Manufacturing & Prototyping

Castable Amorphous Metal Mirrors and Mirror Assemblies

Commercial applications include optics for spacecraft and satellites, mirror components for telescopes, and mirrors for lasers, sensing, and solar energy collection.

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The use of mirror assemblies is commonplace in the aerospace industry, as most satellites and spacecraft contain optics. The fabrication of these mirrors is extremely complex due to the nature of their intended use, which includes telescope lenses, camera optics, or laser mirrors. Some of the common requirements of spacecraft mirrors are that they have the correct optical curvature to some defined tolerance, they have low surface roughness, they have high reflectivity, and they are rigid (either against thermal expansion or flexing).

Typical spacecraft mirrors are either fabricated by coating oxide glass with a metal layer or by machining, polishing, and coating metal mirrors. Oxide glass exhibits a low coefficient of thermal expansion (CTE) and can be made very smooth but is also dense, brittle, and difficult to bond to mirror-mounts. Metal mirrors are tough and light, but must typically be diamond-turned to achieve an optical surface and exhibit very high CTEs. Moreover, support structures, such as isogrids, flexures, or tabs, must be machined out of large blocks of metal or bolted on separately to the mirror. The use of different CTE materials in a mirror and mirror assembly causes misalignment and thermal cracking.

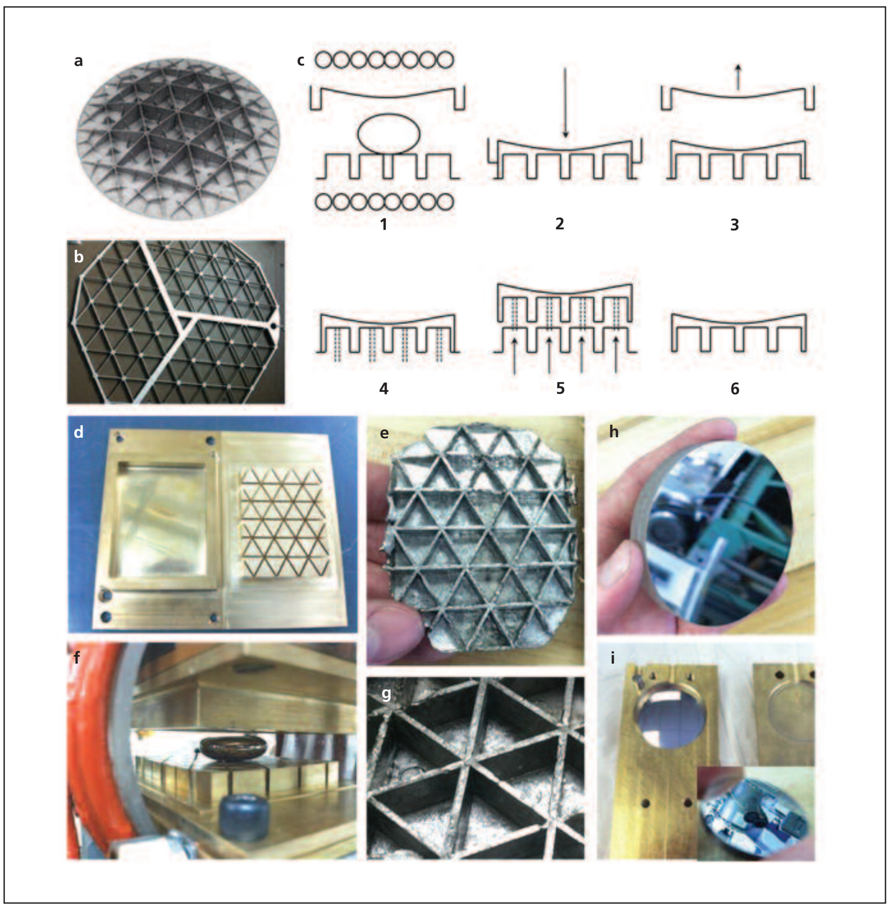

Figure (a) Example of an **Isogrid Mirror Backing** machined from a solid block of metal. (b) An aluminum isogrid machined from a solid plate. (c) The processing steps necessary to fabricate an amorphous metal mirror and isogrid in a single step. An ingot of amorphous metal or composite is heated using radio frequency heating while sitting on water-cooled molds. The liquid is forged into the mold and cools into a glass, which allows it to be ejected from the mold without sticking. With sufficient casting pressure, the isogrid and the mirror surface can be fabricated in one step. (d-g) The water cooled brass molds used to make the mirror, the isogrid, and the part after being ejected from the mold. (h) Example of a mirror assembly with isogrid backing all made from an amorphous metal. (i) A mirror polished steel mold with curvature acts as the template for casting a perfect metallic glass mirror (shown in the inset).

