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:
The goal of this project is to build an MSM micropump operated by the SSDS for applications specified by our primary industry partner Shaw Mountain Technology LLC. This device will be useful for various applications in the medical and semiconductor sectors and potentially in the automotive sector. We will build a prototype "solid-state drive system" (SSDS) actuator device for medical and industrial applications.

PROJECT START DATE: July 1, 2016	PROJECT END DATE: June 30, 2017
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 MSE	Not required
CO-PRINCIPAL INVESTIGATOR	Dr. Nader Rafla	Associate Professor, Chair ECE	Not required

NAME OF PARTNERING COMPANY: Shaw Mountain Technology LLC	COMPANY REPRESENTATIVE NAME: Aaron Smith

	NAME:	SIGNATURE:
Authorized Organizational Representative	Karen Henry, Executive Director	Karen Henry 4/1/16

Solid State Drive System

1. Name of Idaho public institution

Boise State University

2. Name of principal investigator directing the project

Dr. Peter Müllner (PI, MSE), Dr. Nader Rafla (co-PI, ECE)

3. Indicate the technology being proposed

We will build a prototype “solid-state drive system” (SSDS) actuator device for medical and industrial applications. This is a continuation request for a multi-year project.

a) The original proposal “Solid State Positioning Device” was submitted in April 2015.

b) The first project phase demonstrated proof of concept, secured additional intellectual property, and resulted in a local company, Shaw Mountain Technology LLC (SMT [1]), licensing intellectual property from Boise State University. This request proposes to develop the new intellectual property into a prototype that meets industry specifications.

4. Executive Summary

We develop the “material machine”, a device consisting of an actuation mechanism and a morphing magnetic shape memory (MSM) alloy, which substitutes mechanical parts. We demonstrated the material machine with a micropump for medical research. To make the device fully “solid state”, we propose to develop a solid state drive system (SSDS) to control the micropump electrically. The SSDS consists of a yoke, a set of small magnets, and a set of coils. The goal of this project is to build an MSM micropump operated by the SSDS for applications specified by our primary industry partner SMT. This device will be useful for the medical, the semiconductor, and the automotive sectors. Boise-based SMT is a start-up company registered by the PI in the State of Idaho. SMT aims to produce high-quality advanced technology with product development, manufacturing and company operations located within Idaho. SMT specializes in shape memory alloys, particularly the MSM alloy Ni-Mn-Ga, and develops various technologies within the fields of sensors, microfluidics, energy harvesters and actuators.

5. Gap Projects Objective and Total Amount Requested

In existing MSM devices such as the micropump [2,3], a rotating magnet controls the MSM element. The MSM micropump replaces the functionality of the traditional pumping mechanism by the material machine. Unlike any other technology, this mechanism works without a single moving part. This feature creates unprecedented opportunities for micro-devices. However, the current prototype micropump, is driven by an electro motor. Thus, the drive system nullifies the unique advantage of producing mechanical work without moving parts. The goal of this project is to replace the electromotor with a *solid state* drive system. The project objectives are

a. To develop a solid state drive system for actuating an MSM element.
b. To drive an MSM micropump and a long-stroke actuator with the solid state drive system.
c. To build a prototype for a solid state driven micropump to industry specifications at technology readiness level (TRL) 9 for medical applications.

Total amount requested for the second year: $75,000.

6. Resource commitment and priorities of Boise State University

Boise State University lists five research strengths/priorities [4] including (1) Materials Science (2) Geosciences, (3) Sensors, (4) Public Policy (including economic development, access to health care, strong civic leadership, clean environment, and affordable energy), and (5) Creative Writing. The proposed project covers three of these areas by advancing novel materials (area 1), developing an integrated system of actuators and sensors (area 3), and developing technology for the health sector (area 4). Thus, this project fully aligns with institutional priorities. Boise State 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

Twelve years of MSMA research at Boise State, availability of a trained workforce, and access to international MSMA research suggest the potential for a real impact to Idaho's economy. This research secured MSM-related intellectual property which has recently been licensed to SMT. This project will help facilitate the growth of this new MSM industry in Idaho.

