# Idaho Incubation Fund Program

Progress Report Form

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| **Proposal No.** | **IF15-003** |
| **Name:** | **Peter Mullner (PI)** |
| **Name of Institution:** | **Boise State University** |
| **Project Title:** | **Integral 3D Strain Sensor Phase II** |
| **Reporting Period:** | **July 1, 2014 to June 30, 2015** |

**Information to be reported in your progress report is as follows (attach additional information as needed):**

1. Summary of project accomplishments for the period just completed and plans for the coming reporting period:

Research activities focused on two project parts: (A) producing and characterizing Ni-Mn-Ga particles for composites and (B) evaluating the strain sensing capacity of the MSM strain sensor using single crystals.

*A: Ni-Mn-Ga particles*

Switching field experiments serve to identify twin reorientation which is a precondition for the strain sensing mechanism. Switching field tests were done alternating at 90 degree angles, switching the magnetic axis between orthogonal directions in the crystal. The graphs in Figure 1 show tests done at the same angle, with one orthogonal test done in between. We see a switching event in the first experiment (left, note the step-like increase of the blue curve around 3500 Oe) but no switching event in the second experiment (right).

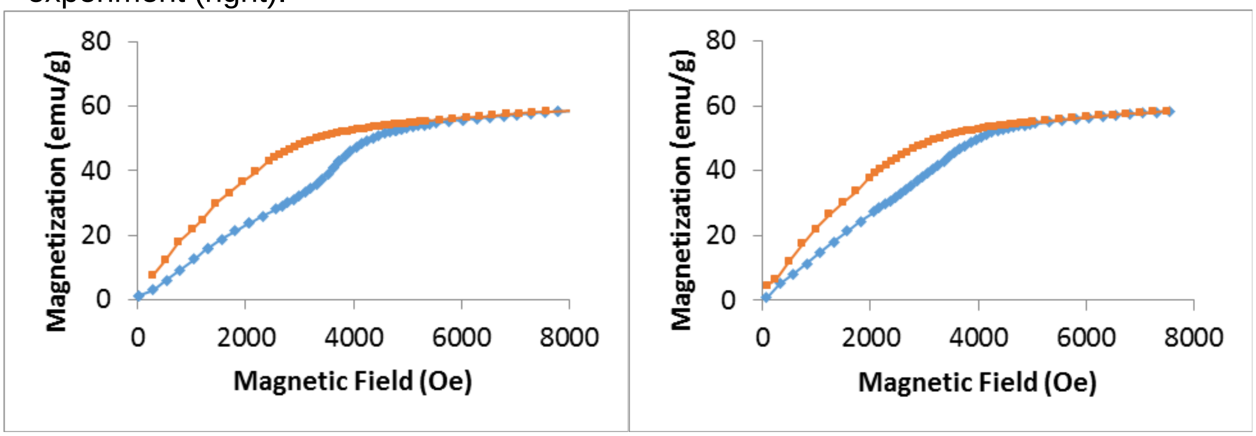


*Figure 1: Switching field tests performed at the same angle, with one perpendicular switch in between.*

To systematically characterize particles and compare their properties with bulk crystals, we grind the irregularly shaped particles into cubes with all faces parallel to {100}. For this purpose, we apply a magnetic field which orients the particles, embed the oriented particles in an epoxy, and polish one face and subsequently the opposite face. We then perform an x-ray diffraction experiment to verify that the surface is parallel to {100}

(Figure 2). With additional x-ray diffraction experiments we can identify a second {100} orientation and polish that pair of faces. Finally, we polish the third pair of faces to make a cube. To date, we demonstrated the first pair of faces and are in the process of preparing finished cubes with three pairs of {100} faces.

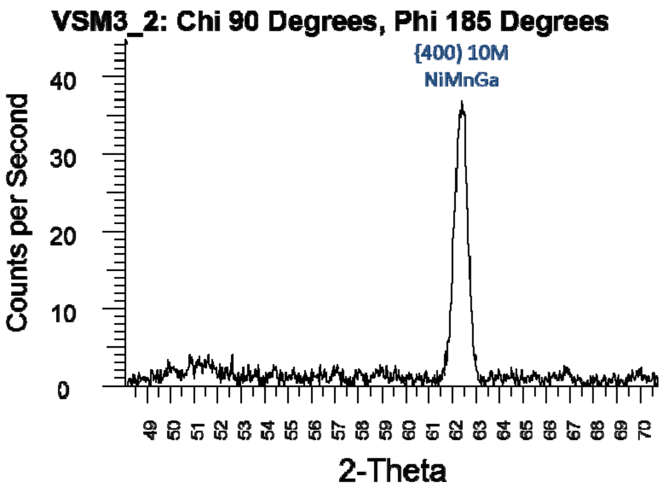


*Figure 2: X-ray trace taken from a polished surface of a particle demonstrating that the surface is parallel to {100}.*

*B: Sensing capacity*

As reported earlier, we developed a testing device outlined in Figure 3. This device permits actuating a Ni-Mn-Ga cube single crystal at a frequency between 20 and 800 Hz and strokes up to 300 μm. A double coil is positioned around the single crystal where one coil is given a drive frequency between 1 and 100 kHz. The second coil picks up the signal and detects the deformation state (strain) of the crystal.

