

IMPROVED MIRROR DESIGN AND MANUFACTURING PROCESS FOR OPTOMECHANICAL SYSTEMS

Field of the Invention

The present invention generally relates to optomechanical systems. More particularly, the invention relates to an improved design and three-dimensional (3D) printed manufacturing process of mirrors used in such systems.

Background of the invention

In optomechanical systems, mirrors play a crucial role in directing and focusing light. However, the design and manufacturing of these mirrors present significant challenges. One of the primary issues is the need to balance rigidity, cost, and weight. This balance is particularly important due to the need to mitigate the effects of differences in the thermal expansion of materials, as characterized by the Coefficient of Thermal Expansion (CTE).

This issue is especially significant in dynamic mirrors, such as those used in scanners, but it is not limited to these applications. For example, the current methods to address this issue may include: adhering a glass mirror to an aluminum housing, fabricating a mirror from materials with high rigidity, such as Silicon Carbide (SiC) or RSA, or employing kinematic mechanical bending.

There have been attempts to produce printed aluminum mirrors globally, but the low quality of the mirror surface in the printed material has hampered these efforts.

While potentially offering high rigidity, manufacturing mirrors from exotic materials is expensive to develop and produce. This approach also creates a bottleneck in the production process due to the need for specialized capabilities or the low availability of materials. Furthermore, only a minority of manufacturers adopt this method due to its inherent disadvantages.

Mechanical sidewalls refer to physical boundaries or structures integrated into the mirror's design. These sidewalls provide support, alignment, or specific shaping to the mirror surface. They can be of various types and designs, depending on the mirror's intended use. The purpose of these sidewalls is to enhance the mirror's performance, stability, and alignment. However, they come with their own set of challenges. They are sensitive to the

craftsmanship and precision of the component. Any imperfections or inconsistencies can lead to optical distortions or misalignments. Moreover, the assembly components that hold these sidewalls in place must be reliable. Calibration of these sidewalls is also crucial, and any errors in this process can affect the mirror's overall performance.

Therefore, there is a need in the art for an improved mirror design and manufacturing process that can address these challenges, providing a balance between rigidity, cost, and weight while mitigating the effects of differences in thermal expansion.

Other objects and advantages of the invention will become apparent as the description proceeds.

Summary of the Invention

The present invention relates to a method for manufacturing a 3D-printed object, comprising:

- printing a 3D object on a printing bed, wherein at least a part of said 3D object is integrated with a portion of said printing bed; and
- extracting the portion of the printing bed integrated with the 3D object to form a 3D printed object with a mirror surface assimilated within said portion of the printing bed.

In one aspect, the method further comprises applying mirror machining on the portion of the printed bed to ensure the optical quality of the mirror surface assimilated within.

In one aspect, the printing bed comprises a material selected from the group consisting of: metal alloys, composites, glass substrates, ceramics or any other suitable lightweight material that offers a low coefficient of thermal expansion.

In one aspect, the 3D object is printed using a material selected from the group consisting of: metal alloys, composites, glass substrates, or ceramics.

In one aspect, the method further comprises post-processing of the 3D-printed object after extraction.

In one aspect, the manufacturing of the 3D-printed object configured to produce a 3D-printed object with a mirror surface of any desired type, thus the produced 3D-printed object is suitable for applications ranging from basic reflective purposes to advanced optical systems.

In another aspect, the present invention relates to a 3D-printed product manufactured using a 3D-printed object with a mirror surface assimilated within a portion of the printing bed.

Brief Description of the Drawings

In the drawings:

- Fig. 1 is a flow chart generally illustrating the method of the invention for producing a 3D printed object with a mirror surface assimilated within a printing bed;
- Figs. 2A-2D schematically illustrate the different steps of the manufacturing process for producing a 3D printed object with a mirror surface assimilated within a printing bed, according to an embodiment of the invention;
- Fig. 3A shows an example of two 3D printed objects printed on the same printing bed (before their extraction from the printing bed), according to an embodiment of the invention; and
- Fig. 3B shows the two 3D printed objects of Fig. 3A after their extraction from the printing bed and their mirror surface polished to a desired quality, according to an embodiment of the invention.

Detailed Description of the Invention

Three-dimensional (3D) printing, also known as additive manufacturing, is a technology that enables the creation of complex objects by sequentially adding material layer by layer. Traditional manufacturing techniques often involve subtractive methods that involve cutting or drilling materials to shape them. In contrast, 3D printing offers numerous advantages, such as design flexibility, rapid prototyping, reduced waste generation, and the ability to create intricate structures that are challenging to produce using conventional methods.

