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FY2011 Annual Report on DTRA Basic Research Project #BRCALL08-Per3-C-2-0006

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September 1, 2011

FY 2011 Annual Report on DTRA Basic Research Project #BRCALL08-Per3-C-2-0006

"High-Z Non-Equilibrium Physics and Bright X-ray Sources with New Laser Targets"

IACRO #10-4238I

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1. Objectives

This project has two major science objectives, as follows.

- Final Objective: obtain spectrally resolved, absolutely calibrated x-ray emission data from uniquely uniform mm-scale near-critical-density high-Z plasmas not in local thermodynamic equilibrium (LTE) to benchmark modern detailed atomic physics models.
    - Scientific significance: advance understanding of non-LTE atomic physics
- Intermediate objective: develop new nano-fabrication techniques to make suitable laser targets that form the required highly uniform non-LTE plasmas when illuminated by high-intensity laser light.
    - Scientific significance: advance understanding of nano-science
- Relation to DTRA C-WMD mission: The new knowledge will allow us to make x-ray sources that are bright at the photon energies of most interest for testing radiation hardening technologies, the spectral energy range where current x-ray sources are weak.

2. Status of Effort

This project consists of three principal tasks: laser target development, laser experiments, and computational design and modeling. Progress has been made in FY 2011 on target development and modeling. The main-line approach in target development is a four-step ion lithography process. In Step 1 we use an ion accelerator at LLNL to track Xe ions through a 3-5-μm-thick polycarbonate substrate. In Step 2 we etch out the intersecting damage tracks left by the ions. Step 3 is to electro-plate the metal into the ~10-nm-diameter holes left by the etch process. Finally, we assembly several etched and plated substrates into the final target dimensions, and dissolve the substrates, leaving a self-supporting array of metal nanowires. Step 1 and Step 2 are largely complete, Step 3 is in progress, and the design of Step 4 is in progress.

An additional approach is to mechanically trap nanowires in the pores of low-density aerogel foam. We succeeded in demonstrating that this process will work by fabricating a 100 mg cm^{-3} silica aerogel foam with <1 mg cm^{-3} of embedded Cu nanowires.

The modeling effort this FY has focused on optimizing the x-ray conversion efficiency and designing a Cu foam target.

3. Accomplishments

For the main-line target we developed and constructed the etch cell, and developed an electric current measurement technique for monitoring and control of the etch process. In the course of this work we discovered flaws in the polycarbonate membranes via imaging by a scanning electron microscope, flaws that contribute to tearing of the membrane upon extraction from the etch cell. Accordingly we developed a new process for extraction that prevents the tearing. In addition, a new calibration of the ion beam intensity has allowed us to track the membranes without introducing the flaws that lead to the tearing.

A scanning electron microscope image of a tracked and etched membrane is shown in Figure 1. In this figure we see an overall density of ~8.5×10^9 cm^{-2} of holes with diameters ~10-30 nm.

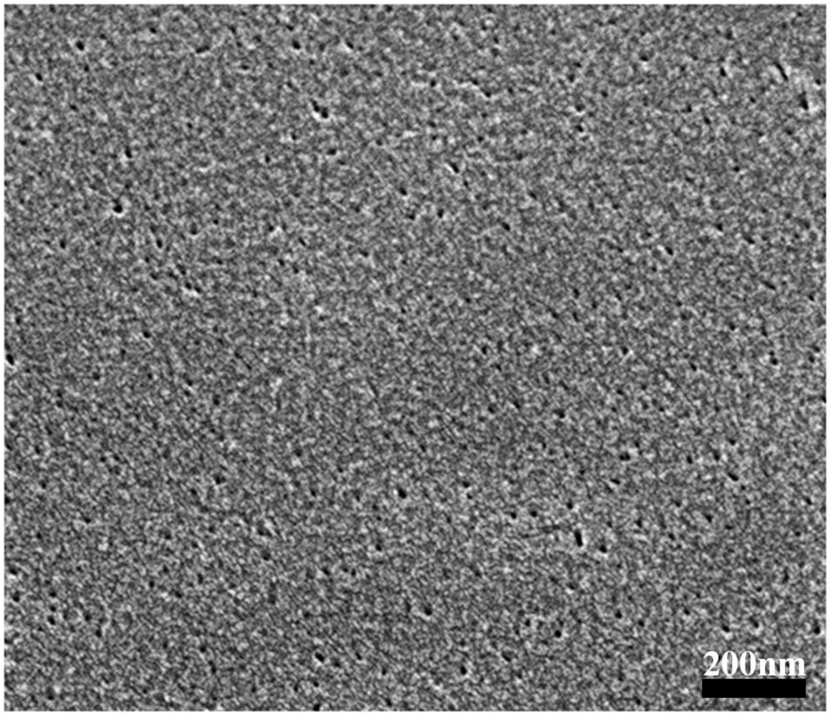


Figure 1. Scanning electron microscope image of a tracked and etched polycarbonate membrane

In addition, we have demonstrated that silica aerogels can be used as scaffolds for metal nanowires. In Figure 2 we show two of the nanowires we made using the ion-lithography process described above, but for non-intersecting ion tracks. These nanowires, with lengths of 1-3 μm and diameters of ~60 nm, were then used in a newly designed chemical process to embed them in the pores of silica aerogel foam.

