

5 - 29 Mechanical Metamaterials Made of Freestanding Quasi-BCC Nanolattices of Gold and Copper with Ultra-High Energy Absorption Capacity*

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Mechanical metamaterials refer to a class of composite materials with artificially designed structures and exhibit extraordinary mechanical properties that traditional materials do not have. Among them, energy absorption mechanical metamaterials can absorb mechanical energy more efficiently, which requires the material itself to have both high strength and high strain capacity. But in general, high strength and high strain capacity of materials are difficult to obtain at the same time.

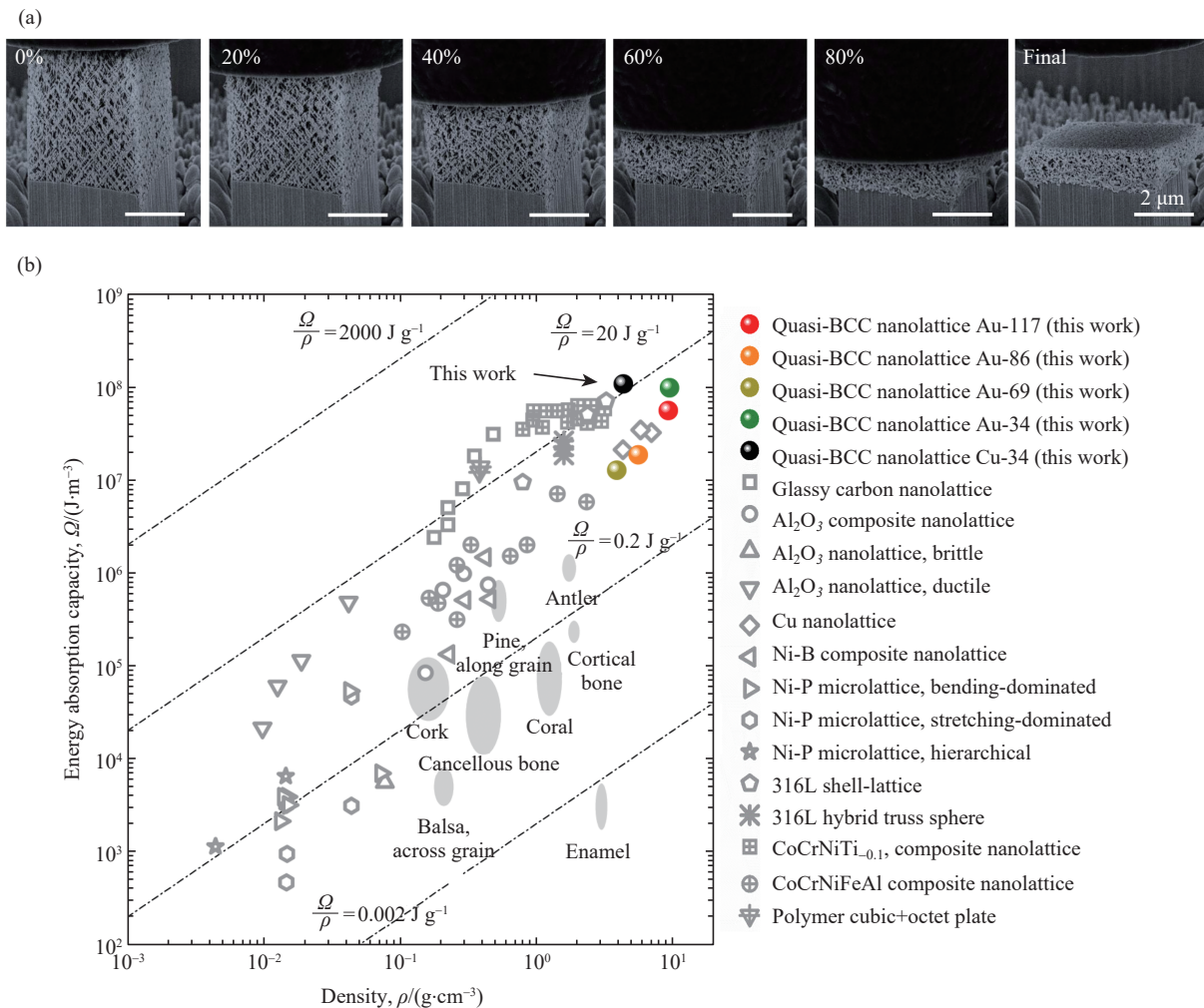


Fig. 1 (color online) Compression tests on the gold and copper quasi-BCC beam nanolattices. (a) SEM snapshots of the deformation process of the sample Au-69, (b) Ashby map of energy absorption per unit volume versus density of gold and copper quasi-BCC beam nanolattices and previously reported micro/nanolattice metamaterials.

