Idaho Incubation Fund Program

Final Report Form

Proposal No. **IF14-005**
Name: **Peter Müllner**
Name of Institution: **Boise State University**
Project Title: **Integral 3-D strain sensor**

Information to be reported in your final report is as follows:

1. Provide a summary of overall project accomplishments to include goals/milestones met, any barriers encountered, and how the barriers were overcome:

This project constitutes Phase I of a two year plan as detailed in the project proposal. During this one-year *Phase I* effort, our objectives were to:

a) Develop a MSMA/elastomer composite transducer material as basis for a sensor device

b) Develop a drive/detect coil system with control electronics.

c) Demonstrate 3D sensor functions.

We have nearly completed *Phase I*, having successfully achieved goals a) and b) and are making good progress towards goal c). As forecast in last year's proposal, *Phase II* will build on *Phase I* outcomes. This *Phase II* is currently in progress.

Specific outcomes:

a) *Activities for identifying industry partners*: The kick-off meeting of MSM-Net is scheduled for the ACTUATOR 2014 conference June 23-25, 2014, in Bremen, Germany. The purpose of MSM-Net is to connect researchers and industrial developers and bringing our technology to the market. We have invited 10 core members. Müllner will co-chair this meeting on June 25, 2014.

b) *Research activities*: We produced Ni-Mn-Ga single crystal powders by crushing single crystals and annealing the powders. With X-ray diffraction, we demonstrated the desired crystallographic structure. With magnetization experiments, we demonstrated successfully a low switching field of 200 mT, which is clearly below the specified upper limit of 300 mT ensuring high twin mobility. We identified and purchased elastomer matrix material, produced Ni-Mn-Ga/elastomer composites, and performed preliminary mechanical experiments. We made double-coils for 1-D sensor tests and measured the strain-induced change of coil inductance at a single crystal.

We oriented Ni-Mn-Ga single crystal powders in a magnetic field and determined the switching fields in well-defined orientations which was 200 mT. From these powders, we produced Ni-Mn-Ga composites by curing the elastomer/Ni-Mn-Ga mixtures in a magnetic field. The magnetic field aligned the powder particles with the crystallographic c direction parallel to the magnetic field. At the same time, the magnetic field aligned particles in lines. We then performed in-situ x-ray diffraction experiments where the Ni-Mn-Ga/elastomer composite was deformed while scattered x-ray intensity was recorded. During the deformation experiment, the intensity of the 004 reflection decreased and the intensity of the 400 reflection increased until the ratio of these intensities had reversed. This result confirmed the strain induced motion of twin boundaries which interchanges the 100 and 001 directions, and provides a prove of concept of using Ni-Mn-Ga/elastomer composites as transducers for strain sensors.

2. Describe the current state of the technology and related product/service:

We have demonstrated single particles with low switching field and implemented these particles to form a particle/polymer composite. We have also built a a drive/detect coil system with control electronics. We further demonstrated the sensor functionality on Ni-Mn-Ga single crystals.

3. List the number of faculty and student participants as a result of funding:

Three faculty (Dr. Peter Müllner, PI; Dr. Nader Rafla, co-PI; Dr. Paul Lindquist, assistant research professor), one graduate student (Tony Hobza, Materials Science and Engineering), and one undergraduate student (Charles Patrick, Electrical Engineering) participate in the project.

4. What are the potential economic benefits:

The MSMA technology, 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.

During the past ten years, close to forty undergraduate and graduate students have worked in the Magnetic Materials Laboratory with Dr. Müllner and received in-depth training on MSMA technology. Many graduates prefer Treasure Valley employment over other places in the US, and stay in the region. With such a large number of experienced students and graduates, the Treasure Valley maintains one of the largest concentrations of MSMA expertise worldwide. Boise is thus the right place to launch a business leveraging MSMA technology.

In addition, Dr. Müllner collaborates with many international, leading scientists in the field in about ten countries. These contacts ensure sustaining new research development with cutting edge know-how. For example, two faculty from China and Poland are currently visiting Boise State and will spend a 15 months here. They are introducing our group to magnetocalorics, a hot research topic that aims to facilitate environmentally friendly refrigeration technologies.

The 3D strain sensor project is one technology commercialization initiative of a series of further technology development efforts at Boise State, among them a MSM-based pump for micro-fluidics applications (lab-on-the-chip, insulin pump, medical research), and four-state memory and energy.

