Tensile Behaviors of Amorphous/Nanocrystalline ZrCu/Cu Multilayered Thin Film on Polyimide Substrate

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Abstract

The tensile behaviors of the monolithic ZrCu thin film metallic glass (TFMG), monolithic crystalline Cu thin film, and the ZrCu/Cu multilayered thin film with various individual layered thicknesses deposited on the polyimide (PI) foil have been investigated. The modulus and strength of the multilayered thin film are demonstrated to be consistent with the theoretical Rule of Mixture values. As the individual layer thickness decreases from 100 to 10 nm, the Young's moduli are varied slightly. However, the maximum tensile stress exhibits a highest value for the 25 nm layer thickness. The higher crack spacing, or the lower crack density, of this 25 nm multilayer film leads to the highest strength.

Results and discussion

Equations

$$\sigma_{film} = \frac{1}{w_{film} t_{film}} (F_{total} - F_{PI})$$

σ_{film} : Tensile stress of thin film
w_{film} : Width of the coated specimen
t_{film} : Thickness of the coated specimen
F_{total} : Tensile load for the coated specimen
F_{PI} : Tensile load for the uncoated PI foil

$$E_{Multilayer} = (1 - f) E_{ZrCu} + f E_{Cu}$$

$E_{Multilayer}$: Modulus of multilayer thin film
E_{ZrCu} : Modulus of ZrCu thin film
E_{Cu} : Modulus of nc Cu thin film
f : volume fraction of nc Cu thin film

Tables 1 Summary of the Young's modulus data on the amorphous ZrCu and crystalline Cu, the theoretically predicted modulus and stress values based on iso-strain rule of mixture (ROM).

Materials	Testing methods	Young's modulus, E (GPa)
Amorphous ZrCu	Tensile test	83
Nanocrystalline Cu		104
Theoretical ROM values		94
Amorphous ZrCu	Nanoindentation	93
Nanocrystalline Cu		127
Theoretical ROM values		110

