstrating the actuation mechanism without rotational parts; (3) developing a proof of concept device; (4) characterization of the final device; and (5) reporting and application for funding of second project year.

11.3 Project plan

The project milestones and project timeline are outlined in ***Table 4***.

Table 4: Milestones and timeline of seed grant phase

No.	Milestone	Qt. 1			Qt. 2			Qt. 3			Qt. 4		
1	Hiring and training students and post-doc. researcher	■	■										
2	Defining device specifications	■	■										
3	Purchasing materials		■	■									
4	Designing device (long stroke and solid state comps.)		■	■									
5	Growth of single crystal and MSM element production			■	■								
6	Fabrication of device parts (electrical, mechanical)			■	■	■							
7	6-month report						■						
8	Assembling magnetic circuit						■	■					
9	Magnetic circuit characterization							■					
10	Modifications/optimization of magnetic circuit							■	■				
11	Device assembly								■	■			
12	Device characterization									■	■	■	
13	Proposal for funding continuation										■	■	■
14	Final project report and request for funding												■

12. Institutional and Other Sector Support

New materials is one of five strategic research emphasis areas of Boise State University. Initiated by two large gifts of the Micron Foundation, Boise State University (1) founded in 2004 the Materials Science and Engineering (MSE) Department offering Bachelor of Science and a Master of Science degrees and (2) created a PhD program in MSE in 2012, which has grown rapidly into the largest engineering PhD program in Idaho. Materials research includes now six department and includes research facilities covering more than 15,000 sqft. The Magnetic Materials Laboratory headed by the PI is housed in two buildings and totals about 1,500 sqft. Acutus Medical commits to provide in-kind support consisting of (i) establishing parameters for a linear positioning device, (ii) helping to transition the project from bench-top testing to practival use, and (iii) providing trials of the device integrated in a prototype surgical machine.

Appendices

A: Facilities and Equipment; B: Biographical Sketches; C: Letter of Collaboration Acutus Medical; D: References.

APENDIX A: FACILITIES AND EQUIPMENT

Most of the equipment is available in the laboratories of the PIs, the Department of Materials Science and Engineering, the **Boise State Center for Materials Characterization** (BSCMC, located in the College of Engineering http://coen.boisestate.edu/bscmc/index.htm), the **Idaho Mircrofabrication Laboratory** (IML, located in the College of Engineering http://coen.boisestate.edu/IMFL/index.html). The Magnetic Materials Laboratory includes the rooms HML103 and ERB2114 totaling 1500 sqft.

The instruments available to this project at BSU include

- Sputter deposition system with co-sputter (2 targets) and reactive sputter capability
- 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
- Scanning electron microscope -- LEO 1430VP with energy-dispersive X-ray spectroscopy (EDS) capability, electron beam lithography (EBL), electron backscatter diffraction (EBSD).
- Transmission electron microscope JEOL 2100 LaB_6, with scanning transmission electron microscopy capabilities, EDS, EELS, and magnetic domain imaging.
- x-Ray diffractometer Bruker D8 Discover with variable temperature up to 1600ºC, texture capabilities, thin film reflectometry, phase analysis, HiStar area detector, and scintillation detector
- Optical microscope -- Zeiss Axiovert 200 MAT with CCD camera and software
- 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
- Variable temperature probe station for electrical measurements between 5.5 K and 450 K
- 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
- 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
- 1A power supply, platinized titanium anodes, beakers, hot plate, exhaust hood used for electrochemical deposition of thin films on conductive substrates
- High-precision wire saw
- Induret casting furnace for the fabrication of sputter targets and ingots
- Pumping system to evacuate samples in a quartz glass tube and to flush the tube with inert gas such as argon
- Tube furnaces
- Custom made single crystal growth furnace
- 5 custom made devices for magneto-mechanical testing
- PAR model 263 potentiostat/galvanostat
- PAR model 273A potentiostat/galvanostat