A revolutionary way to produce a mirror and mirror assembly is to cast the entire part at once from a metal alloy that combines all of the desired features into the final part: optical smoothness, curvature, flexures, tabs, isogrids, low CTE, and toughness. In this work, it has been demonstrated that castable mirrors are possible using bulk metallic glasses (BMGs, also called amorphous metals) and BMG matrix composites (BMGMCs). These novel alloys have all of the desired mechanical and thermal properties to fabricate an entire mirror assembly without machining, bonding, brazing, welding, or epoxy. BMGs are multi-component metal alloys that have been cooled in such a manner as to avoid crystallization, leading to an amorphous (non-crystalline) microstructure. This lack of crystal structure, and the fact that these alloys are glasses, leads to a wide assortment of mechanical and thermal properties that are unlike those observed in crystalline metals. Among these are high yield strength, carbide-like hardness, low melting temperatures (making them castable like aluminum), a thermoplastic processing region (for improving smoothness), low stiffness, high strength-to-weight ratios, relatively low CTE, density similar to titanium alloys, high elasticity, and ultra-smooth cast parts (as low as 0.2-nm surface roughness has been demonstrated in cast BMGs). BMGMCs are composite alloys that consist of a BMG matrix with crystalline dendrites embedded throughout. BMGMCs are used to overcome the typically brittle failure observed in monolithic BMGs by adding a soft phase that arrests the formation of cracks in the BMG matrix. In some cases, BMGMCs offer superior castability, toughness, and fatigue resistance, if not as good a surface finish as BMGs.

As shown in the figure, this work has demonstrated that BMGs and BMGMCs can be cast into prototype mirrors and mirror assemblies without difficulty. Optical curvature, ultra-smooth surfaces, and isogrids have all been demonstrated using this technology. A commercially manufactured version of these alloys would exhibit a smooth surface directly off a mold, any desired curvature or size, and all flexures, tabs, and isogrids built into the final part. This would eliminate the need for machining, would reduce the CTE mismatch in the part by making it all from the same material and removing connections, would eliminate fatigue or stress cracking, and would be low-cost (since thousands could be fabricated using a single mold).

The novelty of the current work is that tremendous cost and time savings can be achieved by casting the mirror assembly into a net or near-net shape using a metal alloy. This work suggests that mirror assemblies can be cast or fabricated using BMGs or BMGMCs where the entire part can be made using a simple and repeatable processing procedure to form the mirror into the same shape as the conventional mirror assembly, but without the need for machining from a billet. This idea is novel for a number of reasons, including that conventional metal alloys cannot be cast into net shapes without great expense, and this unique class of metal alloys has the ability to be cast, repeatedly, into reusable molds to net shapes and yet still have the hardness and toughness to satisfy the requirements for being used as a mirror assembly. Unlike crystalline metals, BMGMCs also have unique joining properties that allow them to be welded together into solid structures without heat-affected zones, which removes bonding, bolting, and brazing from assembly.

This work has the potential to make a broad impact in the way that mirror assemblies are fabricated for spacecraft, satellites, and terrestrial optics. Since most NASA spacecraft and satellites require optics, the current invention may provide a path for creating high-performance mirrors while greatly reducing their cost. Moreover, the invention may result in an assembly-line-type process for fabricating mirror assemblies that will reduce the cost of terrestrial optics, such as mirrors and telescopes.

The last technique demonstrated is a localized surface treatment as a way to take a near-net shape and turn it into a mirror finish. In this technique, the BMG mirror assembly is fabricated through one of the strategies described above, but the mirror finish is left in a rough state. The mirror assembly is then subjected to a surface treatment that produces an optical mirror surface without machining, grinding, or polishing.

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