Tensile Behavior of Metallic Glass Coating on Cu Foil

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Abstract

The tensile behavior of the monolithic ZrCu thin film metallic glass and the ZrCu/Cu multilayer coating on pure Cu foil is systematically examined. The extracted tensile modulus and strength of the 1 micrometer films are in good agreement with the theoretically rule of mixture prediction. The extracted 2 micrometer film data are lower, but can be corrected back by considering the actual intact cross-sectional area during the tensile loading. The current results reveal that the ZrCu/Cu multilayer coating exhibit much better tensile performance than the monolithic ZrCu coating despite of the brittle deformation. To obtain ductile amorphous/crystalline multilayer coating, two principles is suggested in this study.

Results and discussion

Table 1 Summary of the Young’s modulus (*E*) and stress (σ_{max}) data on the amorphous ZrCu and crystalline Cu, the theoretically predicted modulus and stress values based on the iso-strain mode of Rule of Mixture (ROM), and the extracted 1 and 2 μm ZrCu/Cu multilayer thin films (ZCC100MLTF-1 and ZCC100MLTF-2).

Materials	Sample type	Young’s modulus, *E* (GPa)	Maximum stress, σ_{max} (MPa)
Amorphous ZrCu	Monolithic	93	1600
Crystalline Cu	Monolithic	127	280
Theoretical ROM values	Multilayer	110	940
ZCC100MLTF-1	Multilayer	111±6	909±27
ZCC100MLTF-2	Multilayer	68±3 (95±5)	497±14 (803±17)

Table 2 The Young’s modulus (E), maximum tensile stress (σ_{max}), tensile strain (ε), and displacement of the Cu foils coated with 1- μm -thick monolithic ZrCu TFMG and 1- μm -thick ZrCu/Cu multilayer thin films with various individual layer thicknesses (*hi*) of 10, 25, 50, 100, and 250 nm.

Materials	h_i (nm)	Young’s modulus, *E* (GPa)	Maximum stress, σ_{max} (MPa)	Tensile strain, ε (%)
1 μm ZrCu TFMG	Monolithic	74	663	1.03
1 μm ZrCu/Cu MLTF	10	96±19	1109±80	1.64±0.17
	25	91±17	1083±175	1.79±0.17
	50	84±17	987±2	1.60±0.06
	100	111±7	909±27	1.56±0.08
	250	96±1	1083±69	1.72±0.21

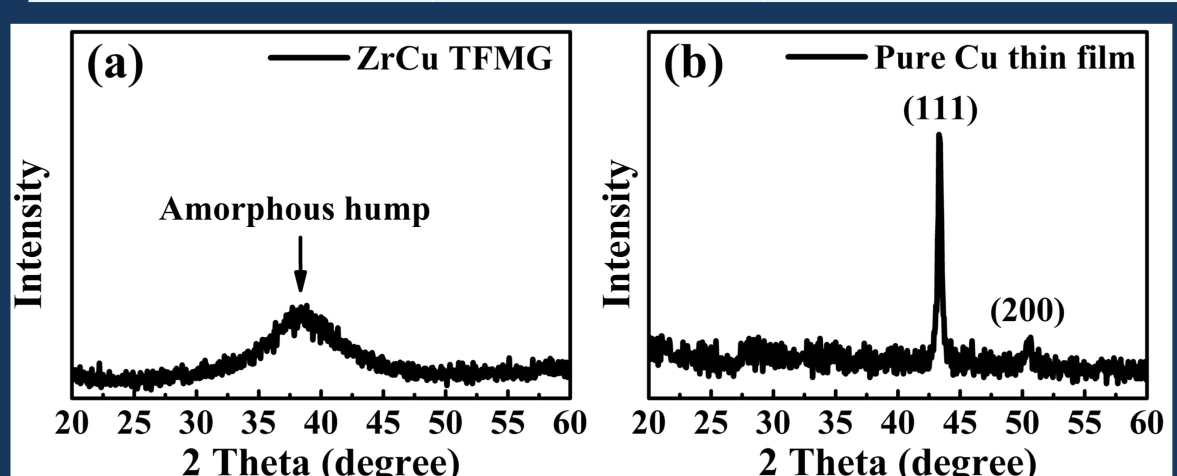

Figure 1 The XRD patterns of different thin films deposited on the Si wafer.

