Tensile deformation of ZrCu/Cu nanolaminated free-standing film via membrane deflection experiment

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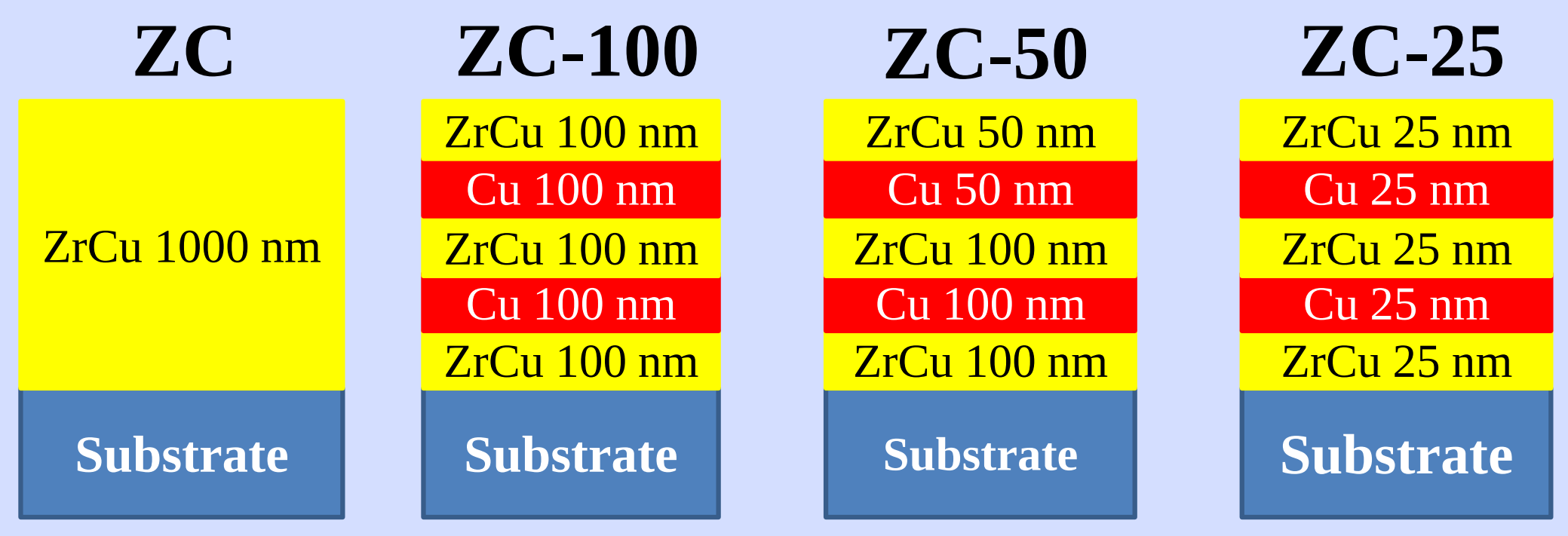
Abstract

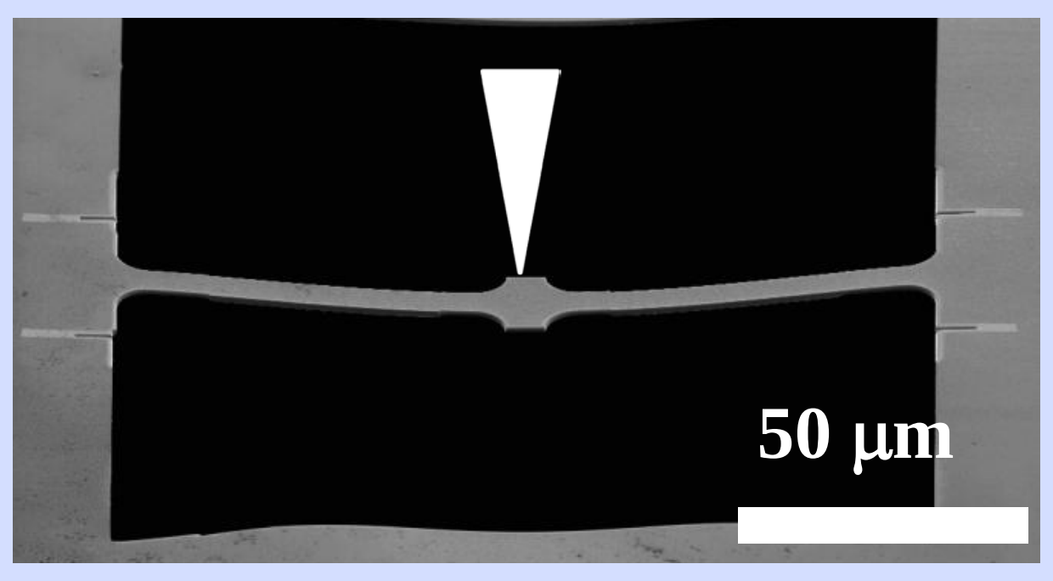
The crystalline-amorphous nanolaminates have been reported as the composite structure to improve the lack of tensile ductility. Free-standing and micro bridges of amorphous ZrCu film and ZrCu-Cu nanolaminates with individual layer thickness from 100 to 25 nm were fabricated via laser patterning, wet etching and FIB micromachining. A membrane deflection experiment on the nano-indentater system was conducted to study tension deformation of these nanolaminates. The monolithic ZrCu specimen exhibited highly brittle fracture, with poor fracture strength of 600 MPa, low deformability, a fracture angle of 90^o, and the exposure of granular structure as a result of the intrinsic tensile stress formed during film growth. The strength and deformability of the ZrCu/Cu nanolaminates increased with decreasing layer thickness. The fracture angle became close to 45^o when the layer thickness decreased to 25 nm, meaning it performed better ductility. These nanolaminates exhibited the much higher fracture strength of 2000-2500 MPa. A layer thickness of 25 nm is demonstrated to be an optimum selection for the improvement of tensile ductility in amorphous/crystalline nanolaminates.