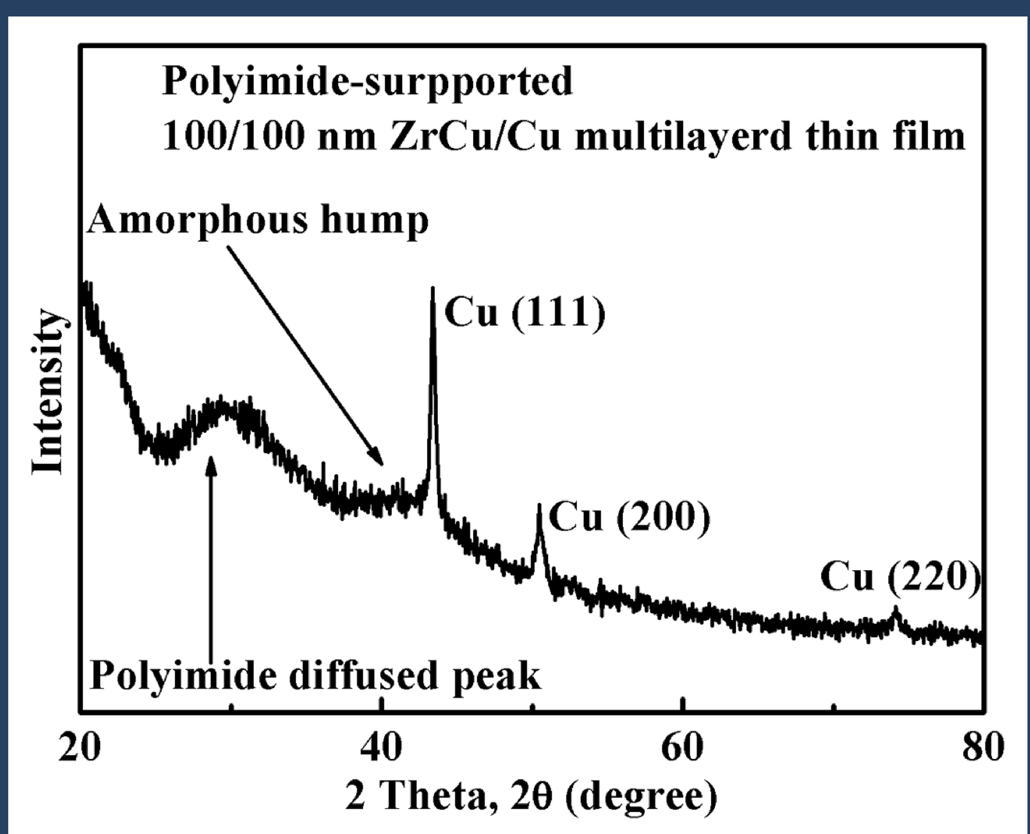

Figure 1 The representative XRD patterns of ZrCu/Cu multilayered thin film with individual thickness of 100 nm deposited on the polyimide foil.

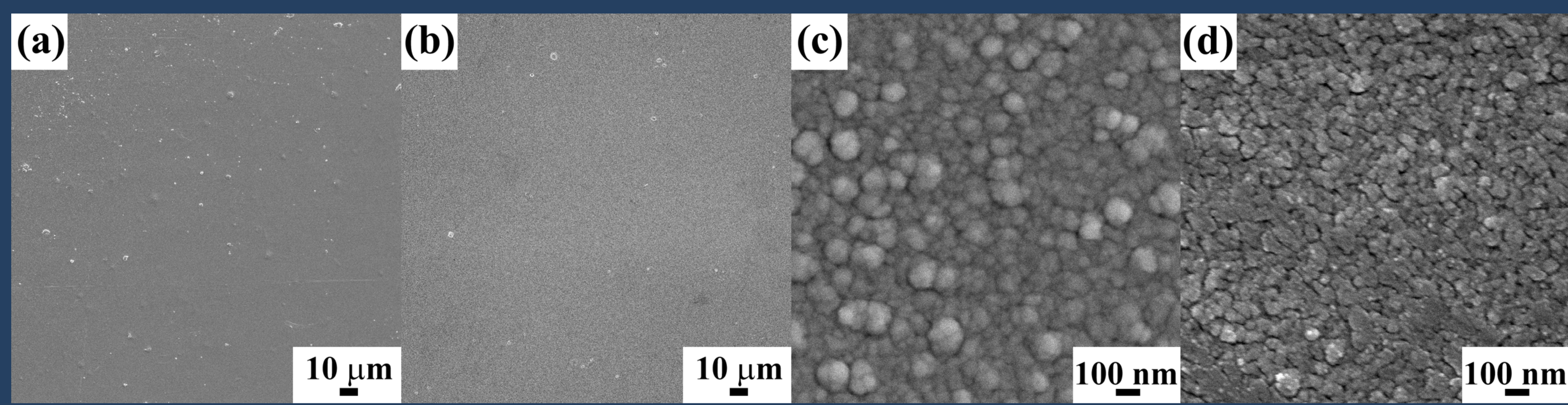

Figure 2 Surface morphology of the undeformed ZrCu/Cu multilayered thin films with various individual layered thicknesses of (a) 100 nm at a low magnification, (b) 25 nm at a low magnification, (c) 100 nm at a high magnification, (b) 25 nm at a high magnification.