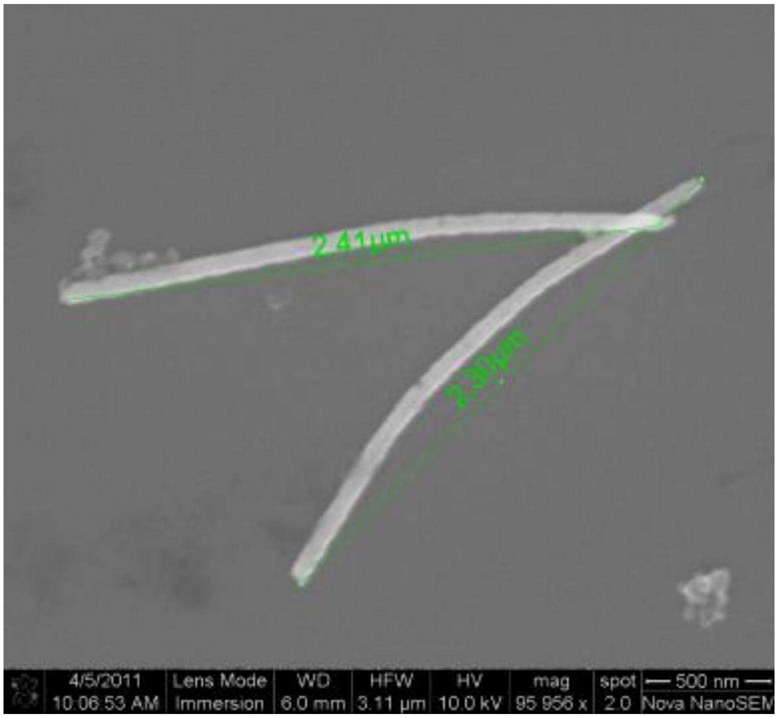


Figure 2. Cu nanowires made by the ion-lithography process

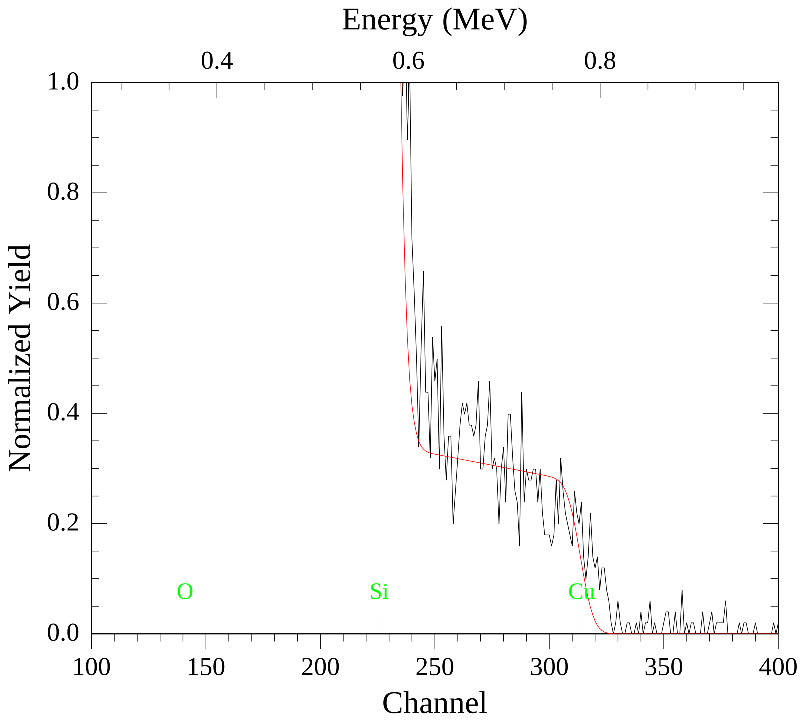
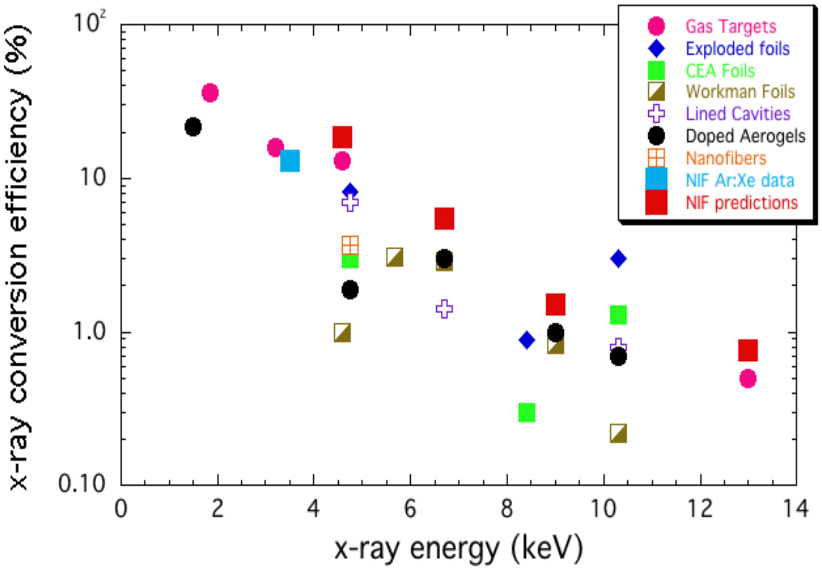


