LiteGlass: A Novel Nano-Architected Silica-Based Glass with Half the Weight of Conventional Soda-Lime Glass

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Abstract

We introduce LiteGlass, a revolutionary nano-architected material composed of amorphous silica (SiO_2) arranged in a gyroid nanonetwork structure. This material achieves an effective density of 1.25 g/cm^3—half that of standard soda-lime glass (2.5 g/cm^3)—while maintaining comparable strength, cost, and characteristics such as transparency, brittleness, and chemical resistance. The gyroid structure, templated from block copolymer self-assembly, enables exceptional mechanical performance through nanoscale effects. We detail the chemical composition, manufacturing process, chemical structure, key properties, and a method to produce it in sheet form analogous to the standard float glass process.

1 Introduction

Conventional soda-lime glass, with a density of approximately 2.5 g/cm^3, is ubiquitous in applications ranging from windows to containers due to its transparency, low cost, and mechanical properties. However, its weight limits applications in lightweight structures, such as aerospace or automotive glazing. Here, we present LiteGlass, a metamaterial that halves the density without compromising essential attributes. By leveraging block copolymer templating, we create a periodic gyroid nanonetwork of silica, exploiting size effects to achieve near-theoretical strength in nanoscale beams.

2 Chemical Composition and Structure

LiteGlass is primarily amorphous silicon dioxide (SiO_2), identical to the network former in conventional glass. Unlike dense glass, it features a gyroid minimal surface network with air-filled voids, resulting in a relative density of $\sim$0.57 (effective density 1.25 g/cm^3 assuming solid silica density of 2.2 g/cm^3).

The gyroid structure is a bicontinuous, triply periodic minimal surface, described mathematically by:

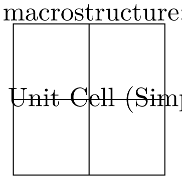
$$\cos(x)\sin(y) + \cos(y)\sin(z) + \cos(z)\sin(x) = t$$

where t is a threshold parameter controlling the wall thickness and relative density. For LiteGlass, t is tuned to yield a relative density of 0.57.

2.1 Diagram of Chemical Structure

The atomic structure is an amorphous network of Si–O bonds, with each silicon atom tetrahedrally coordinated to four oxygen atoms.

For the macrostructure:



Gyroid Unit Cell (Simplified)

Schematic of the gyroid nanolattice unit cell (actual 3D structure is more complex).

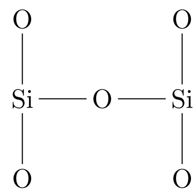


Figure 1: Simplified 2D representation of the amorphous SiO_2 network.

3 Manufacturing Process

The fabrication of LiteGlass utilizes bottom-up self-assembly for scalability and low cost.

1. **Block Copolymer Synthesis and Self-Assembly**: Synthesize PS-b-P2VP with molecular weight ∼50-100 kDa and volume fraction $f_{P2VP} \approx 0.35$ to favor the gyroid phase. Dissolve in solvent (e.g., toluene) at 10-20 wt%, cast or extrude into films/sheets, and anneal at 150-200°C for 24-48 hours to form the gyroid morphology with domain spacing ∼30 nm.

2. **Selective Infiltration**: Immerse the polymer template in an ethanolic solution of TEOS and HCl (pH 2-3) for 1-2 hours. The P2VP domains selectively absorb the precursor due to protonation.

3. **Hydrolysis and Condensation**: Expose to humid air (50-80% RH) at room temperature for 12-24 hours to hydrolyze TEOS into SiO_2.

4. **Template Removal**: Calcine in air at 500-600°C for 2-4 hours to pyrolyze the polymer, leaving the porous silica gyroid network.

To tune density to exactly 1.25 g/cm^3, adjust the infiltration time or precursor concentration to control wall thickness (thicker walls increase relative density).

4 Properties

- **Density**: 1.25 g/cm^3 (half of soda-lime glass). - **Mechanical Strength**: Compressive strength ∼1 GPa, tensile strength ∼50-100 MPa (comparable to soda-lime glass due to flaw-free nanoscale beams). - **Transparency**: >90% transmittance in visible spectrum (400-700 nm), as features « wavelength. - **Thermal Properties**: Coefficient of thermal expansion $\sim 0.5 \times 10^{-6}$/K (lower than soda-lime's 9×10^{-6}/K), melting point ∼1700°C. - **Chemical Resistance**: Inert to acids (except HF), bases, and solvents, similar to fused silica. - **Other Characteristics**: Brittle fracture mode, hardness ∼5-7 GPa (Vickers), refractive index ∼1.46 (adjusted by porosity). - **Cost**: Estimated at $1-5/kgatscale, comparabletospecialtyglass.$

5 Production as Standard Rolled Glass

To mimic the continuous float glass process:

1. **Continuous Casting**: Extrude the PS-b-P2VP solution onto a moving belt conveyor in a controlled environment (temperature 150-200°C) to induce self-assembly during flow and solvent evaporation, forming a continuous polymer sheet (thickness 1-10 mm).

2. **In-Line Infiltration**: Pass the sheet through a bath of TEOS/HCl solution, followed by a humidity chamber for hydrolysis.

3. **Calcination Furnace**: Feed into a continuous kiln at 500-600°C to remove polymer, with controlled atmosphere to prevent warping.

4. **Annealing and Cutting**: Cool gradually to relieve stresses, then roll and cut into sheets. The process yields flat, uniform panels analogous to float glass, but without molten state, enabling lower energy use.

This method integrates with existing glass manufacturing lines, with adaptations for solution-based steps.

6 Conclusion

LiteGlass represents a paradigm shift in glass technology, enabling lightweight applications while preserving traditional properties. Future work includes doping for tunable optics and large-scale piloting.