Throughout this description, the term "printing bed", also known as a "build plate", refers to the foundational surface in a three-dimensional (3D) printer where objects are constructed layer by layer during the 3D printing process. It serves as a stable and level platform upon which the printed object adheres and takes shape. The printing bed is typically made from a

heat-resistant material, such as glass or metal, and may be equipped with heating elements to aid in proper adhesion and minimize the warping of the printed material. The size and dimensions of the printing bed vary based on the specific 3D printer model, and its surface may be treated or coated with materials like adhesive sheets or specialized coatings to enhance print adhesion. According to an embodiment of the invention, the printing bed plays a crucial role in becoming a surface intended for mirror processing, in addition to the common roles of supporting the printed object, ensuring accurate layering, and facilitating successful 3D printing outcomes. This term does not imply any particular shape, construction material or geometry, and the invention is applicable to all printing bed materials suitable for mirror processing.

According to an embodiment of the invention, the printing bed suitable for mirror processing is compatible with various 3D printing techniques, including but not limited to fused deposition modeling (FDM), stereolithography (SLA), selective laser sintering (SLS), and digital light processing (DLP). The printing bed can be used with a wide range of 3D printers, including industrial-scale and desktop printers, enabling widespread applicability.

According to an embodiment of the invention, one of the critical components of the 3D printing process is the printing bed on which the objects are printed. The printing bed possesses specific characteristics to facilitate successful printing, ensure structural integrity, and exhibit desirable properties in the final 3D printed object such that the printing bed becomes assimilated within the final 3D printed object and serves as a mirror surface. For example, utilizing the printing bed as a mirror surface can be done by processing one or more available surfaces of the printing bed.

According to an embodiment of the invention, optical quality can be achieved through various methods or techniques, including but not limited to diamond turning, electroless nickel plating, and polishing techniques, that are applied to one of the surfaces of the printing bed, like in the case of a traditionally manufactured mirror substrate. For example, such a surface treatment/processing can be applied to one of the surfaces of the printing bed to convert it to an optical front of the mirror, while the opposite surface of the printing bed (i.e., the one on which the object is printed) can be defined as a backside of the mirror.

According to an embodiment of the invention, the printing bed for the platform on which the 3D printing is done is made from the same material as the printing substance. This unique characteristic ensures compatibility and optimal adhesion between the printing bed and the printing substance during the printing process. Using the same material for both the printing substance and the base can minimize or eliminate issues related to material compatibility and differential thermal expansion. This results in a mirror 3D printed structure design with a mirror surface assimilated within the printing bed. This may lead to superior print quality and enhanced structural integrity of the printed objects that utilize the printing bed as an assimilated mirror in the 3D-printed object.

Furthermore, using the same material for the printing bed and the printing substance offers advantages such as improved bonding between the printed layers and the base, reduced warping or curling, enhanced dimensional accuracy, and improved surface finish of the printed objects. The consistent material properties throughout the printed structure contribute to the overall strength, durability, and functionality of the 3D-printed objects, with at least one mirror surface assimilated within the printing bed.

According to an embodiment of the invention, the printing bed, in combination with the printing substance, enables the 3D printer to produce high-quality objects with a mirror surface assimilated within the printing bed with improved precision and reliability. The identical material composition of the printing bed and printing substance simplifies the printing process, eliminates the need for additional bonding agents or adhesives, and streamlines the overall workflow of 3D printing to produce mirror-based objects, wherein the 3D printed structure is provided with a mirror surface from the printing bed.

According to an embodiment of the invention, in order to be able to obtain an assimilated mirror surface in a 3D printed object, a wide range of materials can be used for the printing bed and printing substance, such as metal alloys and composites (e.g., aluminum alloys, titanium, etc.), glass substrates (e.g., that may offer chemical resistance while providing high thermal stability or resistance to environmental factors and temperature changes), ceramics (e.g., Silicon Carbide (SiC) or other suitable lightweight material that offer a low coefficient of thermal expansion), or any other material that can be used in additive manufacturing for 3D printing and for serving as a mirror surface (after suitable treatment/process). For example,

such materials for additive manufacturing can be produced in powder form or in wire feedstock.

Fig. 1 is a flowchart of a manufacturing process for producing a 3D-printed object with an integrated mirror, according to an embodiment of the invention. 3D printing creates a three-dimensional object with a mirror surface assimilated within the printing bed by adding material layer by layer based on a digital model or design and by processing the printing bed.

