FROM MICROLATTICES TO 3D MICROPRINTING OF MULTIPHASE MICRO-COMPONENTS – RESOLUTION LIMITS AND MECHANICAL PROPERTIES UNDER EXTREME CONDITIONS

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Two-photon lithography (TPL) enables the fabrication of metamaterials such as polymer micro-lattices. They are designed to achieve their envisioned mechanical properties through stretching and bending of individual trusses. Several novel approaches are developed here to a) directly print metal microlattices, b) fabricate multiphase composite microlattices and c) shrink the truss diameter below the diffraction limit of light, all with the ultimate goal to enable fabrication of a full dense material with microprinted 3D architecture of different phases. Copper microlattices and micropillars with truss diameters in the few micron range were printed directly via fluid AFM based local electroplating [1]. It was identified that microcrystalline copper micropillars deform in a single-shear like manner exhibiting a weak strain rate dependence at all strain rates. Ultrafine grained (UFG) copper micropillars, however, deform homogenously via barreling and show strong rate-dependence and small activation volumes at strain rates up to ∼ 0.1 s−1, suggesting dislocation nucleation as the deformation mechanism. At higher strain rates, yield stress saturates remarkably, resulting in a decrease of strain rate sensitivity implying a transition in deformation mechanism to collective dislocation nucleation. Finally, the copper microlattices are shown to increase in strength if conformally coated with Nickel with thicknesses in the several 100nm range.

To extend the resolution of 3D electroforming photoresist templates with complex 3D geometries are generated using two-photon lithography and shrunken by a factor of ∼ 5 through pyrolysis [2]. This shrunken template is used for electroforming, or template-assisted electrodeposition, and then etched away. On the one hand positive templates were used to fabricate octet truss nanolattices with truss diameters down to 200nm from either gold or copper and *in situ* SEM microcompression tests revealed that these lattices have high yield strength related to mechanical size effects. On the other hand negative templates were used to fabricate the matrix of a fiber reinforced composite which was subsequently filled to 100% density via atomic layer deposition of alumina. This resulted in a gold matrix composite reinforced by sub-micron sized alumina fibers. The alumina reinforced gold micropillars exhibit a yield strength of 850MPa exceeding the unreinforced gold pillars deposited under the same electrodeposition conditions.

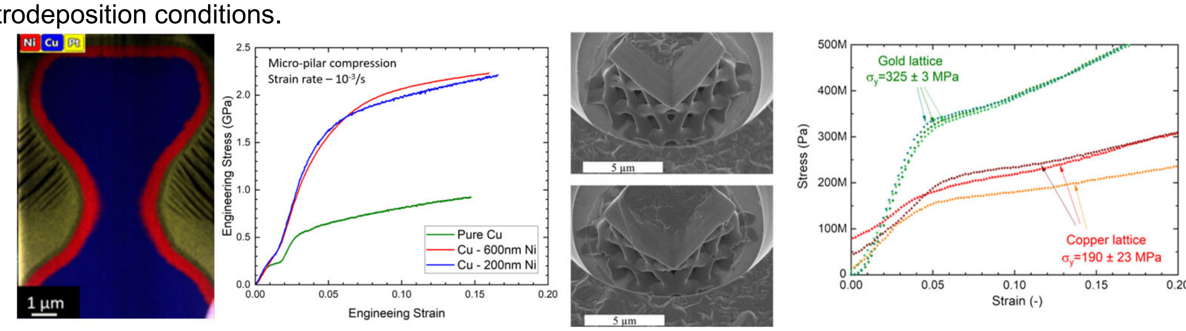

Figure 1: Left: EDX of a Ni coated Cu micropillar showing conformal coating and resulting stress-strain curves of pure Cu and Ni reinforced micropillars. Right: Microlattices prepared by electrodeposition into pyrolyzed templates and results of micromechanical experiment on Au as well as Cu microlattices.

References:

[1] Ramachandramoorthy, Kalácska et al., Anomalous high strain rate compressive behavior of additively manufactured copper micropillars. Applied Materials Today 27, 101415, 2022.
[2] Gunderson et al., Nanoscale 3D electroforming by template pyrolysis. Advanced Engineering Materials 23(5), 2001293, 2021