Methods



UV Laser Pattern
Wet etching
Focus ion beam maching

Membrane Deflection Experiment



Gage length: 65~45 µm
Gage width: 6.6~7 µm

Results and discussions

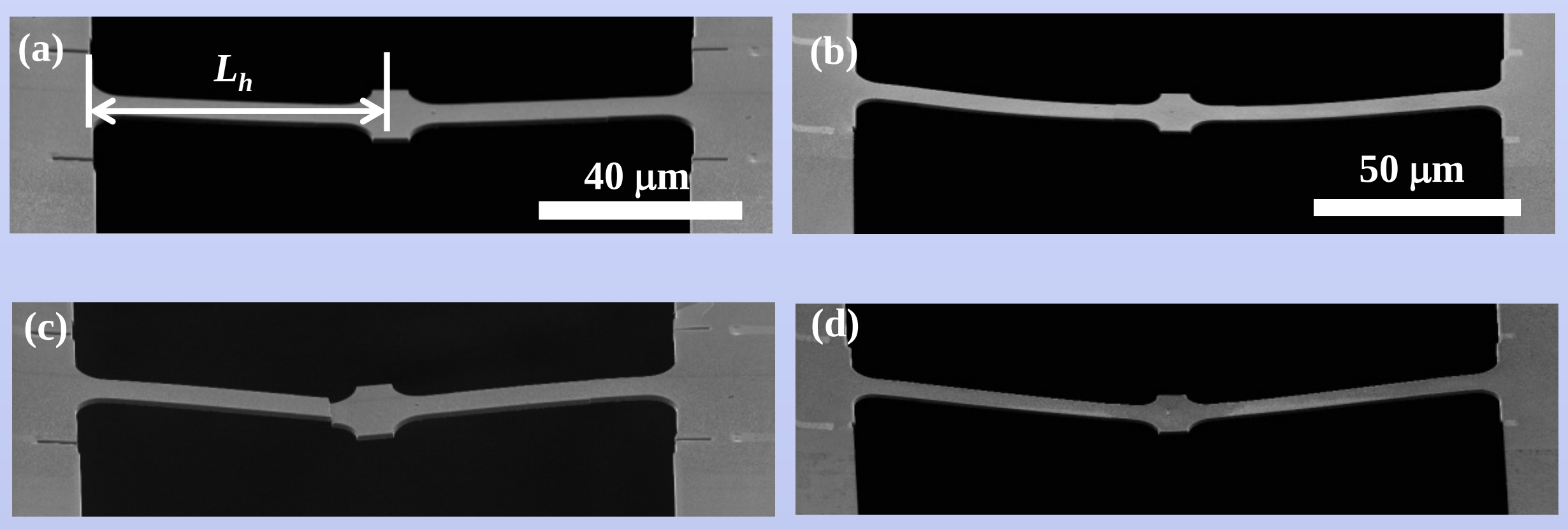


Fig. 1 SEM micrographs showing the dog-bone bridge specimens of ZCC-100 and ZCC-25: before indentation (a)(b) and after indentation (c)(d), respectively.

