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Stewardship Science Today (SST) highlights the stewardship science and academic programs supported by the Department of Energy/National Nuclear Security Administration (DOE/NNSA). SST is published quarterly by the NNSA Office of Research, Development, Test, and Evaluation. Questions and comments regarding this publication should be directed to Terri Stone via email at terri.stone@nnsa.doe.gov.

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Calendar

7/19-22/2021
Computational Science Graduate Fellowship Virtual Program Review, Zoom

8/2-6/2021
University of California, San Diego High Energy Density Science Summer School

8/10-11/2021
Stewardship Science Graduate Fellowship/ Laboratory Residency Graduate Fellowship Annual Meeting Virtual Program Review

Inside

*National Laboratory Detailee **Contractor Support

Welcome to the latest issue of *Stewardship Science Today*. Along with you, we celebrate the change to the mask protocols by the Centers for Disease Control and Prevention and gradual re-opening of our Nation. We also continue to celebrate the exciting scientific successes that the National Nuclear Security Administration (NNSA) and its national security laboratories have achieved during the pandemic. We feature a few of the successes in this issue.

DOE/NNSA recruits outstanding talent through its fellowship programs. The programs focus on the scientific, engineering, and computational capabilities necessary to meet the NNSA mission and provide practical experience at state-of-the-art experimental facilities. Four thriving programs are highlighted below.

Physicists at Lawrence Livermore National Laboratory use the OMEGA EP laser at the University of Rochester Laboratory for Laser Energetics to accelerate streams of metallic microparticles to velocities exceeding thousands of miles per hour. The high-speed particles form what is called an ejecta microjet and originate from laser-driven shocks in tin foil samples. Other exciting research includes the collaborative study of X-pinches by the University of California, San Diego and Cornell University. Supported by the Stewardship Science Academic Alliances program, this work has produced results that show remarkable differences between wire, hybrid, and laser-cut foil X-pinches. At Los Alamos National Laboratory, researchers are conducting experiments at TA-55 to measure shocked temperatures for the purpose of validating equation-of-state models for materials.

We remain dedicated to featuring the talented individuals and ground-breaking research being conducted by the Stockpile Stewardship community. Have an enjoyable summer and stay safe.

Dr. Mark C. Anderson
Assistant Deputy Administrator
for Research, Development, Test, and Evaluation

DOE/NNSA Fellowship Opportunities: CSGF, LRGF, SSGF, and NGFP

The Department of Energy/National Nuclear Security Administration (DOE/NNSA) offers fellowship programs to train the next generation of national security leaders. Four programs that help identify, educate, train, and recruit young talent to DOE/NNSA, the national laboratories, and other government agencies are highlighted below.

Computational Science Graduate Fellowship (CSGF)

The CSGF is open to senior undergraduates and students in their first year of doctoral study and provides up to four years of financial support for students pursuing doctoral degrees in fields that use high-performance computing to solve complex problems in science and engineering. It also funds doctoral candidates in applied mathematics, statistics, or computer science who are pursuing research that will contribute to more effective use of emerging high-performance systems. For more information, visit www.krellinst.org/csgf.

Laboratory Residency Graduate Fellowship (LRGF)

The LRGF provides outstanding benefits and opportunities to U.S. citizens who are entering their second (or later) year of doctoral study to work at premier national laboratories while pursuing degrees in areas relevant to the national Stockpile Stewardship Program. It includes at least two 12-week research residencies at a NNSA national laboratory or the Nevada National Security Site. Visit www.krellinst.org/lrgf to learn more.