7.a International Leadership at BSU

Dr. Müllner collaborates with many international scientists in the MSM field in countries such as Germany, England, Spain, Italy, Switzerland, Austria, China, and Japan. With these contacts, he sustains 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, Dr. Müllner and ETO Magnetic GmbH (Stockach, Germany) created the interest group MSM Net [5] with the goal to advance MSM technology transfer. Bringing ICFSMA to Boise demonstrates the recognition of Boise State University as a globally leading institution in the field.

7.b Why Southwest Idaho?

Since 2004, more than forty (40) undergraduate and graduate students have worked in the Magnetic Materials Laboratory and received in-depth training on MSMA. Many Materials Science and Engineering graduates prefer employment in the Treasure Valley 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 and that is why the PI Müllner founded SMT (section 10.1) in Boise in 2015. Finally, this project will attract venture capitalists to invest in the Treasure Valley. This is the first technology project of a series of further technology development efforts. Thus, this project will initiate a new industry in Idaho.

Future industry partners may include car manufacturers, 3M, Medtronic, or Lockheed Martin.

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

PI Müllner holds eight patents, has several patents pending on this technology, and continuously develops new MSM technology. 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 20, 2015	***Shaw Mountain Technology LLC*** registered with State of Idaho
July 1, 2015	***Shaw Mountain Technology LLC*** hires Dr. Aaron Smith
March 17, 2015	Collaboration established with ***Acutus Medical Inc.*** [6]
November 19, 2015	***Shaw Mountain Technology LLC*** licenses Boise State University's inventions "Apparatus for Multi-axial Actuation" (BSU file 90), "Micropump for Biomedical Diagnostic" (BSU file 96), and "Actuation method and apparatus, micropump, and PCR enhancement method" (BSU file 122), and US Patent No. 9,091,251.
December 11, 2015	***Shaw Mountain Technology LLC*** (PI) and Boise State University (Co-PI) submit an STTR Phase I proposal "MSM µPump: Precision Dosing for Laboratory Research) to the National Science Foundation.
February 25, 2016	***Shaw Mountain Technology LLC*** and Boise State University establish an Option Agreement "Actuation via Magnetic Torque Driven Deformation" (BSU file 144), "Self-Resetting Power Breaker" (BSU file 174) and U.S. Patent Applications serial Nos. 62/131,729 and 62/218,685, respectively.
March 11, 2016	Boise State University files conversion of provisional patent 61/968,863 (BSU files 144 and 174).
March 31, 2016	Boise State University files patent application for BSU file 188.
April, 2016	***Shaw Mountain Technology LLC*** and Boise State University negotiate an Option Agreement on "Electrically driven magnetic shape memory apparatus" (BSU file 158) and "Permanent-magnet-assisted electrically driven magnetic shape memory apparatus" (BSU file 188, as CIP to 158).

8. The Market Opportunity

8.a Need addressed by the project

Microfluidic systems such as the lab-on-a-chip, minimally invasive surgery, and positioning devices on micro-satellites, are but a few examples of industry sectors that rely on the miniaturization of actuators. Many contemporary actuators make use of a conventional electromotor and a crankshaft mechanism to produce linear motion or to transport fluid. Such technology bears severe limitations towards miniaturization. In particular, friction associated with rotational motion increases with decreasing size and prevents motion at very small scale. A technology is needed for building friction-free actuators. Such technology must avoid rotational motion. MSM provides a unique solution.

8.b Applications and markets for the technology

The microfluidic market is projected to exceed $5 billion in 2018 [7]. The MSM micropump is but one example in which the SSDS enables a frictionless actuator. The SSDS may also create linear motion for minimally invasive surgery which is a rapidly growing multi-billion dollar market with the forecast to double within the next five years exceeding $14 billion in 2019 [8]. For example, an SSDS-driven positioning device will enable instruments such as the real-time imaging apparatus of Acutus Medical.