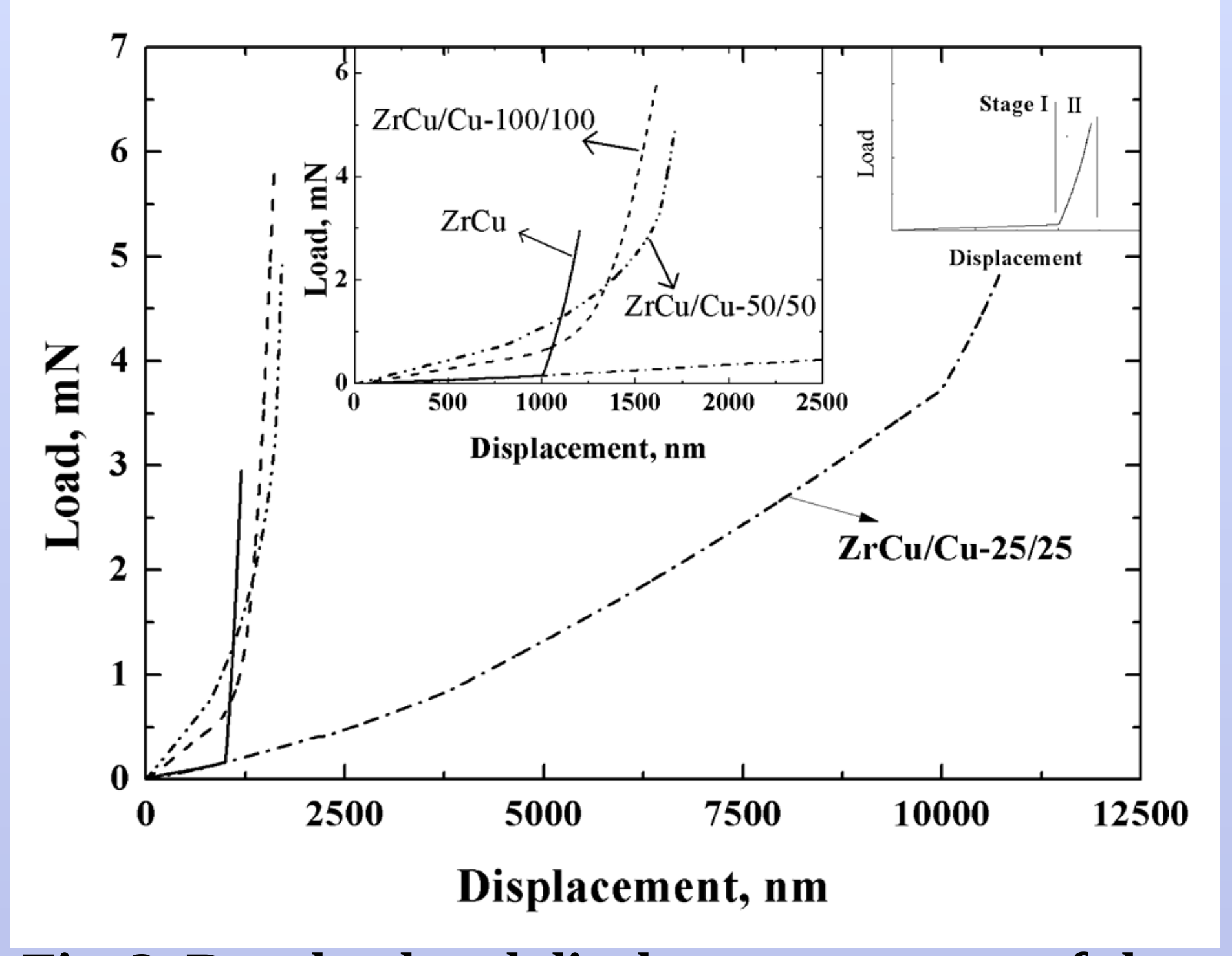


Fig. 2 Raw load and displacement curves of the Membrane deflection experiment for the ZC, ZCC-100, ZCC-50 and ZCC-25 specimens.

Table 1 Comparison of the slopes, the deformability index, and fracture stress of the four different free-standing specimens.

