Scale-Bridging Analysis of Hierarchical Mesoporous Transition Metal Foams

Jonas Frohne[1], Dr.-Ing. Julian Müller[1], Dr. Jean Marie Vianney Nsanzimana[1], Charles Otieno Ogolla[1], Prof. Benjamin Butz[1]

[1]Micro- and Nanoanalytics Group/University of Siegen, Siegen, Germany

Mesoporous materials have attracted tremendous attention in recent decades due to their unique property portfolio and potential applications in various fields such as energy storage, catalysis and sensoring. Mesoporous copper for example has proven suitable as a material for large-scale production due to its properties, cost efficiency and excellent accessibility. Mesoporous transition metals comprise an enormous surface area, high electrical conductivity, improved catalytic activity, and long-term mechanical stability. Those properties are strongly influenced by the material's morphology specifically the pore size, pore distribution as well as connectivity. The chemical composition of the surface particularly governs the material's catalytic properties.

Dealloying as a technique utilises the differences in the galvanic series. A porous structure is created by selectively etching out an element of an alloy. Dealloying has been established as a facile method to tailor hierarchical porous structures with extensive pore networks of varying sizes dependent on the depth and location in the material. It is, therefore, a robust, scalable and cost-effective approach for the synthesis of mesoporous transition metals and their alloys [1].

In this study, dealloying is applied under various process parameters to investigate their influence on the porous structures formed using a copper-manganese alloy sample. The dealloying process is conducted under acidic conditions (hydrochloric acid). To unravel structure formation dependent on the various process parameters, e.g., pore size and distribution, morphology of pores, composition etc., advanced 3D imaging techniques including micro-computed tomography (µCT), focused ion beam (FIB), and transmission electron microscopy (TEM) tomography are employed along different length scales. To gain a deeper understanding of how morphology and composition influence catalytic activity and stability, we evaluated the performance of mesoporous copper foams as electrodes for the hydrogen evolution reaction (HER).

The resulting structures exhibit systematic channel networks and variations in pore size depending on depth and location in the material. We found that even small changes in the synthesis process can have a significant impact. For example, very small concentrations (≤1 at%) of other elements may lead to strongly altered morphologies with, e.g. an order of magnitude smaller pores and higher overall mechanical stability; moreover, the catalytic properties and overall morphology were affected.

We successfully have fabricated mesoporous copper for HER reaction. Multiscale analysis of the structures of the dealloyed material from the millimetre to the nanometre range facilitate the understanding of structure formation and unravels the complex structure-property relationship. The project, therefore, contributes to the detailed understanding of the impact of the various reaction parameters of the dealloying process to the structures formed, and subsequently their impact on the performance of the material.

Graphic:

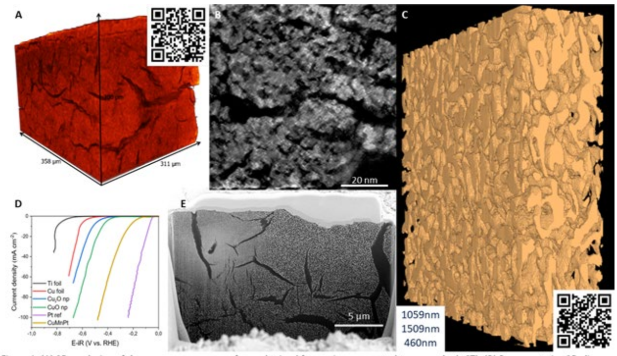

Figure 1. (A) 3D rendering of the mesoporous copper foam obtained from micro-computed tomography (µCT). (B) Representative 2D slice from TEM tomography of a modified foam after 20 iterations of algebraic reconstruction technique (ART) algorithm. (C) 3D rendering of the foam from FIB-SEM tomography. (D) HER measurements with mesoporous copper-based electrodes. (E) FIB cross-section of a mesoporous copper foam with good visible cracks.

Keywords:

Dealloying, Nanostructured-material, Hierarchical, Scale-bridging-analysis, Catalyst

Reference:

[1] McCue, I., Benn, E., Gaskey, B., & Erlebacher, J. (2016). Dealloying and Dealloyed Materials. Annual Review of Materials Research, 46(1), 263–286.