Stewardship Science Graduate Fellowship (SSGF)

SSGF provides outstanding benefits and opportunities to U.S. citizens pursuing a PhD in areas of interest to stewardship science, such as properties of materials under extreme conditions and hydrodynamics, nuclear science, and high energy density physics. The fellowship includes a 12-week research practicum

(continued on page 4)

Experiments and Simulations of Laser-Driven Tin Ejecta Microjets

by A.M. Saunders,[1] C.V. Stan,[1] K. Mackay,[1] B. Morgan,[1] J. Horwitz,[1] S.J. Ali,[1] H.G. Rinderknecht,[2] T. Haxhimali,[1] Y. Ping,[1] F. Najjar,[1] J. Eggert,[1] and H.-S. Park[1]

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The study of metal ejecta microjet interactions has broad applicability to fields ranging from planetary formation[1] to cloud interaction dynamics.[2] An ejecta microjet forms when a strong shock travels through a metal sample and, upon reaching the opposite side, interacts with a micron-scale surface perturbation, such as a dent or a groove. The surface perturbation then inverts to form a jet of material traveling at a high velocity, often in excess of 1 km/s (~2,200 mi/hr).[3] The jet itself also is micron-scale, the exact size being set by the original size of the surface perturbation, and is comprised of particles with average diameters of about 1 μm.[4] Many experiments have been performed to understand how experimental parameters, like the type of metal and surface perturbation dimensions, affect microjet characteristics, such as total amount of material and velocity. We aim to study the effects of different shock pressures on ejecta microjet generation in tin, as tin transitions from a solid to either a liquid or an intermediate mixed phase under the shock pressures readily accessible by common high-pressure drivers.[5]

To that end, we developed an experimental platform using the OMEGA EP laser at the University of Rochester Laboratory for Laser Energetics to generate ejecta microjets from tin foil samples. The tin foils are 100 μm thick and 3.2 mm x 3.2 mm in area. We carve 45 μm deep grooves with 60° opening angles across the rear surfaces of the tin. As shown in Figure 1a, an 8-ns-long laser-pulse with tunable energy impinges on the front surface of the tin and drives a shock wave into the foil, with the pressure in the shock corresponding with the energy of the laser. Radiation hydrodynamics simulations allow visualization of the shock propagating through the foil and the subsequent formation of the microjet: Figure 1b shows the results of simulations for a shock pressure before release of 11.7 GPa, which results in a planar tin ejecta microjet traveling at a velocity of 2.2 km/s. At a later time, a short pulse laser incident on a titanium microwire generates a bright source of X-rays, which is used to record X-ray radiography images of the jetting material down the axis of the jet (jet view) or from the side (sheet view). Figure 1c shows an example of a radiograph of a 11.7 GPa shock recorded 600 ns after jet formation. The color scale of the radiograph correlates with the intensity of X-rays on the detector: darker colors imply higher density material. The simulation captures the jet morphology of the experiment, including a lower-density region at the front of the jet and a high-density region closer to the tin foil sample.

Simulations of the jetting tin identified three different regimes: a low-energy regime where material-strength inhibits jet formation, a moderate-energy regime where the tin is a mixed solid-liquid material, and a high-energy regime where the tin is expected to be fully melted into liquid.[6] We recorded radiographs at two different shock pressures, 11.7 GPa and 116.0 GPa, which are in the moderate- and high-energy regimes, respectively. Figure 2 shows radiographs at each pressure condition. At 11.7 GPa, the jets travel at 2.2 km/s, whereas at 116.0 GPa the jets travel at 6.5 km/s. As observed in the images, the jets also present different features. The microjet from the lower pressure shock has regions of higher and lower density, whereas the jet from the high pressure appears more uniform. In addition, the higher pressure jet shows a rounded feature at the front of the jet not observed in the lower pressure case. Sheet view radiographs show a different roughness, which is expected to correspond to different material phases at the pressures. The exact material effects that lead to these differences are the subject of future investigations.