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

The product is a motionless drive system for micro-devices such as a micropump or a fast and precise long-stroke actuator. There are many target audiences (market audiences) such as diabetics needing accurate and temporally adjustable delivery of insulin, 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) for added security measures. The novelty of the MSM technology presents a barrier to the market. To overcome this barrier, we target research laboratories as first adopters. 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 schizophrenia. He was unable to perform new experiments because he could not find a small, lightweight pump that could consistently deliver very small drug doses to the brains of live rats. The lack of a commercial solution led Vreugdenhil to review scientific literature where he identified our 2012 paper [2] 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

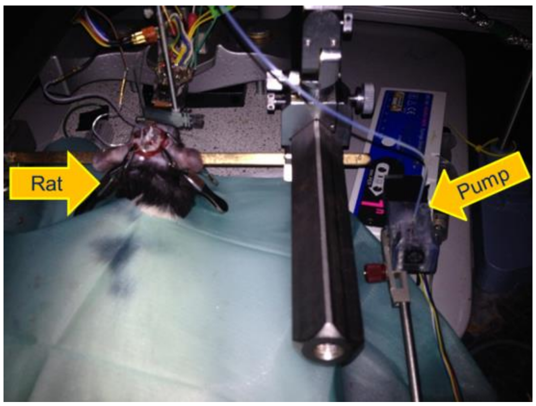

Fig. 1: First drug-delivery pump experiment performed at the University of Birmingham, England.

In April 2014, the PI Müllner collaborated with TechHelp to develop a working product for Vreugdenhil. Undergraduate students contributed to the pump development, 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 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 [3]. This micropump is the first MSM device that successfully uses MSM technology to solve a problem.

Since we are describing a technology not seen 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. 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.

MSM technology is similar in concept to the "liquid metal" robot. Although not humanoid, MSM does shape-shift in response to magnetic fields. Apply a magnetic field, and the material responds with a shape change. Apply a different magnetic field and the material re-forms into a new shape. Do this quickly and with purpose and you have a small machine.

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

The SSDS is an enabling technology that lets the MSM micropump and other MSM technologies (positioning devices, valves, etc.) work without moving parts. Three patents for the SSDS “Electrically driven magnetic shape memory apparatus” (BSU file 158), “Magnetic shape memory apparatus with long stroke” (BSU file 169), and “Permanent-magnet-assisted electrically driven shape memory apparatus” (BSU file 188) are pending. Furthermore the SSDS enables the effective development of several Boise State inventions including “Apparatus for Multi-axial Actuation” (BSU file 90), “Micropump for Biomedical Diagnostic” (BSU file 96), “Actuation method and apparatus, micropump, and PCR enhancement method” (BSU file 122), and US Patent No. 9,091,251, which was recently licensed by SMT.

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 $3.6 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 solid state actuation mechanism as described in BSU file 188,
ii. Demonstrating a MSM micropump and a long-stroke actuator with the SSDS,
iii. Prototyping a solid state driven micropump to industry specifications at technology readiness level (TRL) 9 for medical applications.

10. Commercialization Partners

10.1 Shaw Mountain Technology LLC

Peter Müllner established Shaw Mountain Technology LLC [1] in January 2015 in Boise, Idaho.

SMT manufactures high-quality, advanced technology in Idaho and is initially focused on devices utilizing MSM alloys. SMT has licensed Boise State micro-pump technology and plans on licensing technology developed by this project. They will support this project by (i) exploring market opportunities for the MSM micro-pump, (ii) identifying and contacting early adopters, and (iii) developing specifications for an MSM micro-pump.

10.2 Acutus Medical Inc.

Acutus Medical [6] pioneers 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 revolutionize the way electrophysiologists operate on these patients. In March 2016, Acutus Medical secured additional $75 million to develop a complete product portfolio [9]. The PI established collaboration with Acutus Medical in 2015. After demonstration of the SSDS at the MSM micropump, we the PIs plan to develop a long stroke actuator for heart surgery. Acutus Medical may then provide in-kind support consisting of (i) establishing parameters for a linear positioning device, (ii) helping transition the project from bench-top testing to practical use, and (iii) providing trials of the device integrated in a prototype surgical machine.

11 Specific Project Plan and Detailed Use of Funds

11.1 The project budget is outlined in Table 2

Table 2: Budget by category

Budget Category	Amount ($)
Salary (PI, co-PI, graduate student, UG students) plus fringe benefits and fees	62,900
Other Expenses including materials and supplies (crucibles, gasses, raw materials Ni, Mn, Ga, lab supply, data acquisition cards, computer dedicated to the SSDS device, soft iron for magnet cores, permanent magnets, copper wire for windings, electronic parts), rapid prototyping in New Product Development	11,100

Lab (Idaho TechHelp), fees for material characterization at the Boise State Center for Materials Characterization	
Travel domestic (development of industry partners)	1,000
Total	**75,000**

