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Tailored Glass Using Direct Ink Writing Technology

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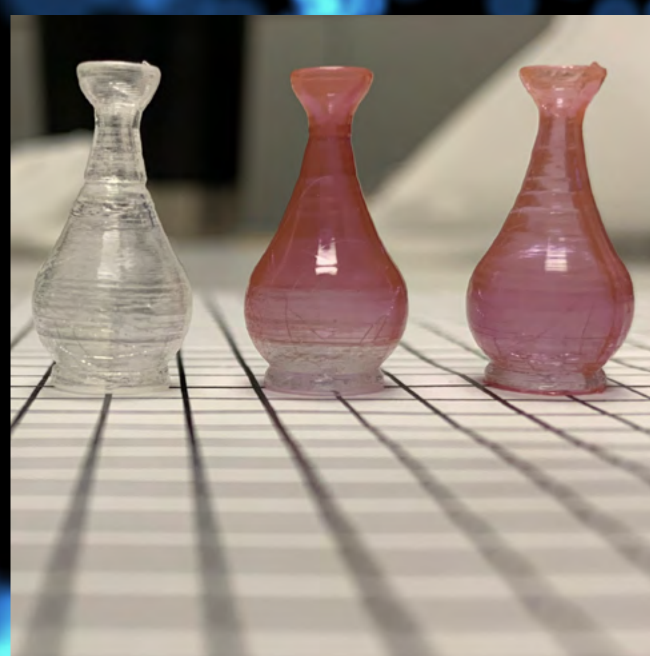
R&D 100
Award Entry



LLNL-MI-834648

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Tailored Glass Using Direct Ink Writing Technology

1. PRODUCT/SERVICES CATEGORIES

A. Title

Tailored Glass Using Direct Ink Writing Technology

B. Product Category

Process Prototyping

2. R&D 100 PRODUCT/SERVICE DETAILS

A. Primary submitting organization

Lawrence Livermore National Laboratory

B. Co-developing organizations

None

C. Product brand name

Tailored Glass by DIW

D. Product Introduction

This product was introduced to the market between January 1, 2021, and March 31, 2022.
This product is not subject to regulatory approval.

E. Price in U.S. Dollars

The price each potential customer would pay for this process will vary depending on the properties to be modified. Customers will select Tailored Glass by Direct Ink Writing (DIW) for a unique route to glass compositions and structures that cannot be fabricated by any competing technology.

Cost benefits exist for low-volume glass manufacturing as new structures can be produced by the same equipment rather than requiring expensive custom molds, which can be cost-prohibitive. Similarly, the technology may reduce or eliminate the need for expensive small-tool finishing or joining processes. Further, costs for power consumption and specialized work safety requirements may be reduced by working at lower temperatures than those used for melting glass. For some applications, the method also eliminates the need for costly precision subtractive manufacturing techniques and the resulting waste material. For example, use of a flat, refractive index-graded lens in place of an aspheric lens could result in a 90% reduction in finishing costs. Lightweight glass mirrors could be made by a single process, eliminating the need for numerous expensive, high risk process steps. Whereas different facilities would typically make GRIN lenses and lightweight glass mirrors, Tailored Glass by DIW can produce both.

F. Short description

Tailored Glass by DIW augments Direct Ink Writing additive manufacturing to print silica-based optics and glass components with customizable forms and spatially varying material properties. Flow of multiple glass-forming inks is finely controlled to achieve the desired structure and optical properties. Subsequent heat treatment renders a dense, transparent glass product.

G. Type of institution represented

Government or independent lab/institute

H. Submitter's relationship to product

Product developer

I. Photos

Attached inline

J. Video

https://www.youtube.com/watch?v=HWZtWoeTe1s (for optical glass applications)

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3. PRODUCT/SERVICE DESCRIPTION

A. WHAT DOES THE PRODUCT OR TECHNOLOGY DO?

Tailored Glass by DIW utilizes direct ink writing (DIW) technology to 3D print silica-based glass structures with overall superior control of form and material composition. Glass is typically produced from melting silica powders and subsequent shaping by molding techniques or by subtractive manufacturing methods. These traditional glass-shaping methods produce articles of a uniform composition in a limited range of achievable structures and may leave the glass susceptible to aberrations that negatively impact its structural integrity. Designers have long desired a means by which to tune the material properties within their glass components--whether it be color, or density, or refractive index.