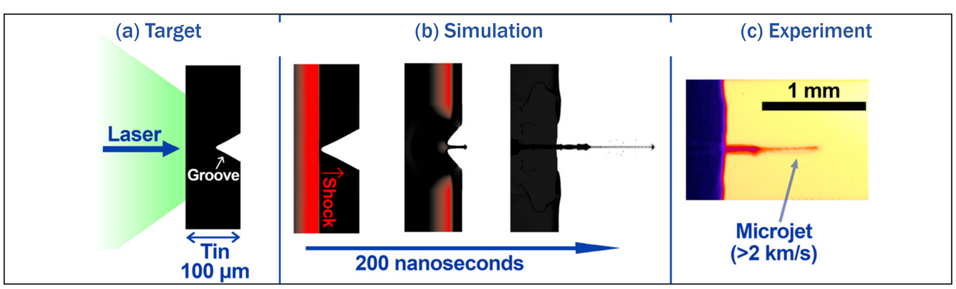

Figure 1. (a) A schematic of the experiment as viewed from the side. The tin foil has a 45 μm, 60° opening angle groove carved across its rear surface. A laser impinges on the front side of the foil and drives a shock wave into the tin. (b) Simulations show an 11.7 GPa shock wave traveling through the tin and interacting with the groove to form a planar ejecta microjet with a velocity of several kilometers per second. (c) An X-ray radiograph of an ejecta microjet generated by an 11.7 GPa shock on OMEGA EP.

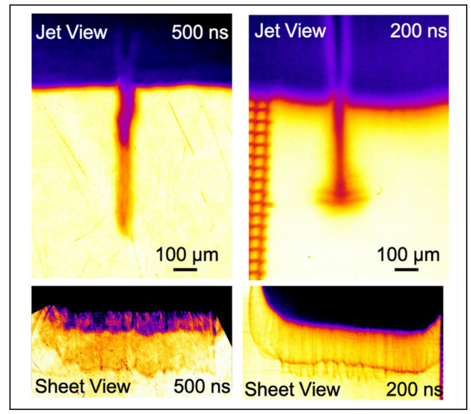

Figure 2. Jet view and sheet view X-ray radiographs of tin microjets from a shock pressure of 11.7 GPa (left) and 116.0 GPa (right). The jets appear very different based on the sensitivity to material effects at the different shock pressures.

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Multi-Institution Collaboration to Study Copper Wire, Hybrid, and Laser-cut Foil X-pinches *by Gilbert Collins (University of California, San Diego)*

X-pinches are a pulsed power, wire-array configuration that produce nanosecond and micron-scale X-ray sources with numerous applications. The earliest embodiment of the X-pinch inspired its name, as it typically is composed of two or more fine (5-50 µm) wires crossed into the shape of an X (Figure 1a).[1] The 'X' ablates when subjected to large (10^1-10^4 kA), fast-rising (~1 kA/ns) currents. Extreme magnetic pressure at the cross-point constricts the ablated plasma which develops instabilities and then pinches to a near-zero radius. This drives the development of localized 'hot spots' that emit X-rays from a sub-nanosecond and 1 µm scale source that is characteristic of a hot (~1 keV), dense (10% solid density) plasma.[2] A subsequent gap forms where the hot spot(s) occurred, across which substantial potential accelerates electron beams (e-beams) that generate larger, longer-lasting, X-ray bursts composed of harder X-rays.

The instability-initiated hot spots and e-beam generation cause shot-to-shot source variability, limiting the overall usefulness of wire X-pinches (WXPs). However, two novel X-pinch configurations show improvement over WXPs. The Hybrid X-pinch (HXP, Figure 1b) employs two solid conical electrodes bridged by a few-millimeter-long wire or capillary cross-point. It has demonstrated reduced e-beam generation and more reproducible pinch parameters than WXPs.[3] Laser-cut foil X-pinches (LCXPs, Figure 1c) are cut from a flat foil using a high-resolution cutting laser and have demonstrated reduced e-beam formation and pinch parameters equal or superior to those of WXPs.[4]

Now, thanks to a collaborative effort drawing upon the diverse expertise of two Centers of Excellence supported by the Stewardship Science Academic Alliances program (in HXPs from Cornell University and LCXPs at the University of California, San Diego (UCSD)), a national laboratory (spectroscopy at Sandia National Laboratories), an NNSA-supported company (laser-cutting at General Atomics), and another NNSA-supported university (novel diagnostics at Johns Hopkins University), experiments driving copper WXPs, LCXPs, and HXPs on a single, compact, low-inductance, 200 kA, 150 ns rise-time driver at UCSD were carried out and analyzed to study the X-ray sources and dynamics of all three X-pinch configurations.[5]

