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On the manufacturing process of novel ultra-radiopure, high-strength, electroformed Cu-based alloys for rare event searches

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Near-future low-background experiments such as direct Dark Matter (DM) or Neutrinoless Double-Beta Decay search experiments require extremely radiopure detector materials and consistent manufacturing processes to achieve their physics discovery potential. Electroformed copper (EFCu) has been shown to achieve extreme radiopurity. However, its mechanical properties are limited due to high ductility and low strength.
Copper can be procured commercially at low cost and high purity and has no long-lived radioisotopes. Unfortunately, it may be contaminated during manufacturing and is activated by cosmogenic neutrons. In an effort to achieve even higher radiopurity, attention is focused on EFCu. To fulfil the unique radiopurity requirements, experiments pioneer large-scale, additive-free Cu electroformation, e.g. the former Majorana Demonstrator or the on-going NEWS-G collaboration ECuME project. Copper electroforming has been demonstrated to achieve extreme radiopurities with contamination below 10^{-14}g of ^{232}Th and ^{238}U per Cu gram. However, Cu is highly ductile and of low strength, limiting its use for moving mechanical, high-pressure, and load-bearing parts. The ECuME project would improve the capability for experiments such as DarkSPHERE [2], a large-scale electroformed underground spherical proportional counter. DarkSPHERE will operate under high pressure, to probe uncharted territory in the search for DM. This level of radiopurity is also vital for neutrinoless-double β-decay experiments e.g. nEXO, LEGEND, and NEXT to name a few.
To improve the strength of EFCu alloying has been investigated. The most promising alloying element is chromium (Cr). It has been demonstrated that small additions of Cr, combined with heat treatment and aging cycles, improve EFCu strength by 70% [3]. However, Cr additions lead to impurities, and a compromise between strength and radiopurity is required by exploring a complex parameter space of compositions and strengthening mechanisms [4]. Additionally, Cr solubility in Cu is very limited and small additions of titanium (Ti) can allow for even greater mechanical strengthening due to reinforced precipitation, achieved based on the Integrated Computational Materials Engineering (ICME) framework [5].
A systematic simulation study of manufacturing processes (additive-free electroplating and heat treatments) aiming to achieve homogenized alloy compositions is performed using DICTRA [6]. This will inform the achievable alloy compositions and an ICME approach will follow to enable rapid design of new, application-specific alloys.

References

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