The manufacturing process may involve the following steps:

- Designing (step 101): At first, creating a digital 3D model of the object to be printed, which is a mirror 3D printed structure design with a mirror surface assimilated within the printing bed. This can be done using computer-aided design (CAD) software or by scanning an existing object using 3D scanning techniques. Usually, the 3D model is then sliced into thin layers, typically using specialized software. Each layer is a cross-section of the final object;
- 3D printing (step 102): Once the 3D printer is prepared (i.e., loading the appropriate printing material into the printer, such as aluminum. The printer's settings, such as temperature and print speed, are also configured based on the material used), it starts the printing process. Depending on the printing technology, the 3D printer moves a nozzle or a laser, and deposits or solidifies the material layer by layer according to the sliced model. The material may be melted and extruded through a nozzle (Fused Deposition Modeling (FDM)/Fused Filament Fabrication (FFF)) or selectively cured by a laser or UV light (Stereolithography (SLA)/Digital Light Processing (DLP)). In a typical 3D printer, the nozzle or laser is part of an extruder, which is a component of the 3D printer responsible for feeding, melting, and depositing the print material onto the printing bed. The printer continues building the object layer by layer, following the instructions from the sliced model. Each layer bonds with the previous one, gradually forming the final object. This layering process allows for the creation of complex mirror geometries that may not be possible with traditional mirror manufacturing methods;
- Extracting the 3D printed structure with a mirror surface from the printing bed (step 103). The extraction can be done by any suitable technique/tools, e.g., by using wire EDM (Electrical Discharge Machining), band saws, or other cutting tools, depending on the printer and the part geometry;

- Interfaces machining (step 104): A post-processing treatment is applied to the extracted printed 3D object at this step. This step refers to the precision machining of areas on the printed object that will interface or interact with other components. This step may involve refining the critical connection or contact points on the parts of the printed object to ensure it meets the required specifications and will function correctly in its intended application. For example, after 3D printing, the interfaces or contact surfaces of the printed object might need additional machining to ensure they meet precise dimensions, tolerances, or surface finishes. This ensures the part can fit correctly and perform its intended function when assembled with other components.
- Final mirror machining (step 105): Mirror machining, particularly for precision optics, may involve a series of steps that ensure the optical quality of the surface. The aim is to produce mirrors with smooth and accurate surfaces that can focus or reflect light without scattering it due to imperfections. The mirror machining may involve the following procedures:
 - i. Single Point Diamond Turning (SPDT) - a process where a diamond-tipped tool is used to machine a surface. The diamond, being the hardest known material, provides an extremely smooth finish that is suitable for optical applications. It is particularly effective for materials like aluminum, copper, and some plastics, which are soft enough to be cut with the diamond tool without damaging it. In some embodiments, the process can be computer-controlled, achieving very precise shapes and surface finishes.
 - ii. Polishing - after SPDT or other initial shaping processes, the mirror might still have microscopic roughness or other imperfections. Polishing is a process of removing these tiny imperfections. A softer polishing tool and a slurry containing fine abrasive particles are typically used. The mirror and the polishing tool are moved relative to each other, and the abrasive particles wear away the high spots on the mirror. The exact process and materials depend on the mirror substrate material and the required final quality.
 - iii. Coating - once the desired surface finish is achieved, the mirror may receive a reflective coating to enhance its optical properties. Aluminum, silver, or gold might be deposited on the mirror surface, sometimes with a protective overcoat to prevent tarnishing or other damage. Of course, the exact

material and process depend on the intended use of the mirror (e.g., which wavelengths of light it needs to reflect).

- iv. Testing and Verification - after the machining and polishing processes, the mirror's surface is rigorously tested. This might involve reflecting a known wavefront off the mirror and measuring any deviations with an interferometer. Any imperfections can be corrected with further polishing.

In accordance with an embodiment of the present invention, the manufacturing process allows for the production of mirror surfaces of any desired type. This includes, but is not limited to, flat mirrors, which offer a clear and undistorted reflection due to their smooth and flat reflective surface. Spheric mirrors can be segmented into concave and convex mirrors, each with its unique curvature and application. Aspheric mirrors are tailored to minimize optical aberrations and provide precise light focusing. Free-form mirrors are characterized by their non-symmetrical and intricate design, catering to specific optical needs. The versatility of the manufacturing process ensures that each mirror surface, whether traditional or advanced, retains its inherent properties and advantages, making them suitable for a myriad of applications, from basic reflective purposes to sophisticated optical systems.