We obtain a relationship for the root mean square (RMS) voltage from the coil vs. strain of the sample during post processing using Matlab. Figure 4 (a) and (c) display this relationship. The relationship is fitted using a $5^{th}$ order polynomial shown as the red line. This gives voltage as a function of strain, and vice-versa. Using the equation of the fitted line, we can plot Stress vs. Strain using solely the voltage. The blue curves in Figure 4 (b) and (d) are the direct stress vs. strain curves, while the magenta curves use only the voltage and polynomial fit to approximate strain. The estimated stress vs. strain curve is very similar to that of the directly measured data.

The accuracy of the purple lines in Figure 4 (b) and (d) is a measure for the strain measuring capacity of this method. This result is surprising since the range of induced voltage is only a 1% (50 μm stroke, Figure 4a,c) and 5% (150 μm stroke, Figure 4b,d) of the measured value. Work is needed to improve the RMS voltage range.

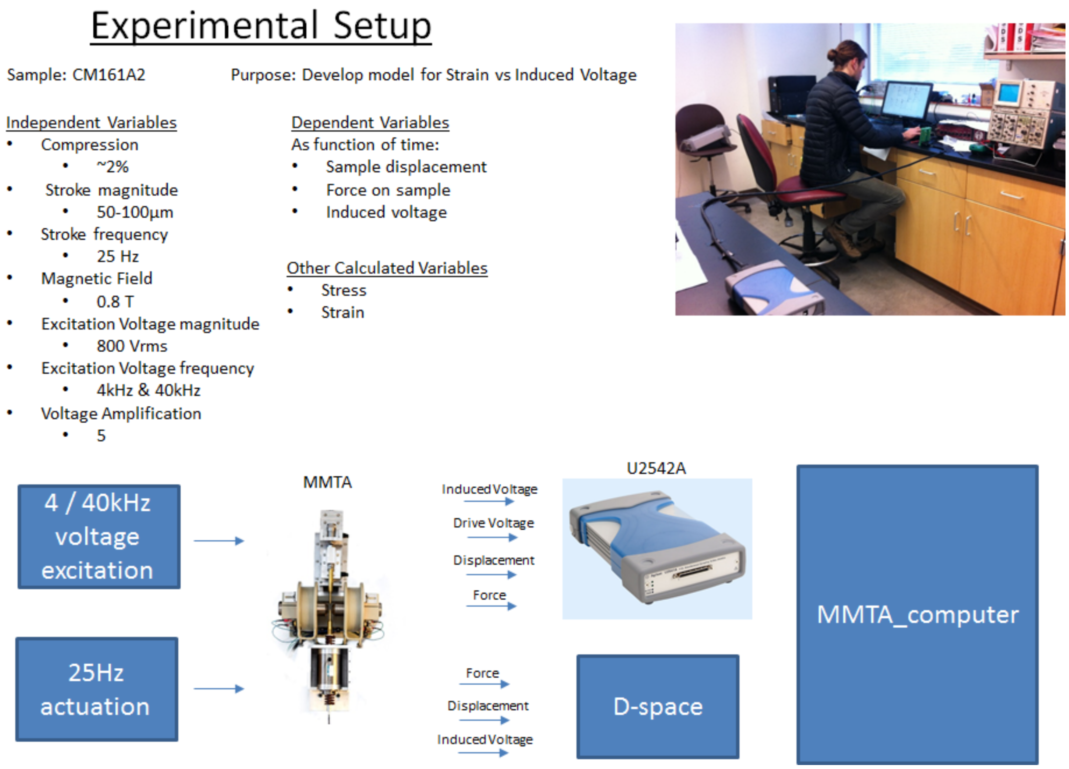


*Figure 3: Experimental setup using the magneto-mechanical testing apparatus. The sample is dynamically actuated, the stress, strain, input and output voltage are acquired using the Agilent U2542A 14-bit analog to digital converter.*