- Pine Instruments model 616 rotator for rotated disk electrodes
- Bruker 600 MHz Nuclear Magnetic Resonance (NMR) spectrometer
- Bruker 300 MHz Nuclear Magnetic Resonance (NMR) spectrometer
- Thermo Gas Chromatograph Trace Ultra/FID or ECD
- Thermo Gas Chromatograph Trace Ultra/ITQ 900 Mass Spectrometer
- Thermo SOLAAR AAS/graphite furnace spectrophotometer
- Agilent HPLC w/ Bruker HCT ultra ETD II MS
- Perkin Elmer FTIR/ATR (1)
- Jasco P-2000 Polarimeter
- Varian Cary 50 Bio UV-Vis Spectrophotometer
- Varian Cary 100 Bio UV-Vis Spectrophotometer
- Varian Cary Eclipse Fluorescence Spec
- Varian Cary 50 Bio UV-Vis SCI 306 UV-Vis
- EL Logic Imaging System SCI 306 photo
- Thermo FTIR/microscope/ATR/Raman SCI 361 Raman
- Dionix Ion Chromatograph SCI 361 IC
- VWR UV-Vis SCI 308 UV-Vis
- VWR UV-Vis SCI 308 UV-Vis
- PTI PL2300 N2 Laser w/PTI PL201 Dye Laser SCI 308 N2 laser
- Bruker Biospin LCMS SCI 300A LCMS
- Varian Cary 50 Bio UV-Vis SCI 300A UV-Vis
- Mathematica software
- Custom made coil winding apparatus with turn numerator

Peter Müllner

Professional Preparation
ETH Zürich, Swiss Fed. Inst. of Tech., Zürich, Mater. Eng., Diploma (M.S.), 1991
ETH Zürich, Swiss Fed. Inst. of Tech., Zürich, Mater. Eng., Dr. sc. techn. (Ph.D.), 1994

Appointments

2013-pres. Chair, Materials Science and Engineering, *Boise State University*, Boise, ID
2012 Visiting Professor, Physics, *University of Vienna*, Austria
2012-pres. Distinguished Professor, *Boise State University*, Boise, ID
2011-pres. Foundational Studies Program Faculty, *Boise State University*, Boise, ID
2009-pres. Professor, Mater. Sci. & Eng., *Boise State University*, Boise, ID
2006-2011 Director, Boise State Center for Mater. Characterization, *Boise State University*, Boise, ID
2004-2009 Associate Professor, Mater. Sci. & Eng., *Boise State University*, Boise, ID
1998-2004 Senior Researcher**,** *ETH Zürich, Institute of Applied Physics,* Zürich, Switzerland
1996-1998 Research Associate**,** *Max-Planck-Institute of Metals*, Stuttgart, Germany
1995 Post-doctoral Researcher**,** *University of Illinois*, Urbana, IL
1991-1994 Research Assistant**,** *ETH Zürich, Institute of Metal Research*, Zürich, Switzerland

Products: 139 published articles, 6 patents issued, 6 patents pending, h-index 25

Selected publications (closely related to proposal, * indicate undergraduate students)

1) P. Zheng, N. Kucza, Z. L. Wang, P. Müllner, D. C. Dunand, "*Effect of directionally solidification on texture and magnetic-field-induced strain in Ni-Mn-Ga foams with coarse grains*", Acta Materialia 86 (2015) 95-101.
2) B. Muntifering, R. C. Pond, L. Kovarik, N. D. Browning, P. Müllner, "*Intra-variant substructure in Ni-Mn-Ga: Conjugation boundaries*", Acta Materialia 71 (2014) 255-263.
3) C. S. Watson, C. Hollar*, K. Anderson*, W. B. Knowlton, P. Müllner, "*Magnetomechanical Four-State Memory*", Advanced Functional Materials (2013) 201203015.
4) D. C. Dunand and P. Müllner, "*Size effects on magnetic actuation in Ni-Mn-Ga shape-memory alloys*", Advanced Materials, **23** 216-232 (2011).
5) M. Chmielus, X. X. Zhang, C. Witherspoon, D. C. Dunand, and P. Müllner, "*Giant magnetic-field-induced strains in polycrystalline Ni-Mn-Ga foams*", Nature Materials **8** 863-866 (2009).

Selected publications (Others)

6) M. Reinhold*, D. Kiener, W. B. Knowlton, G. Dehm, and P. Müllner, "*Deformation twinning in Ni-Mn-Ga micropillars with 10M martensite*", Journal of Applied Physics **106** 053906 (2009).
7) M. Chmielus, V. A. Chernenko, W. B. Knowlton, G. Kostorz, and P. Müllner, "*Training, constraints, and high-cycle magneto-mechanical properties of Ni-Mn-Ga magnetic shape memory alloys*", The Europ. Phys. J. Special Topics **158** 79085 (2008).
8) P. Müllner, V.A. Chernenko, and G. Kostorz, "*Large cyclic magnetic-field-induced deformation in orthorhombic (14M) Ni-Mn-Ga martensite*", Journal of Applied Physics, **95** (3) 1531-1536 (2004).