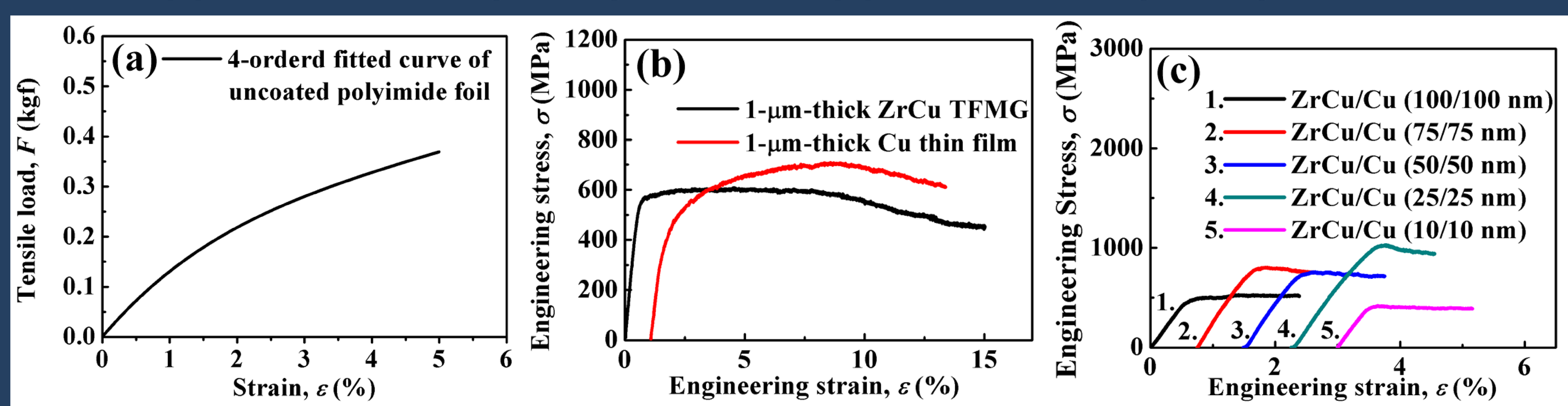

Figure 3 (a) The fitted load-strain curve calculated from the averaged results of the PI substrates. (b) The representative engineering stress-strain curve of the 1-μm-thick monolithic ZrCu TFMG and nanocrystalline Cu thin film. (c) The representative engineering stress-strain curves for the 1-μm-thick ZrCu/Cu multilayered thin films with various individual layered thicknesses of 100, 75, 50, 25, and 10 nm.

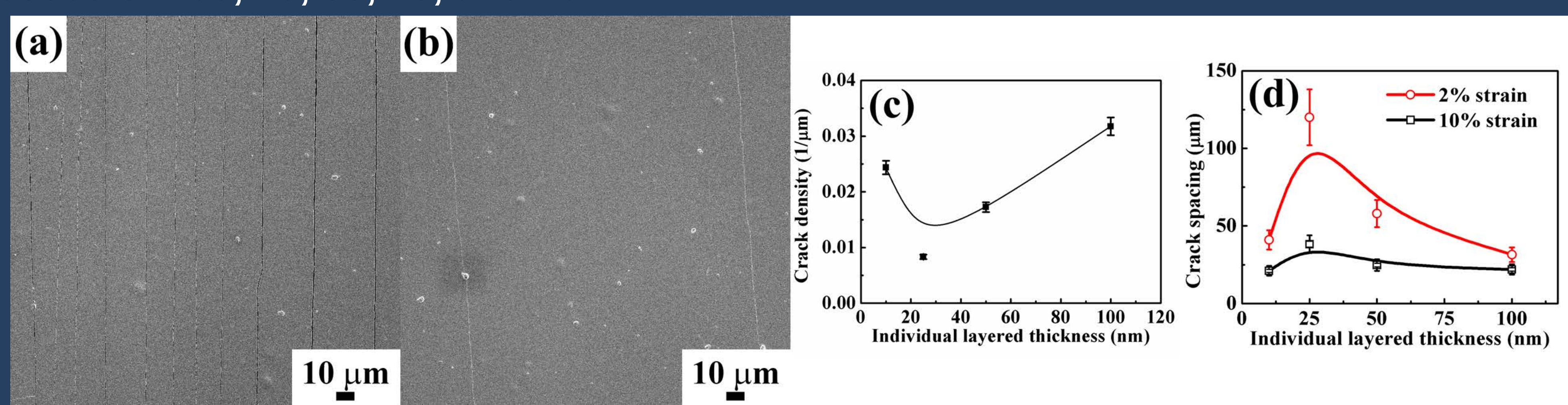

Figure 4 Surface morphology of the deformed ZrCu/Cu multilayered thin films with various individual layered thickness of (a) 100 and (b) 25 nm, subjected to 2% tensile strain. The variations of the (c) surface crack density and (d) average crack spacing as a function of individual layer thickness. Note the parallel variation trend of Fig. 4(d) and Fig. 5.

