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Synthesis and Characterization of Bimodal Nanoporous Cu Foams: Working Towards Inertial Fusion Energy

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Abstract

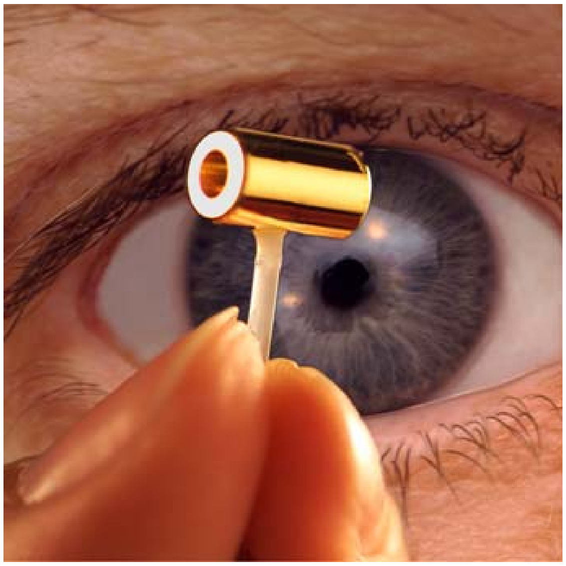
For the National Ignition Facility, at the Lawrence Livermore National Laboratory, nanoporous structures play a crucial role in the development of targets for high energy density experiments. Here we present a new bottom-up synthesis technique termed filter-casting for the creation of bimodal macro/nanoporous Cu structures. Homogeneous nanoporous monoliths can be synthesized using Cu nanoparticles and bimodal porosities can be achieved using sacrificial polystyrene spheres as a template. Control over the structure and composition is critical for target manufacturing. The measured densities of the Cu foam range between 1070 - 3390 mg/cm^3. Filter-casting is a powerful new method for directly synthesizing large nanoporous monoliths with predetermined composition, pore size, and pore structure.

Introduction

As the demand for consumer energy continues to increase, industrial corporations as well as national laboratories or universities search for alternative ways to meet these demands. One potential way of meeting such demands could be from the generation of fusion energy. Fusion energy could be reach by fusing deuterium and tritium particles together. The National Ignition Facility (NIF), which is housed at the Lawrence Livermore National Laboratory (LLNL), is working towards the generation of inertial fusion energy. To accomplish such goal, NIF, with an equivalent building size of three football fields, must focus its 192 laser beams into a 7 mm NIF target. As a result, the scientific and engineering challenges are enormous and therefore, physicists, materials scientists, chemists and engineers must work together.

One possible NIF target design requires a 3 mm double shell to be placed inside the 7 mm NIF target. Such double shell is made of several materials, some of which are low density (100 mg/cm^3) Cu foams. Figure 1(a) and (b) show a hohlraum and a cross-sectional view of a NIF double shell for inertial confinement fusion experiments. Therefore, this paper presents a technique developed at LLNL for the manufacturing of Cu nanoporous foams to meet the NIF target requirements for possible inertial confinement fusion experiments.

(a)



(b)

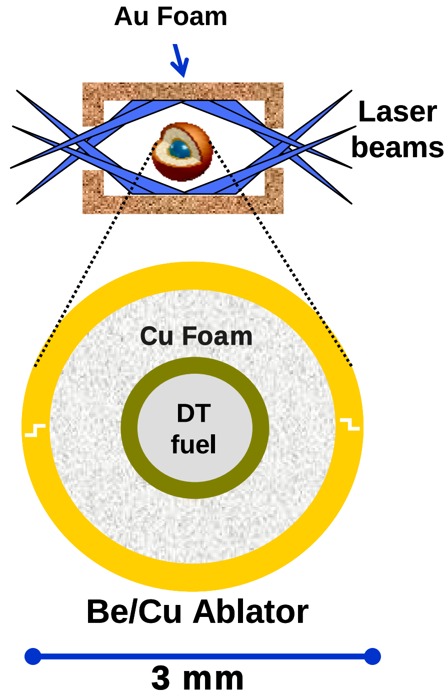


Figure 1(a) shows a hohlraum and (b) a cross-sectional view of a double shell for inertial confinement fusion experiments.