9) P. Müllner, V.A. Chernenko, and G. Kostorz, "*Stress-induced twin rearrangement resulting in change of magnetization in a Ni-Mn-Ga ferromagnetic martensite*", Scripta Materialia, **49** (2) 129-133 (2003).
10) P. Müllner, V.A. Chernenko, M. Wollgarten, G. Kostorz, "*Large cyclic deformation of a Ni-Mn-Ga shape memory alloy induced by magnetic fields*", J. of Applied Physics, **92** (11) 6708-6713 (2002).

Synergistic Activities

- Chair of the ICFSMA'13 conference, June 3-7 2013, Boise ID, which is the main forum for the MSMA community.
- Foundational Studies Program Faculty since 2011; teaching a university foundations UF100 course for all incoming students; the course is entitled "Invention and Discovery in History and Society".
- Chairing and organizing international symposia/workshops including the symposium "Magnetostrictive and Magnetic Shape Memory Materials" at Actuator 2014, June 23-25, 2014, Berlin, Germany; the ICFSMA'13 conference, June 3-7 2013, Boise ID; MRS Spring Symposium Z "Materials Structures – The Nabarro Legacy", San Francisco, March 25, 2008 and Guest Editor for *Progress in Materials Science*, Vol. 54, Issue 6, Elsevier August 2009 Special Issue "The Nabarro Legacy – Perspectives for advanced materials in the 21st century"; and the international workshop 'Magnetic Shape Memory Alloys', Ascona, Switzerland, September 11-16. 2005.
- Director of the Boise State Center for Materials Characterization since 2006-2011.
- Organization and instruction of tutorials and teaching workshops including "Magnetic Shape Memory Alloys" at the MRS Fall Meeting 2009, Boston, MA; and the advanced training course 'Materials Science of Thin Films' of the German Society of Materials, Stuttgart, Germany, March 9-11, 1998.

Current Support:

Sponsor	Project Title	Amount	Project Period	Months Committed
DOE	Fracture Mechanisms and Fatigue of Magnetic Shape-Memory Alloys	$456,000	7/15/11–7/14/15	1 month
NSF	Mechanics of Magnetic Shape-Memory Nanostructure	$400,000	9/15/11–8/31/15	.4 months
NSF	MRI: Acquisition of a GPU-accelerated High Performance Computing and Visualization Cluster	$555,384	10/1/12–9/30/15	0 months
NSF	Collaborative Research: Size Effects on Magneto-mechanics of Ni-Mn-Ga Fibers	$346,345	7/15/12–6/30/15	.5 months
State Board of Education	Integral 3-D Strain Sensor, Phase II	$50,000	7/1/14–6/30/15	.25 months
NSF	REU Site: Materials for Energy and Sustainability	$320,000	3/1/14–2/28/17	0 months
Micron Foundation	Microfluidic devices based on MSM technology	$50,000	7/1/14–6/30/15	0 months
Nuclear Regulatory Commission	Materials for Nuclear Energy Systems Faculty Development Program	$430,000	8/1/14–7/31/17	0 months

Paul G. Lindquist

Professional Preparation

University of Illinois, Ceramic Engineering, Diploma (B.S.), 1978
University of Illinois, Materials Science and Engineering, Diploma (Ph.D.), 1988

Appointments

2009-pres. Research Assistant Professor, Mater. Sci. & Eng., *Boise State University*, Boise, ID
2008-2009 Post-doctoral Researcher, Mater. Sci. & Eng., Boise State University, Boise, ID
2004-2007 Research Engineer, Micron Technology, Boise, ID
2000-2004 Member of the Technical Staff, NuTool Inc., Milpitas, CA
1993-1998 Senior Research Engineer, SCP Global Technologies, Boise, ID
1988-1993 Advisory Engineer, IBM GTD, E. Fishkill, NY
1983-1988 Research Assistant**,** Materials Science and Eng., University of Illinois, Urbana, IL
1979-1983 Research Engineer, Reed Rock Bit Co., Houston, TX
1978-1979 Research Assistant**,** Northwestern University, Evanston, IL
1978 Summer Research Internship CMB-6**,** Los Alamos Scientific Laboratories, Los Alamos, NM