Lawrence Livermore National Laboratory (LLNL) researchers have developed an additive manufacturing method that extrudes glass “inks” capable of forming a continuous concentration grading when deposited with the physical precision of 3D printing. The result is a free-form glass production method capable of yielding monoliths and intricate lattices alike while enabling precision design and engineering of optical and material properties.

Tailored Glass by DIW is effective at not only rendering fine-tuned glass optics but also at streamlining rapid product prototyping. Current processes for developing new silica-based products are cost-intensive and require specialized equipment to deal with the high temperatures necessary for forming glass. LLNL’s glass-forming process bypasses the need for excessive industrial equipment, particularly advantageous when prototyping specialty items for which low production volume and multiple design iterations are desirable. DIW glass, therefore, stands to lower overall prototyping costs while hastening the development of envisioned products. Incipient technologies incorporating glass elements can realize their intended uses more quickly and at lower cost while widening the field of possible component designs.

Tailored Glass by DIW offers extraordinary design freedom and resilient construction over an astounding range of applications. Designs successfully produced so far include gradient refractive index optics, specially shaped liquid-tight containers, and microfluidic channels.

Prominent industry players have already recognized the technology’s promise and committed to research and development cooperation with LLNL. Crystal designer and manufacturer Swarovski has identified the technology’s potential for products ranging from jewelry to interior lighting that require high refractive indices and optical dispersion. Additionally, custom optics manufacturer, Optimax Systems, Inc., has recognized Tailored Glass by DIW’s potential in directed energy projects that require lightweight, robust mirrors to operate within laser systems. Several other corporations and institutions in the fields of laser and optical systems, aerospace, and national security and defense, have also expressed interest in its applications.

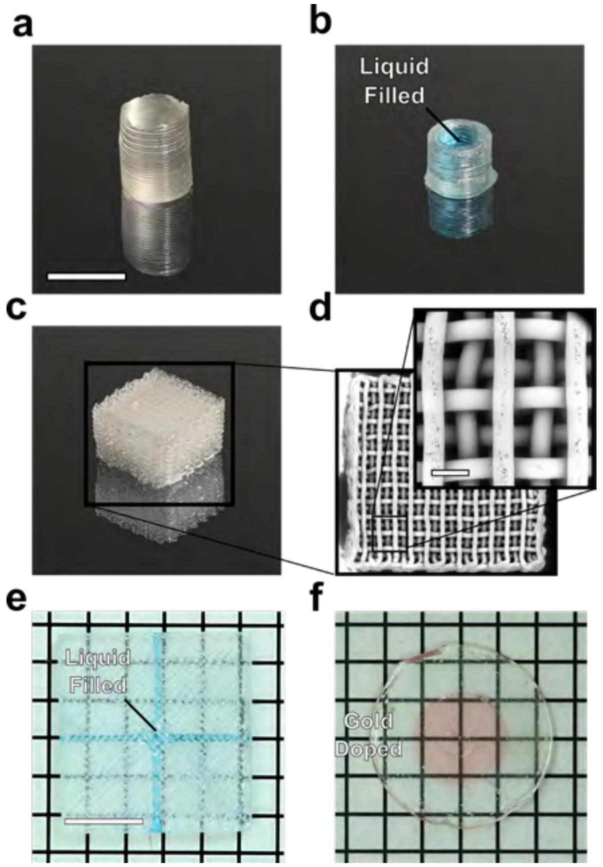

Figure 1: A range of glass structures made possible by DIW technology including solid monoliths, liquid-tight containers, and open lattices

B. How does the product operate?

Direct ink writing (DIW) is an extrusion-based additive manufacturing process that provides high levels of design freedom and precision. Just as commercial 3D printing uses polymers, DIW works by robotically depositing viscous "inks" through a micronozzle over a computer-defined path in order to build an object from the ground up. In Tailored Glass by DIW, the inks form glass.

Glass is a unique and difficult material in the context of 3D printing since it is conventionally produced via a process of melting and fusing silica powders. LLNL's breakthrough technique allows a customizable combination of multiple glass inks to be constantly extruded with the output concentration controlled by manipulating the flow rates of each ink. This method allows for precise spatial control over the glass composition within the printed structure. Because the resulting form and function of silica glass is intrinsically tied to the thermal and compositional characteristics of its production, this means of extrusion allows for smooth, continuous gradients of optical and mechanical properties.

