NANOSCIENCE COLLOQUIUM

Nanoporous Metals: Stronger, Lighter, and Water-Responsive

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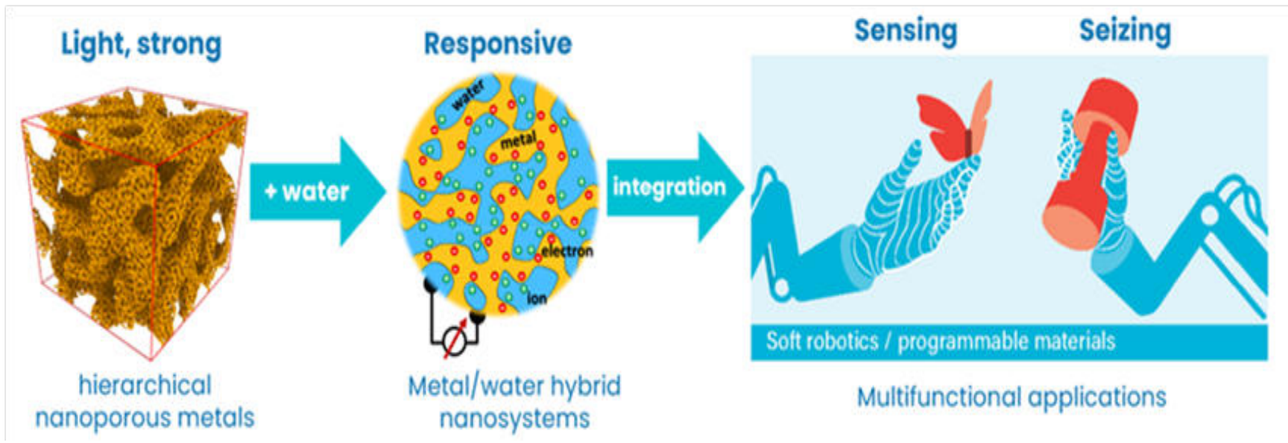
A B S T R A C T : Structural hierarchy is a universal design principle for creating lightweight yet mechanically efficient materials, found in natural systems such as bone and wood as well as in engineered structures ranging from macroscopic truss architectures to microscale 3D-printed metamaterials. Extending hierarchical design to nanoscale network materials opens additional opportunities: nanoscale structural elements can attain exceptionally high strength, while their enormous surface-to-volume ratio enables interface- and surface-controlled mechanical properties that can be actively tuned by environmental stimuli.

In this talk, I will discuss how corrosion-driven self-organization processes can be used to fabricate hierarchical nanoporous metals with outstanding mechanical performance and adaptive functionalities. The first part focuses on hierarchical nanoporous gold synthesized by dealloying. Using a two-stage self-organization process, we produce large-scale hierarchical network materials with independently tunable ligament sizes on two characteristic length scales (10–50 nm and 50–300 nm) and relative densities down to 12% [1]. Compression experiments reveal that structural hierarchy significantly enhances the stiffness and strength of nanoscale random network materials. The results further demonstrate pronounced size-dependent strengthening, where smaller nanoscale ligaments lead to substantially higher strength. These experimental findings are supported by scaling laws developed for hierarchical nested-network materials. Beyond enhanced mechanical properties, the combination of nanoscale geometry and hierarchy also enables unusual water-driven and electrochemically controlled mechanical responses [2]. The second part of the talk highlights hierarchical nanoporous palladium fabricated by dealloying. This material exhibits reversible and switchable stiffness during hydrogen absorption and desorption cycles, together with pronounced actuation behavior and long-term stability [3,4]. Such environmentally responsive mechanics make hierarchical nanoporous palladium a promising platform for adaptive materials, soft robotic systems, and programable mechanical materials.

Overall, our work demonstrates how nanoscale structural hierarchy transforms corrosion-derived porous metals into lightweight materials with exceptional strength and dynamically switchable mechanical properties.



[1] S. Shi, Y Li, B. N. Ngo-Dinh, J. Markmann, J. Weissmüller. Science 371 (2021),1026.
[2] H Jeon, J Markmann, S Shi. Acta Materialia 273 (2024)119954.
[3] S Shi, J Markmann, J Weissmüller. PNAS 115 (2018) 10914.
[4] S Shi, J Markmann, J Weissmüller. Philosophical Magazine 97 (2017) 1571.

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