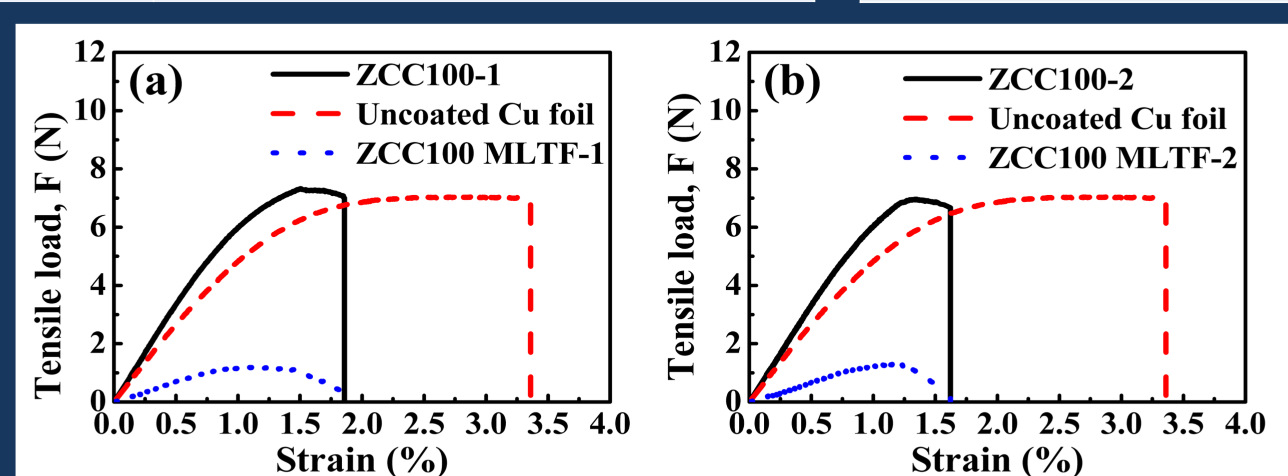

Figure 2 Load-strain curves of (a) 1-μm-thick and (b) 2-μm-thick ZrCu/Cu multilayer thin film with *hi* of 100 nm deposited on the Cu foil, along with the curve for the pure Cu foil. The blue curves are obtained by subtracting the Cu foil contribution.

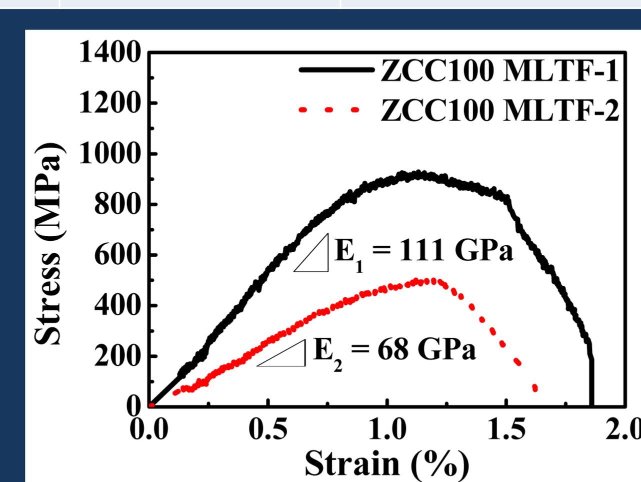

Figure 3 Typical S-S curves for the ZrCu/Cu MLTFs, with the calculated Young’s moduli.

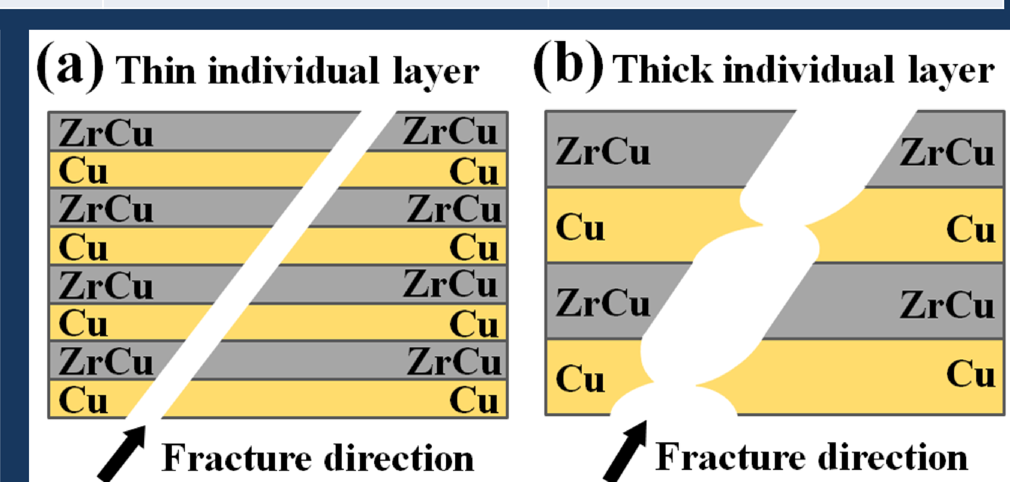

Figure 4 Schematic illustrations of the macrocrack propagation path in the ZrCu/Cu multilayer thin films with (a) small *hi* and (b) large *hi*.