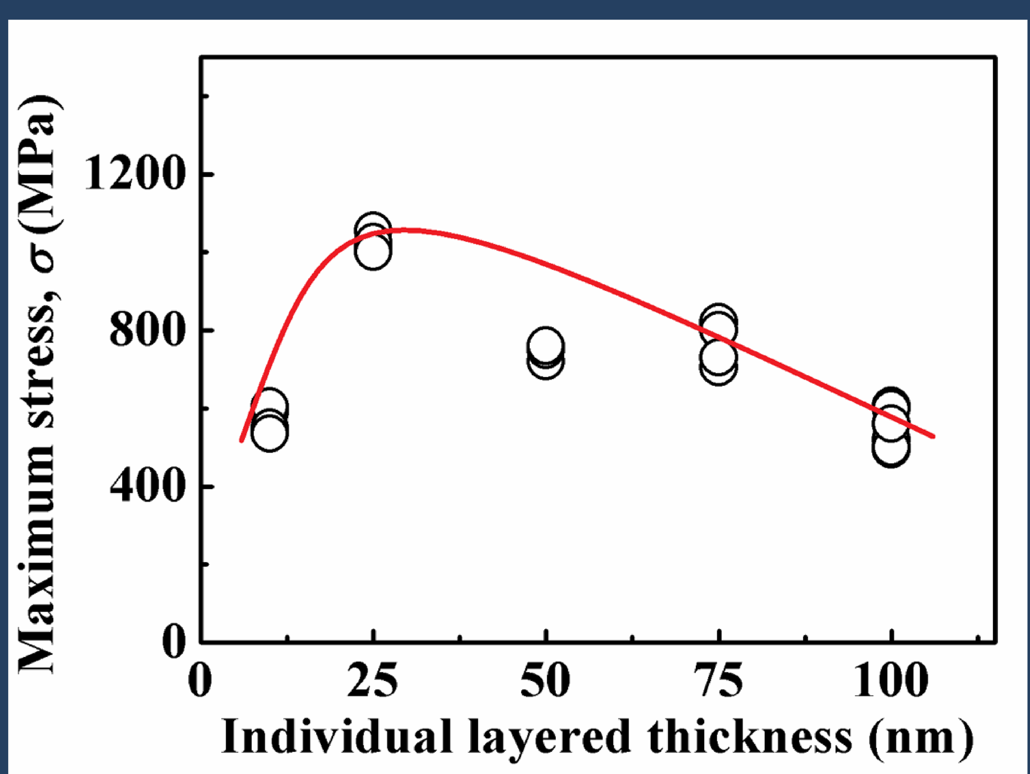

Figure 5 The dependence of maximum tensile stress as a function of layer thickness.

Conclusions

1. The moduli extracted from the tensile loading of the monolithic ZrCu TFMG and monolithic nanocrystalline Cu thin films (83 and 104 GPa) are close to results obtained by nanoindentaiton (93 and 127 GPa).
2. The moduli and stresses of the multilayered ZrCu/Cu thin films extracted by deducting the contribution of the uncoated PI substrate from the coated samples are compatible with the values calculated from the theoretical rule of mixture prediction.
3. As the layer thickness going down from 100 nm to 10 nm, the tensile moduli would vary slightly. But the tensile stresses exhibit strong dependence as a function of layer thickness. The 25/25 nm film shows the highest stress to the level of 1030 MPa.
4. The 25/25 nm film always possesses a lower surface microcrack density, higher microcrack spacing, and thus higher maximum tensile stress. The 25/25 nm ZrCu/Cu multilayered film is demonstrated to be the optimum layer thickness under tensile loading.