Products: 19 published articles, 5 patents

Selected publications (related to proposal)

1. Lindquist, P., Müllner, P., "Working Ni-Mn-Ga single crystals in a magnetic field against a spring load", Shape Memory and Superelasticity, to be published April, 2015
2. Zheng, Peiqi, Lindquist, P.,Yuan, B., Müllner, P. and Dunand, D., "Fabricating Ni–Mn–Ga microtubes by diffusion of Mn and Ga into Ni tubes", Intermetallics, Jan, 2014
3. Gaitzsch, U., McDonald, K., Müllner, P. and Lindquist, P., "Obtaining of Ni-Mn-Ga magnetic shape memory alloy by annealing electrochemically deposited Ga/Mn/Ni layers," *Thin Solid Films,* Nov, 2012.
4. Basol, B., Uzoh, C., Talieh, H., Wang, T., Guo, G., Erdemli, C., Mai, D., Lindquist, P., Bogart, J., Cornejo, M., Cornejo, Manual and Basol, E., "Planar Copper Electrodeposition and Electropolishing Techniques", NuTool Inc., 1645 McCandless Drive, Milpitas CA 95035, National AIChE Meeting, San Francisco, CA, Nov. 17-18, 2002, Symposium on "Metallization Processes in Semiconductor Device Fabrication"
5. Lindquist, P., Rosato, J.J., Fahrenkrug, J., and Olson, C.R., "A Novel Technique for Preventing Corrosion in BEOL Processes", Proc. of the 6th International SCP Symposium on Wafer Cleaning, Boise, ID. March 12, 1999.

Selected publications (others)

6. Lindquist, P. and Wayman, C.M., "Transformation Behavior of Ti_{50}-($Ni_{(50-X)}$, Pd) and Ti_{50}-($Ni_{(50-X)}$, Pt) Shape Memory Alloys", Materials Research Society Meeting, May, 1988, Japan.
7. Lindquist, P. and Wayman, C.M. "Structure of Ti_{50}-($Ni_{(50-X)}$, Pd) and Ti_{50}-($Ni_{(50-X)}$, Pt) Shape Memory Alloys", Materials Research Society Meeting, May, 1988, Japan.
8. Lindquist, P., Butler, J., Velichko, S., "In Situ Measurement and Control of SC-1 Chemistries", Third International Symposium on Ultra Clean Processing of Silicon Surfaces, Antwerp, Belgium, September, 1996.
9. Lindquist, P., Walters, R., Thorngard, J., and Rosato, J.J., "Determination of Rinsing Parameters Using a Wafer Gap Conductivity Cell in Wet Cleaning Tools", Ultraclean Semiconductor Processing Technology and Surface Chemical Cleaning and Passivation, Materials Research Society, V386, San Francisco, California, 1995.
10. Viswanadham, R.K. and Lindquist, P., "Transformation-Toughening in Cemented Carbides – I. Binder Composition Control", Metallurgical Transactions, Vol 18A, pp 2163-2173.

Synergistic Activities

As a Research Assistant Professor and working primarily in the laboratory I have:

1) Developed and taught courses in Materials Science and Engineering:
   a. Materials Processing
   b. Microelectronic Packaging
   c. Materials Selection
   d. Mechanical Behavior of Materials
   e. Materials Analysis Lab.
2) Mentored undergraduate and graduate students in all aspects of materials science, designing experiments and building new research equipment for mechanical, magnetic and electrical testing.
   a. Theodore Lawrence from September of 2012 to present. Ted is a graduate student working affect of surface treatment of Ni-Mn-Ga single crystals on fatigue and fracture mechanical behavior. M.S. completed Dec. 2014.
   b. Ken McDonald from June of 2010 till May of 2011. Ken's primary focus was setting up the lab for electrochemical deposition of Ni, Mn and Ga thin films, thin film plating, heat treating and materials analysis using the SEM, VSM and XRD.
   c. Jessica Drache and Uwe Gaitzsch, two visiting researchers from Leibniz-IFW Dresden. The team made a lot of progress in the fall of 2010 depositing layers of Ni, Mn and Ga that was alloyed by heat treatment with the structure and magnetic properties of NiMnGa magnetic shape memory alloys.

No current support.