	ZC	ZC-100	ZC-50	ZC-25
Nanoindentation Hardness, GPa	6.1	4.9	5.9	5.9
Deformability index, %	1.4	2.2	2.4	>1.5
Fracture stress, GPa	0.6	2.0	2.5	2.5

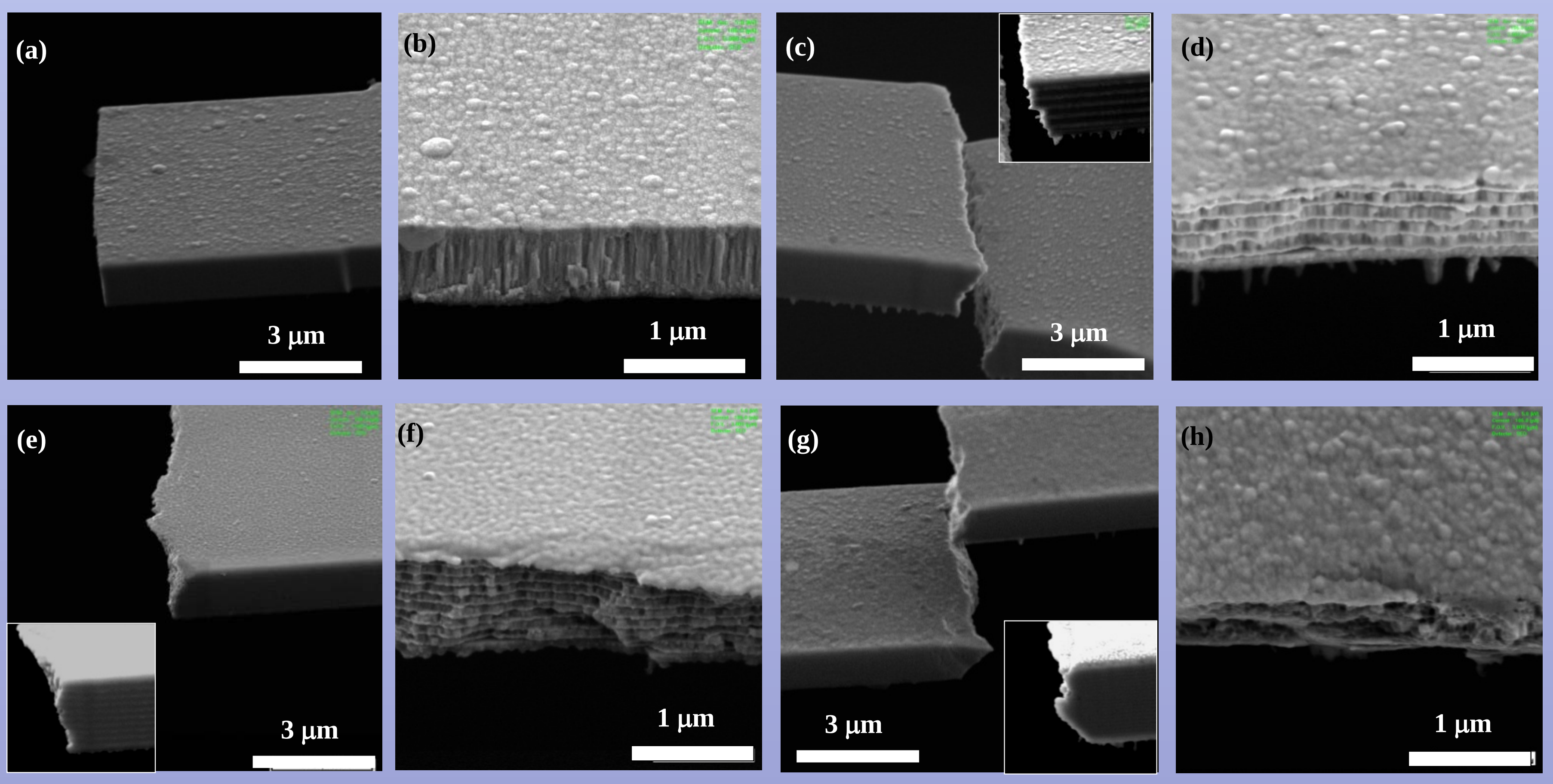
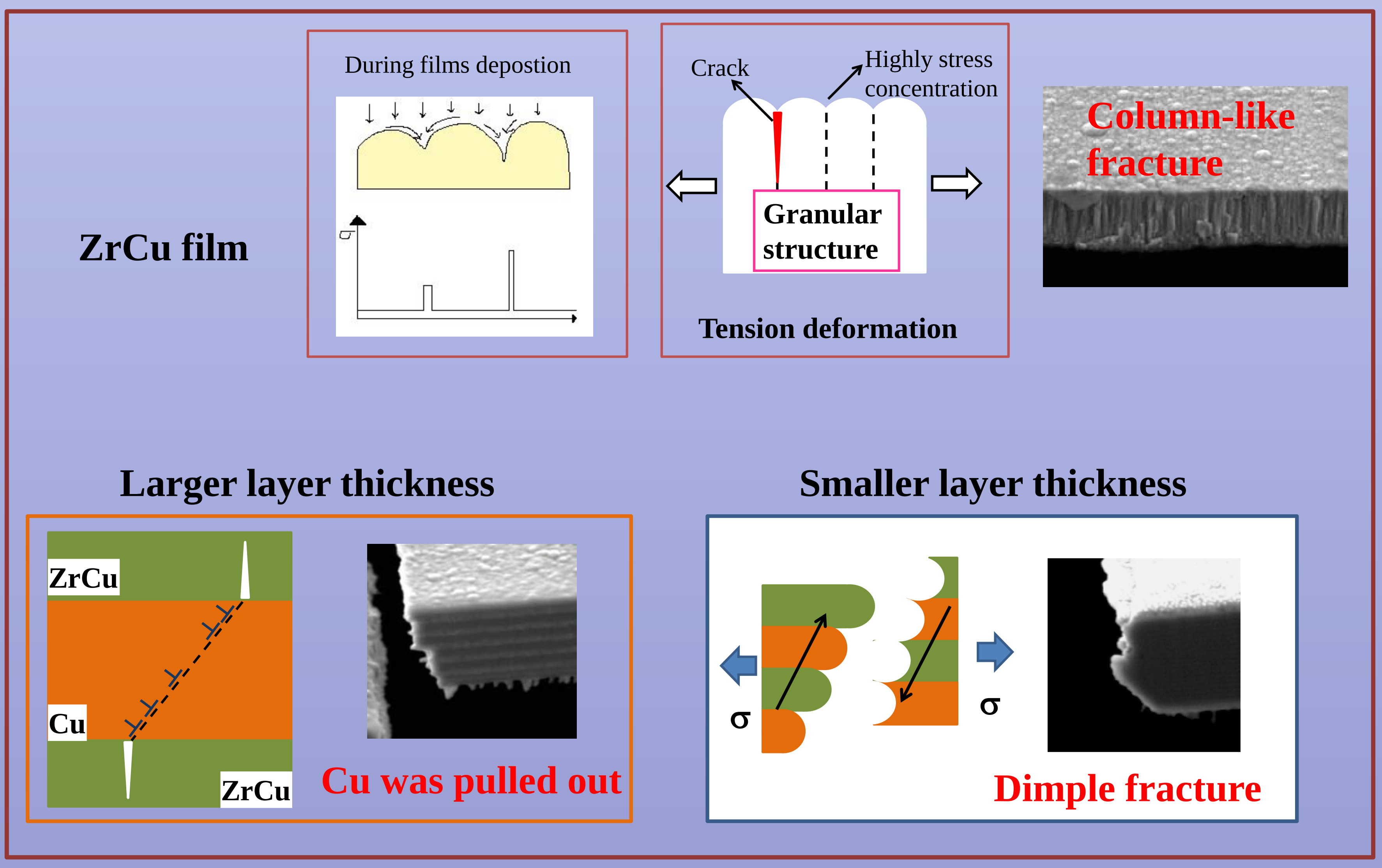


Fig. 3 SEM micrographs showing the side views of the fractured specimens: (a)(b) ZC, (c)(d) ZCC-100, (e)(f) ZCC-50, and (g)(h) ZCC-25. The inserted figures show the enlarged cross-sectional images via the etching by lower-current ion beam.



Conclusions

Micro bridges of amorphous ZrCu film and ZrCu-Cu nanolaminates with individual layer thickness from 100 to 25 nm were fabricated via laser patterning, wet etching and FIB micromachining. A membrane deflection experiment was conducted to study tension deformation. The monolithic ZrCu specimen exhibited highly brittle fracture, with poor fracture strength of 600 MPa, low deformability, a fracture angle of 90^o, and the exposure of granular structure as a result of the intrinsic tensile stress formed during film growth. The strength and deformability of the ZrCu/Cu nanolaminates increased with decreasing layer thickness. The fracture angle became close to 45^o when the layer thickness decreased to 25 nm. These nanolaminates exhibited the much higher fracture strength of 2000-2500 MPa. A layer thickness of 25 nm is demonstrated to be an optimum selection for the improvement of tensile ductility in amorphous/crystalline nanolaminates.