Experimental Procedure

Homogeneous nanoporous Cu without major defects can be achieved through a new technique developed at LLNL called filter-casting, whereby a porous monolith is constructed from the bottom up by assembling nanoparticles. This technique creates great flexibility in the fabrication of nanoporous structures with different porosities, densities and compositions. Porous monoliths are created from liquid suspensions of nanoparticles and polystyrene spheres. This suspension is placed in a Teflon tube imbedded in a water absorbing media. Over the course of a few minutes to several hours, the water is absorbed and the particles are deposited onto the substrate. This leads to the formation of a uniform monolith. Figure 2 shows a schematic representation of the filter-casting mechanism.

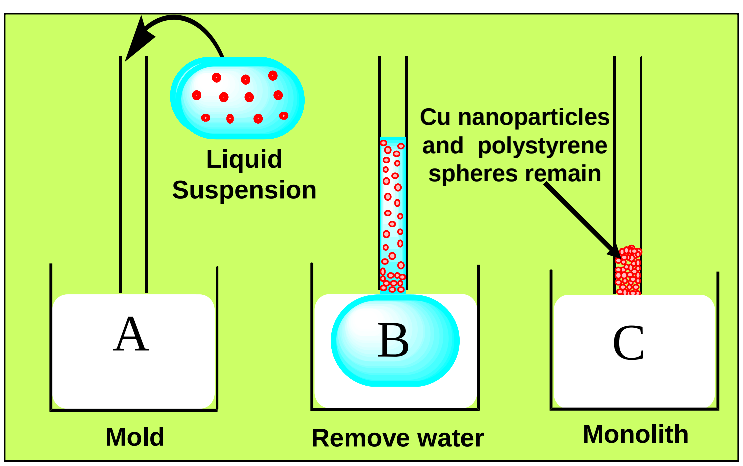


Figure 2. Filter-Casting Diagram.

Results

The Cu foam monolith is removed from the Teflon tube and then annealed. Annealing for 24 hours at 150°C in a 96/4% Ar/H_2 atmosphere reduces any copper oxide. This temperature is sufficient to smooth the particle surface as well as promote necking and interparticle bonding (Figure 3) through classic sintering behavior. The final structures of these Cu foams are strong to be machined into a cylinder (Figure 4). This demonstrates the ability of machining the porous Cu foam for specific applications.

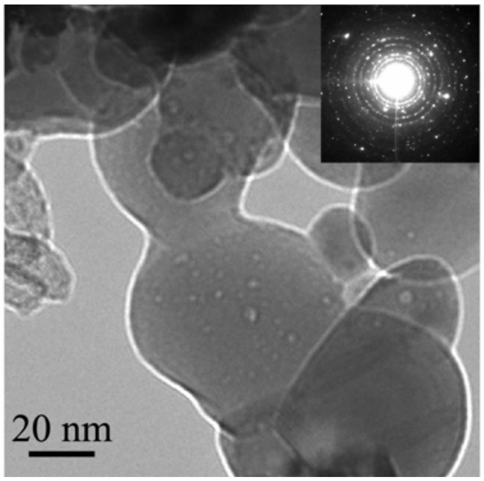


Figure 3. TEM image of Cu foam after annealing showing interparticle bonding.

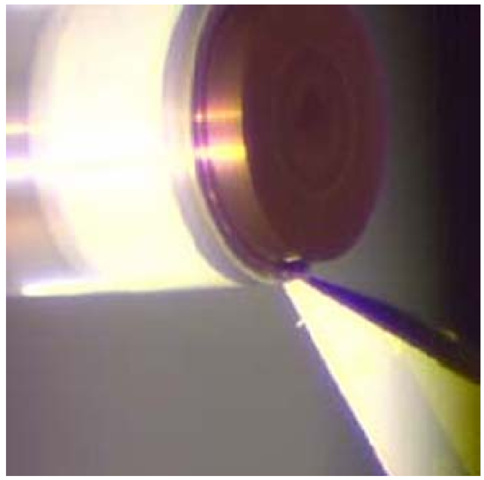


Figure 4. Machined Cu foam cylinder.

