

Toward novel stretchable electronics with nanostructured metallic glass films

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Thin film metallic glasses (TFMGs) are emerging materials characterized by outstanding combination of mechanical/electrical properties involving a yield strength close to the theoretical limit, large ductility (> 10%) [1] and metallic-like conductivity [2]. Nevertheless, the synthesis of advanced TFMGs with engineered microstructure and the understanding of their mechanical/electrical properties is barely tackled, requiring the development of novel synthesis strategies and cutting-edge techniques for submicrometer scale characterization.

Here, we report the use of Pulsed Laser Deposition (PLD) as a novel technique to synthesize nanostructured $\text{Zr}_{50}\text{Cu}_{50}$ (%at.) TFMGs. We show how the control of PLD process parameters (background gas pressure and laser fluence) enables to synthesize different film microstructures involving atom-by-atom or cluster-assembled growth, resulting in a variety of film structures including compact fully amorphous, amorphous nano-porous with large free volume interfaces, and amorphous embedded with nanocrystals. High-resolution TEM reveals a nano-laminated atomic structure characterized by alternated layers with different chemical enrichment and local atomic order.

This self-assembled nanoarchitecture is at the basis of unique mechanical properties including large elastic modulus (145 GPa) and hardness (10 GPa). Quantitative *in-situ* TEM tensile tests reveal that films have an outstanding yield strength (3 GPa) and ductility (> 9%) product which is significantly dependent on the microstructure with large/low plasticity and low/high yield strength obtained for nanogranular/compact metallic glass films. Finally, we developed a stretchable transparent electrode based on nanogranular TFMGs nanotrough network showing excellent stretchability (70%) and low sheet resistance ($\sim 3 \Omega/\text{sq}$) which is then integrated in wirelessly rechargeable transparent heater, demonstrating the potential of these films for novel stretchable electronic devices.

- [1] M. Ghidelli, H. Idrissi, S. Gravier, J.-J. Blandin, J.-P. Raskin, D. Schryvers, T. Pardoen, *Acta Mater.* 2017, 131, 246-259.
- [2] B. Wan An, E.-J. Gwak, K. Kim, Y.-C. Kim, J. Jang, J.-Y. Kim, J.-U. Park, *Nano Lett.* 2016, 16, 1, 471-478.