5. Description future plans for project continuation or expansion:

Magnetic Shape Memory (MSM) technology offers a potentially disruptive engineering advancement. It presents a new way to make motors, pumps, sensors, and other products that potentially offer real economic opportunity for the state of Idaho. This technology would enable manufacturers to greatly simplify and miniaturize products—eliminating parts and friction that cause wheels, gears, and shafts to fail at small scales. In traditional engineering, a machine is made of interconnected parts, each part is a static object, but the machine moves to carry out a single function. Interlinked parts enable the machine to perform as a whole. In contrast our team uses magnetic fields to deform MSMA material in the device, creating "shape shifting" materials manufacturers can use to build machines to operate without rotational motion. For example, localized contraction and expansion of a bar within a motor could make it bend like an elbow.

To further enhance this technology, we seek to incorporate a novel 3D strain sensor into the material itself. Doing so would enable manufacturers to monitor material performance over time. Traditional pressure sensors measure a single force component—a downward push, for instance. But machines are three dimensional objects, with forces up, down, and around enabling machine operation and sometimes limiting performance. For this *Phase II* proposal, we will develop a sensor that uses a change in magnetic permeability to identify all six strain components in the MSMA/elastomer composite material we developed during *Phase I*. We have recently filed a patent for this concept (*Boise State file number 92*). In addition, the sensor will include a local non-volatile storage and wireless transceiver. This will extend sensor capability by enabling users to communicate strain information to a wide variety of wireless devices.

To complete this work, the research team is partnering with Gryphon Business Consultants (Boise, ID) — a group we identified in last year's proposal. This year, we are also adding the start-up company MP Research (Boise, ID). Our 3D sensor commercialization plan with anticipated completion dates is to (1) demonstrate functionality (12/2014), (2) build prototype (8/2015), (3) integrate sensor into pilot device (8/2016), (4) develop license agreement, and (5) manufacture first products (8/2017)

6. Please provide a final expenditure report (attached) and include any comments here:

   The final expenditure report is attached.

7. List invention disclosures, patent, copyright and PVP applications filed, technology licenses/options signed, start-up businesses created, and industry involvement:

   For this project, a non-provisional patent is pending: K. Ullakko, K. Sasaki, P. Müllner, "Sensor Device".

8. Any other pertinent information:

   Phase II of the project is in progress.

FINAL EXPENDITURE REPORT

A. FACULTY AND STAFF		
Name/Title	$ Amount Requested	Actual $ Spent
Peter Mullner	$2,651	$2,653.38
Rafla Nader	$1,916	$1,916.00
Paul Lindquist		$4,379.04
B. VISITING PROFESSORS		
Name/Title	$ Amount Requested	Actual $ Spent
C. POST DOCTORAL ASSOCIATES/OTHER PROFESSIONALS		
Name/Title	$ Amount Requested	Actual $ Spent
D. GRADUATE/UNDERGRADUATE STUDENTS		
Name/Title	$ Amount Requested	Actual $ Spent
Graduate Research Assistant: Anthony Hobza	$12,500	$11,342.60
Undergraduate Research Assistant: Patrick Charles	$8,400	$9,150.18
E. FRINGE BENEFITS		
Rate of Fringe (%)	$ Amount Requested	Actual $ Spent
Peter Mullner	$795	$693.91
Rafla Nader	$613	$518.40
Paul Lindquist		$1,596.61
Anthony Hobza	$688	$216.36
Charles Patrick	$430	$116.28
PERSONNEL SUBTOTAL:	**$27,993**	**$32,582.76**
F. EQUIPMENT: (List each item with a cost in excess of $1000)		
Item/Description	$ Amount Requested	Actual $ Spent
1.		
2.		
EQUIPMENT SUBTOTAL:		$0.00
G. TRAVEL		
Description	$ Amount Requested	Actual $ Spent
1.		
2.		
3.		
TRAVEL SUBTOTAL:	$2,000	$0.00

H. PARTICIPANT SUPPORT COSTS:		
Description	$ Amount Requested	Actual $ Spent
1.Anthony Hobza Student Fees	$4,776	$4,760
2.		
3		
PARTICIPANT SUPPORT COSTS SUBTOTAL:	$4,776	$4,760

I. OTHER DIRECT COSTS:			
Description		$ Amount Requested	Actual $ Spent
1.Recharge Cost (BSCMC)		$4,200	$1,277.25
2 Supplies.		$6,382	$7,082.02
3. Publication and Dissemination		$400	$47.97
OTHER DIRECT COSTS SUBTOTAL:		$10,982	$8,407.24
TOTAL COSTS (Add Subtotals):		$45,751	$45,750
TOTAL AMOUNT REQUESTED:			$45,750
TOTAL AMOUNT SPENT:			$45,750