Crystallizing glassy issues

Understanding the behaviour of metallic glasses requires answers to complex scientific questions, which are also critical for their successful commercialization.

Melt-quenched metallic glasses have captured the attention of scientists for almost six decades, with research output continuing to increase. Such prolonged interest for a class of material that has yet to find widespread use — despite claims of its potential for a number of years — cannot only be ascribed to potential commercial viability. Indeed, if interest in metallic glasses were rooted solely in their possibility to replace traditional materials in service, then we might have long ago concluded that metallic glasses are untenable as engineering materials. Rather, they represent a fascinating material to study, and present intriguing scientific questions regarding the most basic principles behind their structure, properties, and ultimately their existence. Furthermore, metallic glasses have been proven to have broader relevance in understanding amorphous materials in general, as well as the parent liquid. With scientists from a broad range of backgrounds (metallurgists, glass scientists and solid-state physicists, to name a few) having contributed ideas to unravel the basic behaviour and properties of metallic glasses, they are now closer than ever to offering a cost-effective, high-performance alternative to many traditional alloy options. In this focus issue, we explore some of the most pressing gaps in our understanding of metallic glasses, their commercialization outlook, and how these two aspects are linked.

The first report of a melt-quenched metallic glass came from Pol Duwez and colleagues, who, by firing an Au–Si melt at a Cu surface, achieved a cooling rate sufficiently high to bypass crystallization of the alloy[1]. Since then, a central theme in metallic-glass research has been the study of the underlying factors that play a role in glass formation. Early works emphasized the importance of eutectic compositions (where the gap between the melting and glass-transition temperatures is suppressed). But as Lindsay Greer discusses in a Commentary on page 542, recent evidence that glass formation can occur in single-element metals requires a reassessment of our understanding. Indeed, understanding of crystallization in systems capable of rapid atomic ordering is also called into question and might prove critical in obtaining high-speed phase-change materials for solid-state memory.

Microscale metallic glass parts fabricated by a thermoplastic forming-based micromoulding technique. Reproduced with permission from ref. 3, Wiley.

Glass formation and the avoidance of crystallization are not the only fundamental problems yet to be resolved. A central tenet in materials science is the processing–structure–property cycle, a comprehensive account of which is elusive in a material devoid of crystalline structure. As discussed by Evan Ma in a second Commentary on page 547, the amorphous nature of metallic glasses does not necessarily preclude discerning these relationships. Experiments and simulations have established that within metallic glasses there exists a significant amount of order that extends beyond the immediate atomic environment. By isolating the structure and contribution of specific atomic arrangements, it may yet be possible to engineer their macroscopic behaviour.

It is interesting that fundamental behaviour, such as glass formation, crystallization and structure–property relationships, remain some of the largest barriers to widening the application potential of metallic glasses (metallic glass ribbons have been employed for decades in transformer cores because of the reduced energy losses during magnetic cycling compared with crystalline alternatives). In this regard, in an Interview on page 553 William L. Johnson provides some thoughts on the current commercial landscape of metallic glasses. It is apparent that the commercial success of metallic glasses rests on solving a number of issues, both fundamental and applied. In this respect, and although a substantial proportion of current metallic-glass research focuses on the optimization of mechanical behaviour (which remains a critical challenge), it is important to remember that their viability also relies on understanding the basic science of the material, such as the physical factors that control glass formation, and thermally driven relaxation and crystallization events.

Developing appropriate fabrication routes is also necessary, as exemplified by a recent deposition-based approach for the synthesis of metallic glass nanostructures with a wide composition range (ref. 2 and corresponding Research Highlight on page 556), with the possibility for use in microelectromechanical systems. In fact, one of the most attractive features of metallic glasses is the possibility of combining the economics of thermoforming processes (such as those used for plastics) with the properties of high-performance alloys. Modifying existing metals- or plastics-based manufacturing routes for metallic glasses is problematic however, and new technologies are needed.

Metallic glasses are a classic example of basic research providing the foundations needed to take a material forward as a commercial option. In an age where research funding is increasingly targeted, realizing the potential that metallic glasses have as an engineering material becomes ever more important in justifying spending. But let's not forget the fascinating science presented by this unique material: understanding metallic glasses is both intellectually enticing and commercially valuable. ❒

References

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2. Liu, Y. *et al. Nature Commun.* **6,** 7043 (2015).
3. Kumar, G., Desai, A. & Schroers, J. *Adv. Mater.* **23,** 461–476 (2011).