Figs. 2A-2D schematically illustrate the different steps of the manufacturing process for producing 3D printed object 10 with a mirror surface 21 assimilated within a printing bed 20. Fig. 2A schematically illustrates the 3D printing stage as described hereinbefore with respect to step 102 of Fig. 1. In this stage, an extruder 30 of a 3D printer deposits or solidifies the printing material layer by layer according to the sliced model of the digital 3D model, which results in the 3D printed object 10. Fig. 2B schematically illustrates the 3D printed object 10 with mirror surface 21 assimilated within a remaining portion 20A of printing bed 20 (after being extracted from printing bed 20 as described hereinabove with respect to step 103 of Fig. 1). Fig. 2C schematically illustrates the 3D printed object 10 with mirror surface 21 assimilated within remaining portion 20A of printing bed 20 after applying interfaces machining as described hereinabove with respect to step 104 of Fig. 1. Fig. 2D schematically illustrates the 3D printed object 10 with mirror surface 21 assimilated within remaining portion 20A after applying the final mirror machining as described hereinabove with respect to step 105 of Fig. 1.

Fig. 3A shows an example of two 3D printed objects 10, 10A printed on the same printing bed 20 (before their extraction from printing bed 20), according to an embodiment of the invention. Fig. 3A is a top view that shows the top sides 11, 11A of 3D printed objects 10, 10A, respectively. The term top side refers to the side facing upwards during the printing process (i.e., the side opposite to the one in direct contact with printing bed 20). Fig. 3B shows the two 3D printed objects of Fig. 3A after their extraction from printing bed 20, according to an embodiment of the invention. This figure shows the bottom side 12 of 3D printed object 10 with mirror surface 21 assimilated within the remaining portion 20A (Fig. 2D) of printing bed 20 (the bottom side is the side of the 3D printed object 10 that was in direct contact with printing bed 20). For reference purposes, 3D-printed object 10A is shown with its top side 11A facing upward (similar to its position in Fig. 3A).

According to an embodiment of the invention, the printed 3D object with mirror surface assimilated within the printing bed can be used for precision mirror applications, including spectrometer collimating and focusing, laser scanners and beam steering, primary and secondary telescope mirrors, fold mirrors, interferometry, military applications, etc.

According to some embodiments of the invention, it is important to emphasize that cooling can be an essential part of the process of mirror 3D printing with metals, such as Stainless Steel, Titanium, Aluminum, Cobalt Chrome, etc. Metal 3D printing techniques, like selective laser melting (SLM) or electron beam melting (EBM), involve melting and solidifying metal powders layer by layer to create the desired object.

During the metal 3D printing process, each layer of metal powder is selectively melted using a high-energy source (such as a laser or an electron beam) and then rapidly solidified. Cooling is necessary to ensure proper solidification and to prevent excessive heat buildup in the printed part. Cooling strategies in metal 3D printing can vary depending on the specific technology and equipment used. Some printers may incorporate cooling mechanisms, such as built-in cooling chambers or cooling gases, to enhance the cooling process and control the temperature of the printed part. Additionally, post-printing steps, such as heat treatment or stress relief processes, may be employed to optimize the mechanical properties of the metal part and relieve residual stresses resulting from the printing and cooling process.

All the above descriptions and examples have been given for the purpose of illustration and are not intended to limit the invention in any way. Many different 3D printing mechanisms, methods of creating a 3D model, and materials suitable for producing 3D printed objects with an integrated mirror surface can be employed, all without exceeding the scope of the invention.

CLAIMS

1. A method for manufacturing a 3D-printed object, comprising:
 - a) printing a 3D object on a printing bed, wherein at least a part of said 3D object is integrated with a portion of said printing bed; and
 - b) extracting the portion of the printing bed integrated with the 3D object to form a 3D printed object with a mirror surface assimilated within said portion of the printing bed.
2. The method of claim 1, further comprising applying mirror machining on the portion of the printed bed to ensure the optical quality of the mirror surface assimilated within.
3. The method of claim 1, wherein the printing bed comprises a material selected from the group consisting of: metal alloys, composites, glass substrates, ceramics or any other suitable lightweight material that offers a low coefficient of thermal expansion.
4. The method of claim 1, wherein the 3D object is printed using a material selected from the group consisting of: metal alloys, composites, glass substrates, or ceramics.
5. The method of claim 1, further comprising post-processing of the 3D-printed object after extraction.
6. The method of claim 1, wherein the manufacturing of the 3D-printed object configured to produce a 3D-printed object with a mirror surface of any desired type, thus said produced 3D-printed object is suitable for applications ranging from basic reflective purposes to advanced optical systems.
7. A 3D printed product manufactured by the method of claim 1.