Aaron R. Smith

Professional Preparation
Boise State University, Idaho, Mech. Eng., Diploma (B.Sc.), 2012
Lappeenranta University of Technology, Finland, Mater. Techn., Dr. Sc. Techn., (Ph.D.), 2015
Dissertation title: "*Control of the crystallographic twin configuration of 5M Ni-Mn-Ga for the development of applications*"

Appointments
2012-Pres. Project Manager, Mater. Techn., Lappeenranta University of Technology, Finland
2011-2012 Research Assistant, Mater. Scie. & Eng., Boise State University, Boise, ID

Products: 6 published articles, 1 patent pending, 2 invention disclosures

Publications

1) D. Musiienko, A. R. Smith, A. Saren & K. Ullakko, "*Stabilization of a fine twin structure in Ni-Mn-Ga by a diamond-like carbon coating*", Scripta Materialia, Accepted March 27, 2015, *In press*
2) A. R. Smith, A. Saren, J. Järvinen & K. Ullakko, "*Characterization of a high resolution solid state micropump that can be integrated into microfluidic systems*", Microfluidics and Nanofluidics **1** 1-9 (2015)
3) A. R. Smith, J. Tellinen & K. Ullakko, "*Rapid actuation and response of NI-Mn-Ga to magnetic-field-induced stress*", Acta Materialia, **80** 373-379 (2014)
4) A. Smith, J. Tellinen, P. Müllner & K. Ullakko, "*Controlling twin variant configuration in a constrained Ni-Mn-Ga sample using local magnetic fields*", Scripta Materialia **77** 68-70 (2014)
5) K. Ullakko, L. Wendell, A. Smith, P. Müllner & G. Hampikian, "*A magnetic shape memory micropump: contact-free, and compatible with PCR and human DNA profiling*", Smart Materials and Structures, **21** 115020 (2012
6) D. Kellis, A. Smith, K. Ullakko & P. Müllner, " *Oriented single crystals of Ni-Mn-Ga with very low switching fields*", J. of Crystal Growth **359** 64-68 (2012)

Patents and Invention Disclosures

1) K. Ullakko, P. Mullner, G. Hampikian & A. Smith, " *Actuation method and apparatus, micropump and PCR enhancement method*", Boise State University, Patent (Pending), Submitted September 2012
2) A. Smith & K. Ullakko, "*Planar flow controller for microfluidic devices using magnetic shape memory alloy*", Lappeenranta University of Technology, Invention Disclosure, Submitted June 2014
3) K. Ullakko, A. Smith & A. Saren, "*Flow controller constrained in a rigid body*", Lappeenranta University of Technology, Invention Disclosure, Submitted June 2014

International Conference Presentations

1) Poster: "*Rapid control of local twin configuration in Ni-Mn-Ga*", IC of Martensitic Transformations, Bilbao, Spain (2014)
2) Oral: "*Precise, wireless control for rapidly actuating devices*", ACTUATOR 2014**,** Bremen, Germany (2014)
3) Oral: "*A new player in microfluidics: Magnetic shape memory alloys*", IC of Functional Materials, Crimea, Ukraine (2013)
4) Oral: "*Controlling twin variant configuration in Ni-Mn-Ga using local magnetic fields*", IC of Ferromagnetic Shape Memory Alloys, Boise, ID, USA (2013)

Academic Awards

- Top Ten Scholar at Boise State University (2012)
- National Science Foundation Scholar (2007)

No current support.

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Randy Werneth
Acutus Medical

Idaho State Board of Education
Higher Education Research Council
Idaho Incubation Fund Program

March 17, 2015

To Whom It May Concern:

This letter is written in support of the development of the project proposal *Solid State Positioning Device* of Dr. Mullner at Boise State University.

Acutus Medical is committed to pioneering a breakthrough technology to optimize the treatment strategies for complex cardiac arrhythmias such as Atrial Fibrillation (AFib) by developing innovative, safe, efficacious, and cost-effective solutions for individuals suffering from these complex cardiac arrhythmias. Our mission is to develop and market a new leap-frog platform technology which will take the treatment from a strategy based approach to a medical evidence based approach. We believe this will completely revolutionized the way Electrophysiologist operate on these patients. Our current platform is a real-time imaging of the heart chamber (CT Scan Quality), then overlaid on the heart chamber is the real-time electroactivation map of the entire heart chamber, beat by beat. Our resolution is approx. 5 times an improvement over current technology, this added to our real-time aspect, our CT quality imaging of the heart will allow Physicians a look at the heart as they have never seen prior to Acutus Medical.