11.2 The project team and responsibilities are outlined in Table 3

Table 3: Team members, functions, and responsibilities

Team member	Function	Responsibilities
Dr. P. Müllner	PI, team lead, MSE expert	Project oversight, coordination, industry contact, mentor students
Dr. N. Rafla	Co-PI, ECE expert	Mentor ECE undergraduate student
A. Armstrong	MSE graduate student	Design and building of micro devices
J. Freilich	MSE undergraduate student	Crystal growth and MSM element preparation
K. Finn	ECE undergraduate student	Programming and electrical control

11.3 Current state of development

We tested a proof-of-concept device and demonstrated creating concentrated, localized magnetic fields with small coils and demonstrated experimentally the actuation of an MSM element. We also performed finite element analysis calculations for various device parameters such as number windings and amount of current flowing in them. We also tested the effect of including permanent magnets in the magnetic circuit. Figure 2 shows magnetic flux line distributions in a system which includes permanent magnets indicating a high selectivity between active and passive pole which is desirable for this technology.

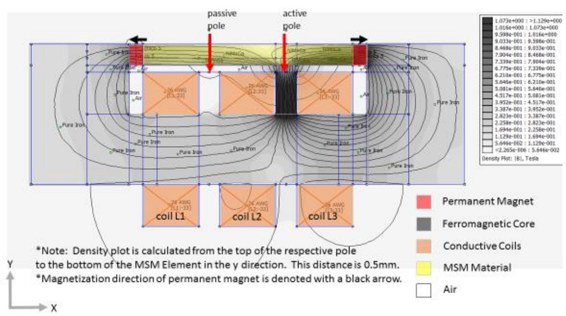

Fig. 2: Permanent-magnet-assisted electrically driven MSM alloy device with three coils (orange), iron core (gray), MSM element (yellow), and two permanent magnets (red). The flux lines are highly concentrated in the active pole (right) and vastly diluted in the passive pole (left).

11.4 Project tasks

Project tasks include

a. Developing an SSDS for actuating an MSM element

b. Driving an MSM micropump and a long-stroke actuator with the SSDS

c. Building a SSDS driven MSM micropump to industry specifications at technology readiness level (TRL) 9 for medical applications.

11.4 Project plan

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

Table 4: Timeline and milestones of year 2

No.	Milestone	Qt. 1			Qt. 2			Qt. 3			Qt. 4		
1	Purchase materials												
2	Build proof-of-concept solid state drive system (SSDS)												
3	Characterize proof-of-concept system												
4	Design prototype SSDS1 for micropump												
5	Build micropump and SSDS1												
6	Assemble and characterize micropump and SSDS1												
7	6-month report												
8	Define micropump specifications (***Shaw Mountain Tec***)												
9	Magnetic circuit FEM analysis												
10	Design SSDS2												
11	Purchase materials												
12	Build SSDS2												
13	Device characterization												
14	Proposal for funding continuation												
15	Final project report and request for funding												

12. Institutional and Other Sector Support

New materials are 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 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 now includes six departments and 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.

SMT commits to provide in-kind support consisting of (i) exploring market opportunities, (ii) identifying early adopters, and (iii) developing specifications.

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

Appendix B: Biographical sketches

Dr. Peter Mullner, PI

Dr. Nader Rafla, Co-PI

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: 149 published articles, 8 patents issued, 5 patents pending, h-index 26

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

1) T. Lawrence, P. Lindquist, K. Ullakko, P. Müllner, "*Fatigue life and fracture mechanics of unconstrained Ni-Mn-Ga single crystals in a rotating magnetic field*", Materials Science and Engineering A 654 (2016) 221-227.
2) B. Muntifering, L. Kovarik, N. D. Browning, R. C. Pond, W. B. Knowton, P. Müllner, "*Stress-assisted removal of conjugation boundaries in non-modulated Ni-Mn-Ga by coordinated secondary twinning*", Journal of Materials Science 51 (2016) 457-466.
3) P. L. Lindquiest, P. Müllner, "*Working Ni-Mn-Ga single crystals in a magnetic field against a spring*", Shape Memory and Superelasticity 1 (2015) 69-77.
4) 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.
5) D. C. Dunand and P. Müllner, "*Size effects on magnetic actuation in Ni-Mn-Ga shape-memory alloys*", Advanced Materials, **23** 216-232 (2011).