At higher annealing temperatures (>300°C), the polystyrene spheres are removed from the Cu foam monolith. The pore structure and final density can be modified by adding polystyrene spheres of various diameters to the liquid suspension. Figure 5 shows the different pore size of the Cu foam obtained from different polystyrene spheres size used.

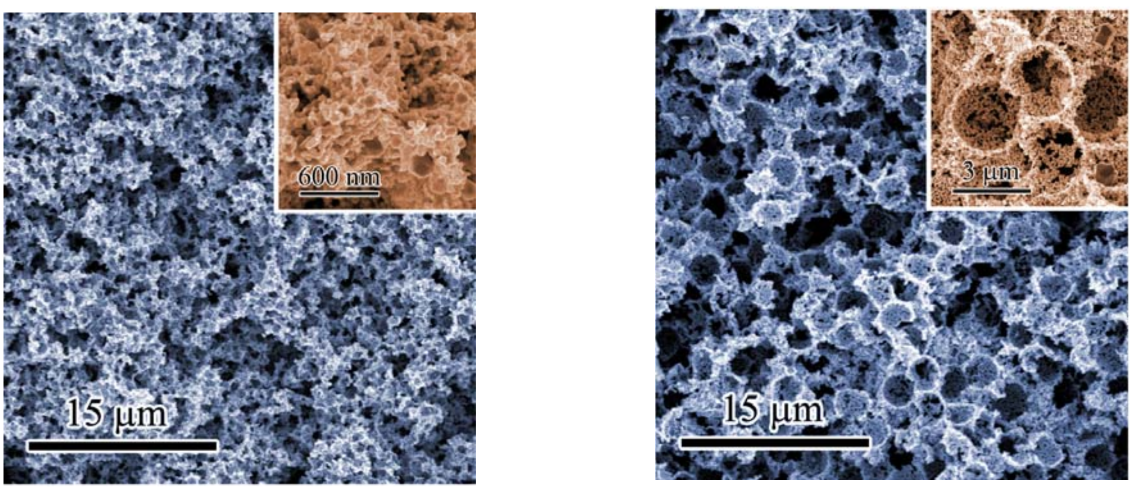


Figure 5. SEM images of Cu foam samples with bimodal pore sizes. The samples were made from ***(a)*** *Cu nanoparticles plus 1µm PS and* ***(b)*** *Cu nanoparticles plus 3µm PS. Inserts show higher magnifications revealing the fine nanoporous structure.*

As previously discussed, the double shells for inertial confinement fusion experiments are required to incorporate metal foams with relative low densities (about 100 mg/cm^3). To this end, the application of filter-casting has shown the ability to produce low dense Cu foams by varying the size of the polystyrene spheres. Table 1 shows the densities obtained using this method. It can be observed that lowest densities are obtained from samples with 3 μm and 10 μm polystyrene spheres.

Sample	Density [mg/cm^3] **
Cu Monolith	3390
Cu + 1.0 μm PS	1350
Cu + 3.0 μm PS	1070
Cu + 10 μm PS	1070

** Density measurements are within ± 2% or ±180 mg/cm^3

Table I. Presents the density values obtained using the filter-casting method.

Conclusions

The National Ignition Facility at the Lawrence Livermore National Laboratory is gearing up to perform inertial confinement fusion experiments. To achieve the desired results, millimeter size NIF targets must be produced. The double shells require the use of metal foams with low densities (~100 mg/ cm^3). Here we have developed a filter-casting method that may allow for the production of such metal foams. Results indicate that by incorporating polystyrene spheres to a liquid suspension of Cu nanoparticles and water, the density drops from 3390 mg/cm^3 for a Cu monolith to 1070 mg/cm^3 for a Cu monolith with polystyrene spheres. The Cu foams produced using this technique may be able to meet the density requirement. If further development is needed, one could combine the filter-casting method with other metal foam producing methods to decrease the density of the metal foam to meet the challenging NIF target requirements.

Reference

[1] Hayes, JR, et. al, NANOTECHNOLOGY 18 (27): Art. No. 275602 JUL 11 2007

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