Through this partnership, we hope to be able to add a robotic catheter to our platform. By delivering to the market, a robotic catheter to deliver the therapy, will can not only show them the exact cause of the arrhythmia but we can also guide the therapy to the exact location in which the therapy is needed for a safe and effective treatment.

We offer to this project in-kind support consisting of the following:

- Establishing parameters for a linear positioning device
- Helping to transition the project from bench-top testing to practical use
- Provide trials of the machine integrated in a prototype surgical machine

We are pleased to be an industry partner with Boise State University on this project.

Sincerely,

Randy Werneth
President & CEO

Headquarters

10840 Thornmint Road, Suite 100
San Diego CA 92127

Advanced Technology Research
Yanke Family Research Park
220 E. Park Center Blvd.
Boise, Idaho 83706

Appendix D: References

[1] http://research.boisestate.edu/areas-of-research-strength-at-boise-state-university/

[2] http://www.thecoreidaho.com/

[3] http://acutusmedical.com/

[4] http://www.marketsandmarkets.com/Market-Reports/minimally-invasive-surgical-instruments-devices-market-682.html

[5] K. Ullakko, L. Wendell, A. Smith, P. Müllner, G. Hampikian, *A magnetic shape memory micropump: contact-free, and compatible with PCR and human DNA profiling*, Smart Mater. Struct. 21 (2012) 115020.

[6] S. Barker, E. Rhoads, P. Lindquist, M. Vreugdenhil, P. Müllner, *Micropump utilizing localized magnetic-field-induced deformation of MSM elements to deliver sub-microliter volumes of drugs to the rat brain*, Proceedings of ACTUATOR 2014, 14th Int. Conf. on New Actuators, Bremen, Germany, June 23-25, 2014, pp. 96.

SUMMARY PROPOSAL BUDGET

Name of Institution: Boise State University

Name of Project Director: Dr. Peter Mullner

A. PERSONNEL COST (Faculty, Staff, Visiting Professors, Post-Doctoral Associates, Graduate/Undergraduate Students, Other)

Name/ Title	Salary/Rate of Pay	Fringe	Dollar Amount Requested
Dr. Peter Mullner, Professor & Chair, one-half month over project period	$169,084/yr	27%	$8,948
Dr. Paul Lindquist, Research Engineer, 3 months over project period	$63,914/yr	38%	$22,050
Post-Doctoral Associate, 3 months over project period	$50,000/yr	42%	$17,750
Undergraduate Research Assistants, 2 for 500 hrs each over project period	$12/hr	4% academic year & 10% summer	$12,452

% OF TOTAL BUDGET:	81.60%	**SUBTOTAL:**	$61,200

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

Item/Description	Dollar Amount Requested
SUBTOTAL:	

G. TRAVEL:

Dates of Travel (from/to)	No. of Persons	Total Days	Transportation	Lodging	Per Diem	Dollar Amount Requested
To be determined / Development of industry partnerships	2-3	2-3	$200	$500	$300	$1,000
					SUBTOTAL:	$1,000

H. Participant Support Costs:	Dollar Amount Requested
1. Stipends	
4. Other	
SUBTOTAL:	$0

I. Other Direct Costs:	Dollar Amount Requested
1. Materials and Supplies Consumable supplies (crucibles, gasses, raw materials Ni, Mn, Ga, lab supply, data acquisition cards, computer dedicated to the SSLSP device, soft iron for magnet cores, copper wire for windings, electronic parts)	$8,500
2. Publication Costs/Page Charges	
3. Consultant Services (Include Travel Expenses)	
4. Computer Services	
5. Subcontracts	
6. Other (specify nature & breakdown if over $1000) Analytical fees for materials characterization at the Boise State Center for Materials Characterization, estimated at 66 hours of usage @ $35/hour. Rapid prototyping at the Idaho TechHelp New Product Development Lab	$4,300
SUBTOTAL:	$12,800
J. Total Costs: (Add subtotals, sections A through I) TOTAL:	$75,000
K. Amount Requested: TOTAL:	$75,000
Project Director's Signature: [signature]	Date: 3/27/2015

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)

In-kind support from Actus Medical:
- Establishing parameters for a linear positioning device
- Helping to transition the project from bench-top testing to practical use
- Provide trials of the machine integrated in a prototype surgical machine