Figure 3. Ion scattering spectrum from Cu-loaded silica aerogel foam

In Figure 3 we show a high-energy ion scattering spectrum from 100 mg cm^{-3} silica aerogel with Cu nanowires corresponding to a density of 0.4 mg cm^{-3}. The scattering spectrum illustrates that the Cu is distributed approximately uniformly with depth in the aerogel, at least to a depth corresponding to the range of the scattering ions, ~10 microns.

We are now extending this approach to ultralow density silica aerogels made by a combination two-step sol-gel chemistry method and a rapid solvent extraction approach.

The modeling effort has proceeded in parallel with the target development effort. One focus of the modeling has been on optimizing the K-shell x-ray conversion efficiencies (XRCEs). As seen in Figure 4, the modeling suggests that the National Ignition Facility laser at LLNL (the red squares in Figure 4), putting some 500 kJ of laser beam energy on target, will be able to produce ~50%-100% larger K-shell XRCEs than the 20 kJ Omega laser.



Colvin_Fig.11

Figure 4. X-ray conversion efficiency vs. x-ray energy in keV

The modeling also shows that adiabatic expansion cooling clamps the plasma temperature at <10 keV. This is one principal reason why NIF, despite having 20-50 times the beam energy of Omega, can produce only a modest increase in the XRCE.

A parallel modeling effort has been to determine the optimum Cu foam density for efficient x-ray production. We found that the optimum is ~1/1000 of solid density. At this optimum density the electron density in the laser-heated plasma is between 0.1 and 0.25 of the critical density for resonance absorption of the laser light. Thus, at this optimum density, the Cu foam can supersonically heat and produce a large-scale, uniform, bright x-ray source. We found that for this optimum-density target nearly 1% of the laser energy is converted to Cu K-shell radiation at Omega laser drive conditions, nearly 2% at NIF laser drive conditions.

We also found that, because of the rapid adiabatic expansion of the heated plasma, the range of acceptable initial Cu foam densities is fairly broad. For example, an initial density of ~1/100 of solid density, ~90 mg cm^{-3}, produces a little less than half the K-shell XRCE than the optimum. This is good news, because it allows for a loosening of the constraints on target development to produce an acceptable target.

The other good news is that, because of the rapid adiabatic expansion of the heated plasma, the foam rapidly homogenizes. This allows for even a greater loosening of the constraints on target development.

In summary, the first-year's accomplishments on this project have greatly increased our confidence in meeting the project objectives.

4. Personnel supported

Some fraction of the labor costs for the following people have been supported by this grant during this FY.

At LLNL:

Dr. Jeff Colvin, PI, staff scientist

Dr. Sergei Kucheyev, staff scientist

Dr. Supakit Charnvanichborikarn, postdoctoral research fellow

Near the end of this FY we added the following people for preparation for the laser experiments that will be conducted in the second year:

Dr. Kevin Fournier, staff scientist

Dr. Mark May, staff scientist

Dr. Reed Patterson, staff scientist

At University of California-Davis:

Prof. Kai Liu

Mr. Dustin Gilbert, student

Mr. Chad Flores, student

At Sandia National Laboratories-California:

Dr. Tom Felter. Staff scientist

5. Publications

This project is synergistic with the LLNL Program in X-ray Source Development (XRSD). One publication during this FY coming out of the LLNL XRSD Program that also has included in it some findings generated in this DTRA Basic Research project is the following:

J. D. Colvin, K. B. Fournier, J. Kane, S. Langer, M. J. May, and H. A. Scott, “A computational study of x-ray emission from high-Z x-ray sources on the National Ignition Facility laser”, *High Energy Density Phys.* **7**, 263 (2011).

6. Interactions/Transitions

None

7. New discoveries, inventions, or patent disclosures

None

8. Honors/Awards

None

9. Courses taught

None