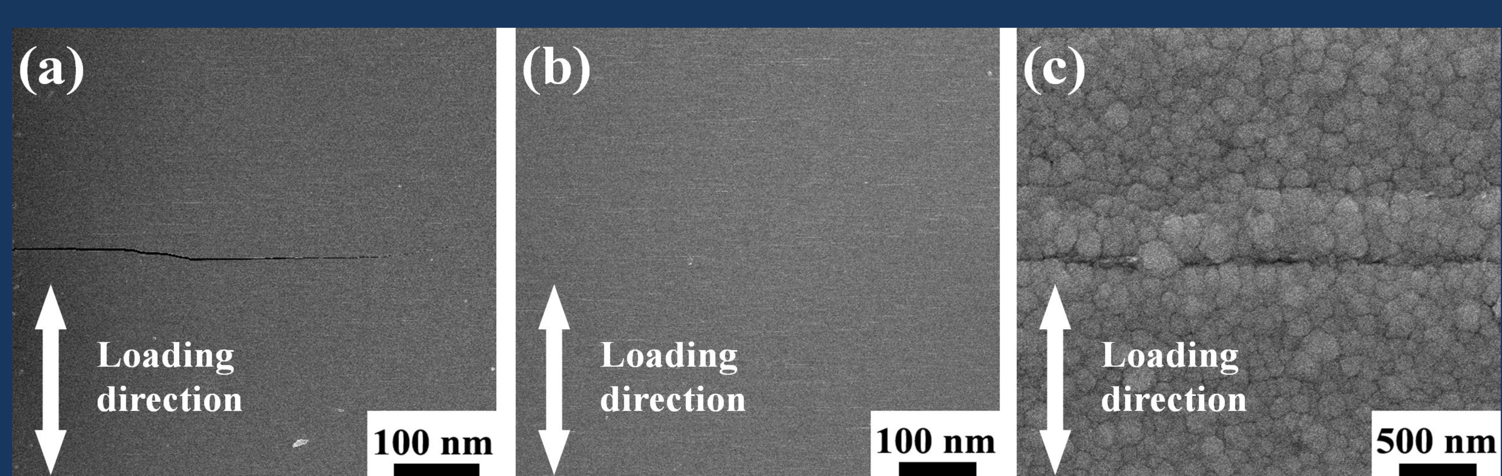

Figure 5 SEM micrographs of (a) the macrocrack in ZCC100MLTF-2 with the length of ~500 μm at σ_{max}, (b) ZCC100MLTF-1 without major microcracks at σ_{max}, and (c) microcrack in ZCC100MLTF-1 with the length of 2-3 μm at σ_{max}.

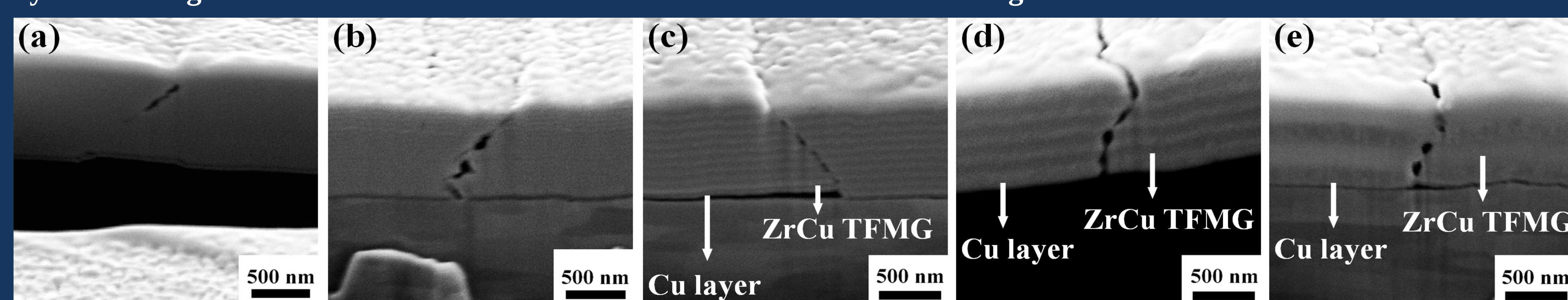

Figure 6 SEM micrographs of the Cu-supported ZrCu/Cu multilayer thin films after tensile failure in (a) *hi* = 10 nm, (b) *hi* = 25 nm, (c) *hi* = 50 nm, (d) *hi* = 100 nm, and (e) *hi* = 250 nm.

Conclusions

1. **The extracted tensile modulus and strength of the multilayer films are in good agreement with the theoretically rule of mixture prediction, and are in the similar range as those measured from the ZrCu/Cu multilayer film micropillars under compression.**
2. **The current results reveal that the ZrCu/Cu multilayer coating exhibit much better tensile performance than the monolithic ZrCu coating. The 1 μm multilayer coatings, even after failure, are always still intact with the Cu foil, distinctly different from the monolithic TFMG coating.**
3. **Two principles for the obtaining of ductile amorphous/nanocrystalline multilayers regarding on layer thickness (nm) are given as follows. One is that the amorphous layer is thinner than critical shear band nucleus size, i.e., less than one decade order; the other is the nanocrystalline layers is thicker than the critical thickness of activating non-plane dislocation movement, i.e., more than a few decade order.**