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Microstructure and mechanical properties of AlCu thin films in a wide range of composition

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Background incl. aims

Copper is a common additive in bulk aluminum alloys, where its effect on phase composition and strength of the alloys is well documented. Thin films, however, often contain non-equilibrium phases, which may change significantly the mechanical properties of the material. AlCu thin films in a wide range of composition have been less discussed in the literature, as the existing papers are mainly concentrating on the cases of small alloying concentration. In this work, we aimed to study systematically the microstructure and mechanical properties, as well as to understand their correlations in the case of AlCu thin films having compositions widely changing.

Methods

Thin films were deposited by dual DC magnetron sputtering of Al and Cu targets. Applying the micro-combinatorial technique [1] 15 Al1-xCux films with different compositions ($0 \leq x \leq 1$) were deposited within a single experiment (under the same vacuum conditions) on a single Si substrate. Depth sensing indentation (DSI) measurements were conducted to reveal the hardness and the deformation mechanism of the layers. Cross-sectional lamellas were prepared from each layer by the focused ion beam (FIB) technique, and then investigated by transmission electron microscopy (TEM) techniques, including: bright field, dark field and HRTEM imaging, selected area electron diffraction (SAED), TEM energy dispersive spectroscopy (EDS), scanning TEM (STEM).

Results

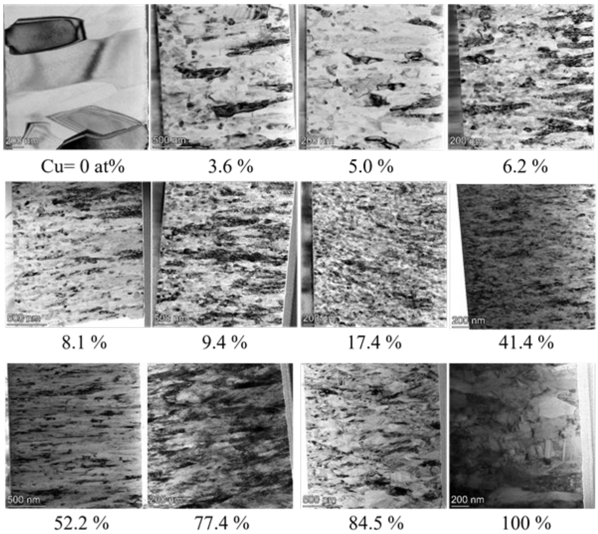
Layers near to the equiatomic compositions (Al59Cu41, Al48Cu52, Al39Cu61) are built up from crystalline columns of ~30-40 nm in diameter. At these compositions the SAED measurements show the presence of the Al4Cu9 crystalline phase, which differs from that predicted by the equilibrium phase diagram. Lamellas prepared from the indentation imprints also indicate the presence of deformation bands, suggesting an amorphous like deformation behavior. This is coupled with an exceptional hardness of ~ 16 GPa [2] and a step-like indentation curve during the loading stage of the indentation.

The pure Al and Cu layers also possess small grain-size (~300-400 nm) structure, coupled with an increased hardness compared to their bulk counterparts. Furthermore, indentation process taken on these ultrafine-grained thin film do not show the size effect often observed in the case of bulk materials. The absence of the indentation size effect may be the consequence of the deformation mechanism as intensive grain boundary sliding (GBS) is revealed in these layers by both surface SEM and cross-sectional TEM images.

Conclusion

Composition-dependent mechanical and structural properties of AlCu alloy thin films were determined over the entire alloying concentration range. The decreasing grain size and the appearance of non-equilibrium phases are in good agreement with the increasing alloying concentration - increasing hardness trend. The presence of GBS suggests a mitigation of the classical dislocation-driven plastic deformation mechanism, which is compatible with the absence of an indentation size effect.

Graphic:



Keywords:

AlCu thin films, TEM, nanoindentation

Reference:

[1] G. Sáfrán et al.: Review on High-Throughput Micro-Combinatorial Characterization of Binary and Ternary Layers towards Databases. Materials 2023, 16, 3005.
[2] D. Olasz et al.: Indentation size effect in exceptionally hard AlCu thin films. Mater. Lett. 2023, 330, 133409.