The production process begins by identifying the desired composition of glass-forming pastes composed of silicon dioxide and other material-property modifying dopants, such as titanium dioxide or germanium dioxide for refractive index modification, blended with solvents. Before being extruded through the micronozzle, the relative concentration of each ink is controlled by manipulating the flow rate into an active micromixer, which combines the several inks into a homogenous substance. The constantly fine-tuned ink mixture is then deposited over the desired path. The resulting low-density preform, or "green body," then undergoes a series of heat treatments to remove solvents and organics. These final steps increase the strength and density of the preform to ultimately render solid, transparent glass products with preserved optical properties defined by composition during the printing phase.

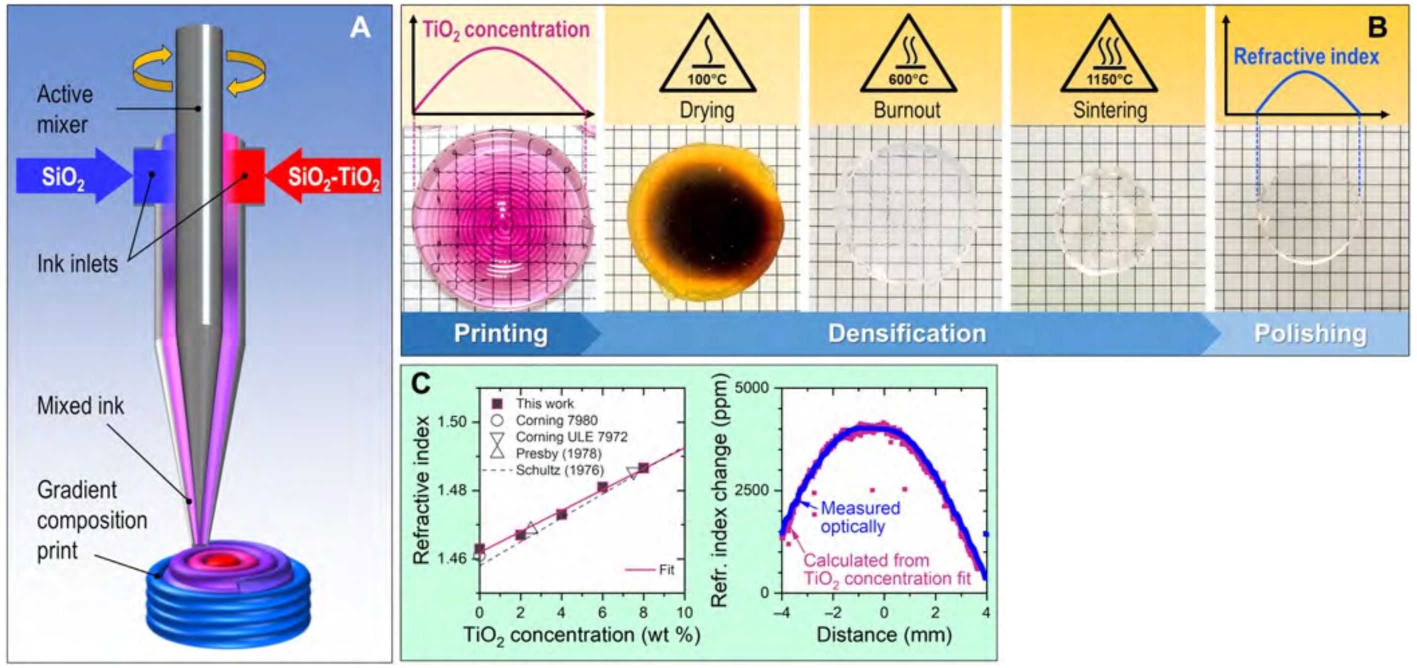

Figure 2: Image showing (A) the extrusion process using mixed ink, (B) the thermal treatment process of a green body that produces a continuous change in refractive index, and (C) change in 3D-printed glass refractive index with TIO2 concentration.