Nanolattice is a new class of mechanical metamaterials with characteristic sizes on the order of hundreds of nanometers. Due to their extremely special size effects, structural characteristics and material selection, the mechanical properties of this type of porous materials are very different from those of bulk materials, and they can even have better mechanical properties at a lighter weight. They are expected to bring revolutionary applications in the field of high-performance functional materials in the future. Beam nanolattice is the main research object of nanolattice materials. However, to date, it is challenging to make breakthrough in the fabrication of metallic beam nanolattice with beam diameter of less than 100 nm, and thus their mechanical properties remain ambiguous.

In this work, a new type of quasi-body centered cubic (quasi-BCC) beam nanolattice mechanical metamaterial is proposed, which is experimentally implemented with ion track technology based on the Heavy Ion Research Facility in Lanzhou (HIRFL). The beam diameter of the quasi-BCC beam nanolattice can be as small as 34 nm, breaking through the size limit of the beam nanolattice mechanical metamaterials. The results of in situ compression experiments show that the energy absorption capacity of the copper quasi-BCC beam nanolattice exceeds that of the previously reported beam nanolattices (Fig. 1). In addition, the yield strength of the gold and copper quasi-BCC beam nanolattices exceeds that of the corresponding bulk materials at less than half the density. Furthermore, experiments and simulations reveal that the supernormal mechanical properties are mainly due to the synergistic effect of size effect, quasi-BCC geometry, and good ductility of metal.

This work proves that gold and copper quasi-BCC beam nanolattices have excellent energy absorption capacity and compressive strength, and deepens the understanding of the mechanical properties of beam nanolattices. At the same time, the application of ion track technology in the study of nanostructured materials has been realized, which provides a new idea for the exploration of beam nanolattice with ultra-high energy absorption capacity.

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5 - 30 Research Progress by Group of Energetic Materials in 2022

Zhang Chonghong

The evaluation and development of materials which can sustain high temperature and intensive neutron irradiation has always been the key issue for the service and safety of nuclear power plants. The in-pile intensive neutron irradiation can produce defects in materials, causing degradation of mechanical properties such as hardening and embrittlement, swelling and accelerated creep rupture. A full understanding of the basic mechanisms underlying the damage production and accumulation is fundamentally important for the optimization of structure/properties of materials and the proper evaluation of the service lifetime of in-pile key components. For high-efficient assessment and screening purpose, the evaluation methodology of candidate materials based on ion accelerators is highly needed. Miniaturized specimen technology is given intensive consideration, because ions with several MeV/u energies (available by current large accelerators) have limited ranges (much less than 1 mm) in materials.

The Group of Energy Materials (GEM) in IMP has been engaged in the study of mechanisms underlying radiation damage of structural materials and the development of the evaluation method based on the irradiation conditions at HIRFL. In recent years, we have updated the experimental terminal SFC-T1 (facilitating homogeneous damage of specimens at a given temperature with a high precision) at HIRFL, and established corresponding miniature specimen test facilities for the post-irradiation examination.

In 2022, our progress is main in the following two aspects.

1. Research and development of structural materials for advanced nuclear reactors

The harsh in-pile conditions of the advanced nuclear reactors (fast reactors, fusion reactors) require materials sustaining higher temperature and more intensive neutron irradiation. After the Fukushima accident, materials for the accident tolerant fuel (ATF) technology have been getting much more attention. The Al-added oxide dispersion strengthened steels (ODS steels) possess high temperature strength and high resistance to oxidation in high-temperature vapor, and therefore are the prime candidates, whose irradiation tolerance is an important concern. The Zr or Hf addition was reported to enhance the stability of the oxide dispersoids. In 2021, we extended the study of the Zr added FeCrAl-base ODS alloys, and investigated the hardening mechanisms of the ODS alloys