Selected publications (Others)

6) 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).
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.

Current Awards

Sponsor	Project Title	Amount	Project Period	Months Committed
NSF	Collaborative Research: Size Effects on Magneto-mechanics of Ni-Mn-Ga Fibers	$346,345	7/15/12–6/30/16	.5
Nuclear Regulatory Commission	Materials for Nuclear Energy Systems Faculty Development Program	$430,000	8/1/14–7/31/17	0
NSF	PFI: AIR-TT: Motionless MSM Micro-pump	$199,955	7/1/15-12/31/16	.5
NASA	Large Stroke Low Power Magnetic Shape Memory Actuators - Proof of Concept	$25,000	6/1/15-5/31/16	.44

Nader I. Rafla

Associate Professor, and Chair
Department of Electrical & Computer Engineering (Phone) 208-426-3711
Boise State University (FAX) 208-426-2470
1910 University Dr. Boise, ID 83725-2075 (E-mail) nrafla@boisestate.edu

PROFESSIONAL PREPARATION:

Case Western Reserve University Cleveland, Ohio	Ph.D. & MSEE	1991, 1982 respectively
Helwan University Cairo, Egypt	MSEE & BSEE	1980, 1978 respectively

APPOINTMENTS:

2014 – Present Chair, Electrical and Computer Engineering Department, Boise State University, Boise, Idaho

1997 – 2014 Associate Professor, Electrical and Computer Engineering Department, Boise State University, Boise, Idaho

1991 – 1997 Assistant, Associate Professor, Manufacturing Engineering Department, Central State University, Wilberforce, Ohio

OTHER RELATED APPOINTMENTS:

Summer 2011 General Chair, 55th IEEE International Midwest Symposium on Circuits and Systems (MWSCAS2012), Boise ID. **Duties**: manage all arrangements for hosting the symposium along will all its technical aspects

Summers 2002 – 2007 R&D Scientist and Consultant, ASCI, Inc., Boise ID. **Duties:** Manage a team of engineers, graduate, and undergraduate students to develop Intellectual Property (IP) Hardware using HDL for different aspects of digital image caption, generation, transmission, and display

MOST RELEVENT PUBLICATIONS

1. Fady Hussien, Luka Daoud, and Nader Rafla, "Low-Complexity and Resource-Aware Compression Algorithm for FPGA Bitstreams," *International Conference in Computers and Their Applications, CATA-2016*
2. Danyal Mohammadi and Nader Rafla, "Optimized Fixed-Point FPGA Implementation of SVPWM for a Two-Level Inverter," *ACM/SIGDA International Symposium on Field-Programmable Gate Arrays, 2/2015*
3. Nader Rafla and Nick Pauly, " An Automated embedded system for Object Measurement," *Proceedings of the International Midwest Symposium on Circuits and Systems, 8/2013*
4. Rafla, Nader I., "Teaching Hardwar Implementation of Digital Signal Processing Algorithms on FPGA," *119th ASEE Annual Conference and Exposition, San Antonio, TX,* 6/2012

5. Rafla, Nader and Gauba, Deepak, "Hardware Implementation of Context Switching for Hard Real-Time Operating Systems," *Proceedings of the 54th IEEE International Midwest Symposium on Circuits and Systems, 8/2011*
6. Nader Rafla, and Sarath Giri, *"A Programmable Pattern Generator for Memory Testing on a Programmable Chip,"* Submitted to the IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems, February 2010
7. Nader I. Rafla and Steve Bard, "Reducing Power Consumption in FPGAs by Pipelining," Proceedings of the 51st IEEE International Midwest Symposium on Circuits and Systems (MWSCAS), Knoxville, TN, 8/2008

SYNERGISTIC ACTIVITIES

- Participated in grant proposal review for NSF/CCLI Proposals - 2009;
- Active member of the Steering Committee of the IEEE/MWSCAS conference since 2005. Will be the General Chair of the conference for 2012 in Boise, Idaho;
- Technical Editor, Analog Integrated Circuits and Signal Processing Journal for MWSCAS2012
- Currently supervising 3 Ph.D. Dissertations and 3 MSEE Thesis advisor

CURRENT AWARDS

Sponsor	**Title**	**Project Period**	**Award Amount**	**Months Effort**
NASA	Large Stroke Low Power Magnetic Shape Memory Actuators – Proof of Concept	6/1/15 – 5/31/16	$25,000	.4

Appendix C: Other Sector Support

Higher Education Research Council
Re: Letter of Collaboration for Solid State Drive System project, Prof. Müllner

To the proposal review committee:

It is my pleasure to be an industrial partner with Boise State University, and I enthusiastically support Prof. Müllner's development project proposal "Solid State Drive System."

