Effects of pulse duration on laser nanostructuring of crystalline copper

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Single-crystal copper is utilized in high-performance electrical components, precision engineering applications, advanced heat sinks, and thermal management systems. The demand for high-performance materials has stimulated the advancement of nanostructured materials, where the grain boundary strengthening in nanocrystalline materials is augmented by hierarchical nanotwinned, and gradient microstructures [1, 2]. One of the ways to achieve thermally stable nanostructured gradient surface layers is processing by short laser pulses in combination with simultaneous doping [3, 4].

This study explores the effects of pulse duration on single shot laser irradiation to generate nanostructured gradient surface layers on single-crystal copper. Laser nanostructuring, which involves rapid heating and cooling of a molten layer, enables the formation of stable nanostructures by controlling grain coarsening through alloying elements. Experiments are performed for copper targets coated with 50 nm Cu+Zr(5%) precursor layer. The target surfaces are irradiated by ultrashort (250 fs, 10 ps) and short (≤15 ns) laser pulses in the single-shot irradiation regime. The laser processing at different laser fluence levels were realized under nitrogen atmosphere to prevent oxidation. The single-shot modifications were analyzed with scanning electron microscope (SEM) for ablation morphology evaluation at different pulse durations. Further, focused ion beam (FIB) and transmission electron microscopy (TEM) characterization was applied to study the traces of nanocrystalline gradient structure formation. The effect of the pulse duration on the grain structure, intra-granular defects, and second-phase precipitation are analyzed. The defect structures are related to the predictions of large-scale atomistic simulations of laser processing.

Acknowledgements: This project is supported by the International Multilateral Partnerships for Resilient Education and Science System in Ukraine (IMPRESS-U) jointly funded by Research Council of Lithuania (LMTLT) through project No. P-IMPRESSU-23-7, U.S. National Science Foundation (NSF) through Grant OISE-2406599, and U.S. National Academies.

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