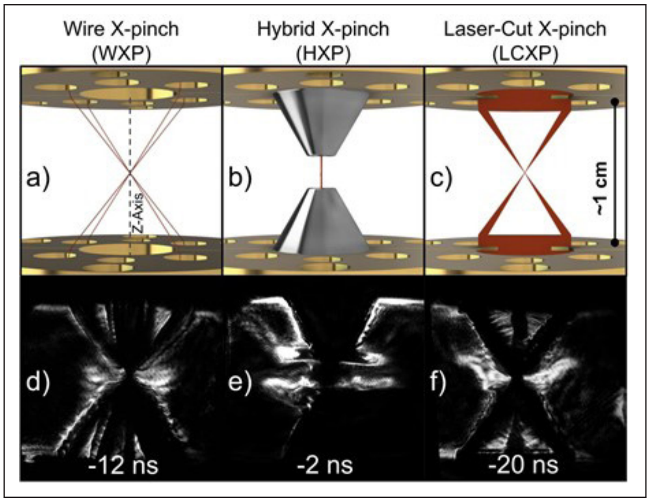

Figure 1. Digital drawings of copper (a) wire, (b) hybrid (b), and (c) laser-cut foil X-pinches, as loaded into the 200 kA, 150 ns rise-time GenASIS driver at UCSD. Approximate scale is given on the right. Frames d-f show corresponding schlieren images of the different X-pinches with times relative to the pinch time given below.

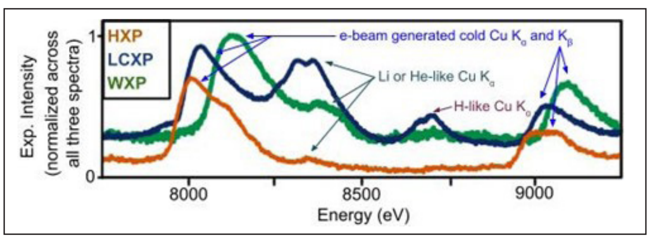

Figure 2. X-ray spectra produced by a flat, highly-oriented, pyrolytic, graphite crystal of the copper K-shell from the three types of X-pinches, normalized across all three spectra. Key transitions are labelled.

Results showed comparable hot spot X-ray source size, pulse-width (diagnostically limited to ≥5 µm and ~1 ns respectively), and total X-ray flux from all three configurations. However, Cu K-shell (~8 keV) spectroscopy and diode signals showed significantly less e-beam-generated emission in HXPs and LCXPs than in WXPs. Additionally, the K-shell spectra (Figure 2) suggest that the peak temperature of the hot spot increased from HXPs to WXPs to LCXPs.

Application of the data to X-pinch models and theories suggest that the initial target mass and geometry play a key role in the ability of the target to remove mass from the cross-point through magnetohydrodynamic processes which significantly can affect pinch temperature pre- and post-X-ray burst. This neatly sets the stage for future HXP and LCXP studies, including MHD simulations and target modifications to alter mass flow near the cross-point.

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Measuring Shocked Temperatures at TA-55, Los Alamos National Laboratory

Experiments at TA-55 Have Used Optical Pyrometry to Measure Temperatures of Shocked Plutonium on the 40 mm Gun

Researchers at Los Alamos National Laboratory (LANL), along with collaborators from Mission Support and Test Services, have worked for more than a decade to develop and implement an optical pyrometry method to measure the temperature of metals shocked to high pressures and temperatures. Because traditional shock wave measurements only provide information on the mechanical state of the material, temperature measurements are required to validate and improve equation-of-state (EOS) models for materials. The conditions sampled are complex, commensurate with those found in planetary impacts, and accessed by conventional and nuclear weapons. Optical pyrometry is currently the best available method for inferring the temperature of shocked metals by careful measurement of the calibrated radiance emitted by a surface at a finite temperature. These measurements are difficult and often are complicated by the short time scales associated with shock wave experiments (<1 μs) coupled with the many sources of non-thermal light (impact flash, fracture light, etc.) that pollutes the radiant light measured from the sample.