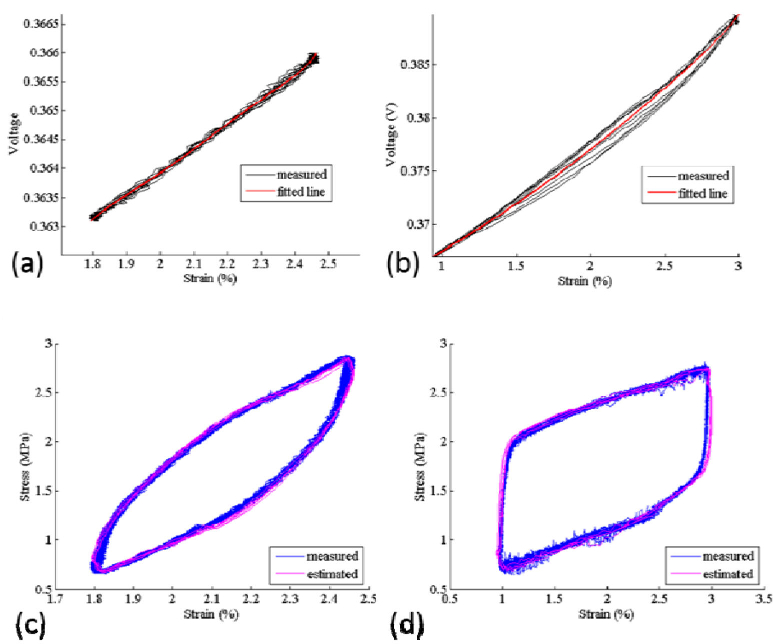


*Figure 4: Experimental setup using the magneto-mechanical testing apparatus. The sample is dynamically actuated, the stress, strain, input and output voltage are acquired using the Agilent U2542A 14-bit analog to digital converter.*

In summary, we demonstrated the fabrication of Ni-Mn-Ga single crystal particles with faces parallel to {100} with suitable magneto-mechanical properties. We also demonstrated the sensing capability. Though the stress-strain curves can be reconstructed well using the RMS voltage values, the resolution is limited by the comparatively small range of the voltage response (Fig. 4a,b).

2. Summary of budget expenditures for the period just completed (include project burn rate):

   $42,281 burn rate 85% as of May 2015.

3. Numbers of faculty and student participation resulting from the funding, including internships:

Faculty involved: Dr. Peter Müllner (PI), Dr. Nader Rafla (co-PI)

Students involved: Tony Hobza (PhD student), Charles Link Patrick (undergraduate student), Miranda Buttram (undergraduate student), Andrew Morrison (undergraduate student), Eric Rhoads (undergraduate student)

4. List patents, copyrights, plant variety protection certificates received or pending:

K. Ullakko, K. Sasaki, P. Müllner, "Sensor Device", Non-Provisional Application for United States Letters Patent.

5. List technology licenses signed and start-up businesses created:

N/A

6. Status of private/industry partnerships (include enough information to judge level of engagement):

The PI registered Shaw Mountain Technology LLC (SMT) with the State of Idaho effective January 20, 2015. SMT aspires to manufacture high-quality high-tech devices in Idaho. Initially, SMT will focus on devices utilizing magnetic shape memory alloys.

7. Any other pertinent information that will indicate to the council that the project is meeting satisfactory progress.

   We received funding for the following projects for technology development:

   (1) *Large Stroke Low Power Magnetic Shape Memory Actuators – Proof of Concept*; NASA ISGC: $25,000; 7/1/2015-6/30/2016
   (2) *Solid State Positioning Device for Real-Time Imaging of the Heart Chamber*; HERC Incubation Fund: $75,000. 7/1/2015-6/30/2016

   The following proposal are pending:

   (1) *Motionless MSM Micropump*; NSF Partnership for Innovation: Accelerating Innovation Research – Technology Transfer, requested amount: $200,000. The proposal has been recommended for funding by the program manager. Funding is now pending approval from the NSF Contract and Budget Office.
   (2) *Improving Patient Safety through Virtual Reality Simulation*; NIH, amount requested: $734,934. Pending.

We submitted the following proposals which were not funded:

(1) *Magnetic Shape Memory Technology for Smaller and Simpler Motor Design Assembly* (Projecdt Number 14627873); Walmart Foundation, amount requested: $2,600,000. Not funded.

(2) *Large stroke low power magnetic shape memory actuators for space applications*; NASA-EPSCoR, amount requested: $706,500. Not funded.

(3) *Proof of Concept Center for Market Acceptance of Idaho Techgnology: Driving the regional confidence required to commercialize disruptive technology and iterate towards high growth spin-off and job development*; Economic Development Administration, amount requested: $500,000. Not funded.