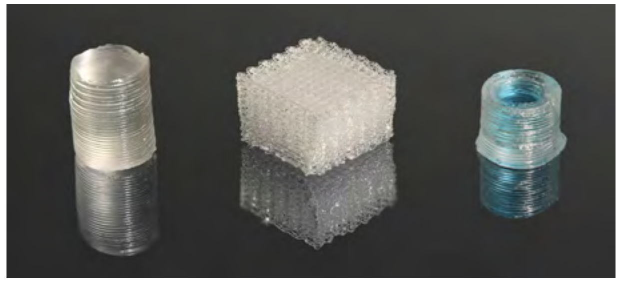

Figure 3: Tailored Glass by DIW can yield an array of completed structures of variable size and optical qualities.

Figure 4: A 3D-printed helical glass structure created by using Tailored Glass by DIW demonstrates the capability to preserve fine features and sharp edges.

C. Product Comparison

Glass-forming resins are an emerging technology in the additive manufacturing space showing enormous potential and extensive applications. As such, LLNL is not alone in working to refine and advance this type of production process. Other researchers have described non-DIW single-material printing techniques that are becoming commercialized.

LLNL's process, however, is uniquely compelling in that it has proven, multi-material compositional control; therefore, it is currently the only process to reliably provide finely controlled optical and material gradients as confirmed by optical interferometry measurements. Tailored Glass by DIW has the potential, for example, to produce a lens with 40 diopters of focusing power in an easy-to-make, easy-to-use planar format. This process can also directly produce stiff, lightweight glass mirrors without requiring aggressive multistage material removal. Optics makers and other users of specialty glass will benefit from the design freedom and manufacturing flexibility that comes with additive manufacturing in combination with the compositional control of DIW glass to enable lower size, weight, and power assemblies.

D. Comparison summary

		Attributes	Gradient profile achievable	Degree of composition tunability	Precision of gradient	Achievable index change	Achievable gradient length scale	Final component geometry achievable
Gradient Refractive Index Glass Fabrication Methods		Chemical vapor deposition	1D	medium	high	0.01	0.1 mm	simple
		Ion exchange	1D, limited	low	highest	0.04	10 mm	simple
Glass Additive Manufacturing Methods	Direct	"Fiber feed (Laser melting)"	n/a	n/a	n/a	n/a	n/a	complex
	Indirect	Projection microstereolithography/ Digital light projection	n/a	n/a	n/a	n/a	n/a	very complex
		Tailored Glass by DIW	3D, arbitrary	high	medium[3]	0.04 demonstrated 0.1 in development[1]	> 30 mm[2]	complex

LLNL has active ongoing work to address these areas. (1) LLNL has developed formulations capable of producing gradients up to 0.1.
(2) LLNL has demonstrated DIW glass up to 3 cm in diameter or length, but the DIW technique can produce larger samples in principle.
(3) LLNL is actively working to improve the precision of the gradients through formulation and post processing.

E. Limitations

Current limitations reflect both process design and the range of conducted tests. Further development is aimed at increasing the gradient precision, achievable index change, and demonstrating larger build sizes. The precision of the concentration gradient is a hallmark of DIW glass and, therefore, a main target of continued refinement. Glass ink formulations have been devised that should produce up to a 0.1 index change, although a value of 0.04 has been demonstrated in practice. Finally, concerning the overall structure size, DIW is effective for large samples in principle, although only glass products up to 3 cm in diameter or length have been tested to date.

4. SUMMARY

Tailored Glass by DIW enables 3D printing of silica-based glass with gradient mechanical and optical properties in unlimited, customized, structural forms of high complexity. By controlling the concentration of multiple specially formulated glass inks throughout the extrusion process, the resulting glass product benefits from the free-form capabilities of 3D printing while allowing for continuous changes in refractive index or other material properties. Following extrusion, a series of heat treatments solidifies the glass structure with the desired material or optical properties in addition to achieving high density and a range of geometries. This technology is applicable to research, consumer, and industrial markets seeking to harness tailored glass structures through rapid prototyping capabilities that cut down on the time and cost of conventional methods, reducing expenses for customers seeking low-volume glass manufacturing. Given design flexibility and manufacturing precision, products ranging from laser system components to microfluidics can be tested and brought to market in a fraction of the time with, potentially, reduced energy requirements and less material waste using LLNL's Tailored Glass by DIW.

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