Figure 1. Photo of the TA-55 40 mm gun and glove box (Left) and the 40 mm powder gun at DEOS (right). The DEOS 40 mm gun is the test bed for developing new experiments and diagnostics prior to being conducted on the TA-55 40 mm gun.

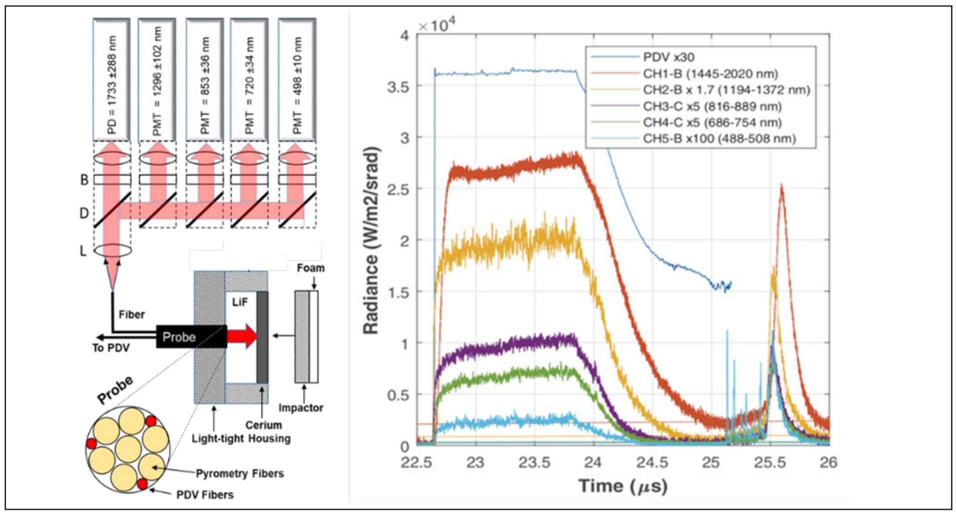

Figure 2. Example optical pyrometry experiment. (Left) Experiment configuration showing an impactor impacting a cerium (Ce) sample. A multi-fiber pyrometry and velocimetry probe couples light to a multi-channel pyrometer to measure the radiant light from the Ce-LiF interface. (Right) Published radiance data and velocimetry shown on the right for shocked Ce. Phys. Rev. B. 102, 214105 (2020).

First Successful Temperature Measurement at TA-55

Over two years, the TA-55 pyrometry team executed a plan of work to qualify the Compact-6 pyrometer complete prove-out experiments at LANL's Dynamic Equation-of-State (DEOS) facility on other metals and to implement the system at TA-55. In July 2020, the Compact-6 pyrometer was installed in the control room, and the first dynamic radiance measurement on plutonium followed in November 2020. A second experiment was completed in March 2021. This work is the culmination of a multi-year effort to meet an FY21 Level 2 milestone for the Dynamic Materials Properties subprogram and supports a collaborative tri-lab temperature measurement effort. The ability to routinely measure temperature in shock metals is a significant step forward in efforts to validate multi-phase EOSs and to modernize LANL's TA-55 40 mm gun—a signature national facility for plutonium studies. The data obtained will have a significant impact on predictive capabilities for simulating weapon physics performance.

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DOE/NNSA Fellowship Programs *(continued from page 1)*

at one of the NNSA national laboratories. For more information, visit www.krellinst.org/ssgf.

NNSA Graduate Fellowship Program (NGFP)

Open to students enrolled in a graduate program, or having completed a graduate degree program, and postdoctoral researchers, this fellowship provides PhD students with the training and practical experience to achieve the NNSA mission. In addition to invaluable training, this salaried fellowship offers tuition, a travel/training allotment, hiring bonus, and a comprehensive benefits package. Visit www.pnnl.gov/projects/ngfp for more information. ◆