Let me briefly introduce myself. I first met Prof. Müllner as an undergraduate research assistant in his Magnetic Materials Laboratory during my Mechanical Engineering undergraduate degree from Boise State University in 2012. I then attended graduate school in Finland where I obtained a PhD in Material Technology where I continued similar research. I specialized in the development of technical applications using magnetic shape memory (MSM) alloys, specifically microfluidic devices. I returned to Boise in Summer 2015 and joined Shaw Mountain Technology LLC (SMT) as senior engineer. SMT currently develops MSM technology with the goal of keeping all its operations in Boise.

Prof. Müllner has been a pioneering researcher in the field of MSM alloys and is internationally recognized for his research on magneto-mechanics. His research has resulted in several patents protecting MSM technology. Shaw Mountain Technology LLC has licensed this technology from Boise State and is currently developing and producing MSM micropumps to be used within the medical industry. We are raising funds through federal sources such as the SBIR/STTR programs of the National Science Foundation, the Department of Energy, the Department of Defense and the National Institute of Health.

A key advantage of MSM technology is that the MSM material can create mechanical motion without classical mechanical parts, such as gears, pistons, etc. In order to the complement this material advantage, a driving system must be developed that also has no moving parts, thus creating a system-wide, technological advantage. The proposed project supports this goal. The results of this project benefit a variety of MSM technologies including SMT's current priority, the MSM µPump. As such, it is my pleasure to extend the full support of SMT to the benefit of this project and Prof. Müllner's developments. We are committed to providing the following support:

- Customer discovery and validation of the MSM µPump
- Identifying and contacting early adopters interested in the technology
- Determining market-driven specifications needed for a minimal viable product

The results of this project will strengthen the advantages of MSM technology which will in turn benefit the Idaho economy. I therefore strongly recommend the funding of this project proposal.

Sincerely,

Aaron R. Smith, PhD
(208) 918-9981
aaronsmith@shawmountaintechnology.com

Appendix D: References

[1] http://www.shawmountaintechnology.com/home.html

[2] 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.

[3] 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.

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

[5] MSM Net, http://www.themsmnet.net/

[6] http://acutusmedical.com/

[7] Yole Developpement, *How will microfluidics applications change the material mix and quadruple the microfluidic device market in the next five years?*, Lyon, France, June 6, 2013, http://www.yole.fr/iso_upload/News/2013/PR_MicrofluidicsApplications_YOLE%20DEVELOPPEMENT_June2013.pdf

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

[9] http://www.businesswire.com/news/home/20160322005272/en/Acutus-Medical-Completes-75-Million-Series-Financing

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	$13,901/mo	$1,933	$9,100
Dr. Nader Rafla, Research Engineer, one-half month over project period	$10,500/mo	$1,730	$7,100
Graduate Student, Andrew Armstrong, 75%	$20,250/yr	$4,400	$24,600
Undergraduate Research Assistants, 2 for 500 hrs each over project period	$12/hr	$800	$12,800

% OF TOTAL BUDGET:	71%	SUBTOTAL:	$53,600

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 SSDS device, soft iron for magnet cores, permanent magnets, copper wire for windings, electronic parts) fees for materials characterization at the Boise State Center for Materials Characterization, small mechanical parts, rapid prototyping at the Idaho TechHelp New Product Development Lab	$11,800
2. Publication Costs/Page Charges	
3. Consultant Services (Include Travel Expenses)	
4. Computer Services	

5. Subcontracts	
6. Student fee	$8,600
SUBTOTAL:	$20,400
J. Total Costs: (Add subtotals, sections A through I) TOTAL:	$75,000
K. Amount Requested: TOTAL:	$75,000
Project Director's Signature: Not required	Date:

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 Shaw Mountain Technology LLC: - Customer discovery and validation of the MSM micro-pump - Identifying and contacting early adopters interested in the technology - Determining market-driven specifications needed for a minimal viable product	