Polymer Selection for Target Fabrication

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New Target Design Tools

- Luxel has expanded its suite of polymers to meet the evolving needs of ICF experiments.
- To aid in target design, we present characterization data for seven Luxel polymers.
- A notable addition to Luxel's capabilities is LUXFilm® EL polyimide, which offers high-elongation for three-dimensional targets and non-planar windows.
- Early data models allow estimation of window deflection and helium leak rates.

He Permeation Rate

- Helium leak rates were measured over a range of thicknesses and aperture sizes to yield mean permeance values for each polymer in Table 1.
- Permeance can be used to estimate helium leak rates for target designs for given window area, thickness, and pressure differential (Eq. 1).
- Window surface area should account for dome deformation from applied pressure (Figs. 3 and 4).

$$He\ Leak\ Rate\ \left(Torr*\frac{L}{s}\right) = \frac{Permeance\left(\frac{Torr*\frac{L}{s}*nm}{Torr*mm^2}\right)*LEH\ Area\ (mm^2)*Pressure\ (Torr)}{Window\ Thickness\ (nm)}$$

Eq. 1: Estimation of He leak rate for design applications [1]

Table 1. Helium Permeance for LUXFilm®

Helium Permeance By Film: $\left(\frac{Torr*\frac{L}{s}*nm}{Torr*mm^2}\right)$		Example He Leak Rate $(Torr*\frac{L}{s})$ 5mm ID window, 850nm thick, 51 Torr deformed @	
		10% Hemisphere	100% Hemisphere
LUXFilm® Polyimide	6.9E-08	7.0E-08	1.4E-07
LUXFilm® EM	3.6E-08	3.6E-08	7.2E-08
LUXFilm® EL	6.3E-07	6.4E-07	1.3E-06

Light Element Composition

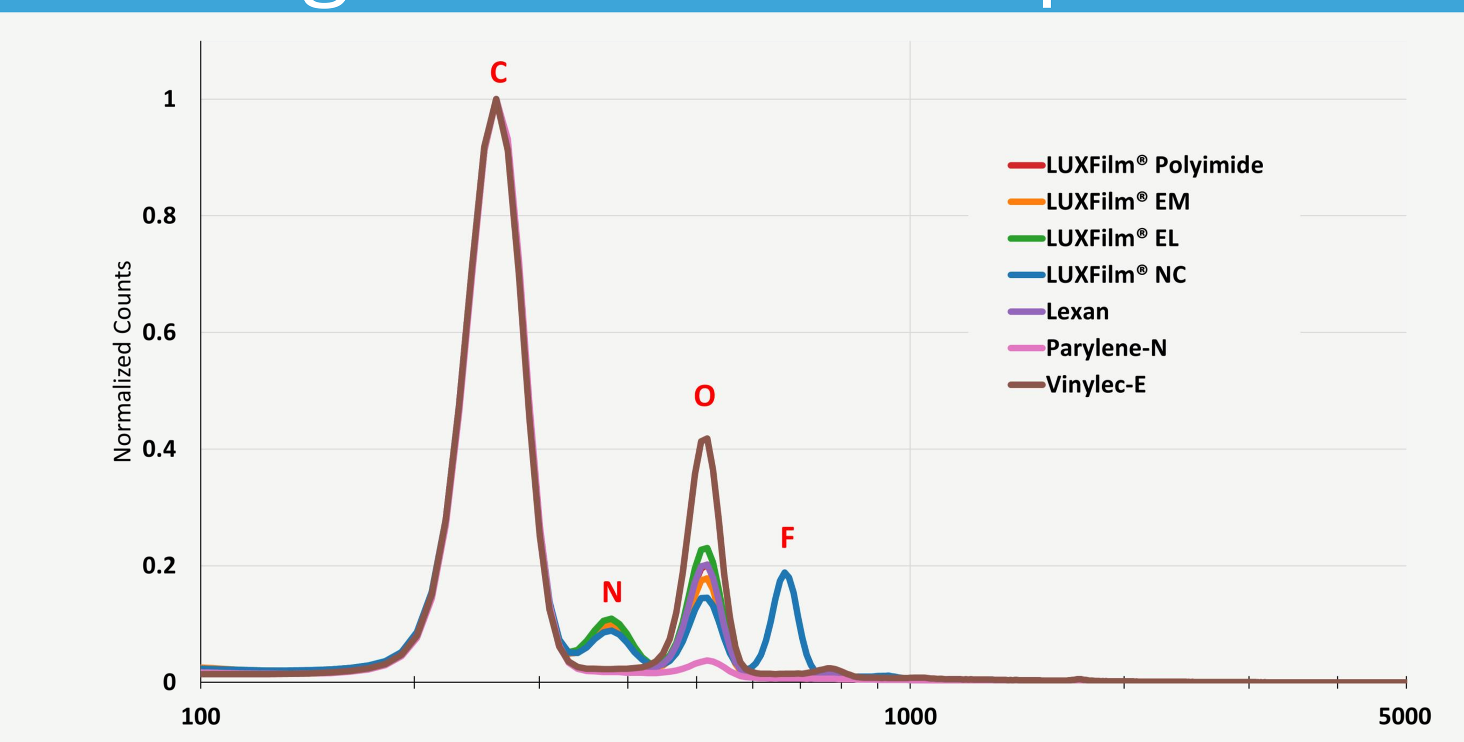


Figure 1: X-ray Spectra of Luxel Polymers
X-ray emission from Luxel polymers excited by a 5 kV scanning electron microscope beam. Counts are normalized to the carbon peak intensity. Luxel polymers consist of light elements only (H, C, N, O, F).

UV-Visible-NIR Spectra

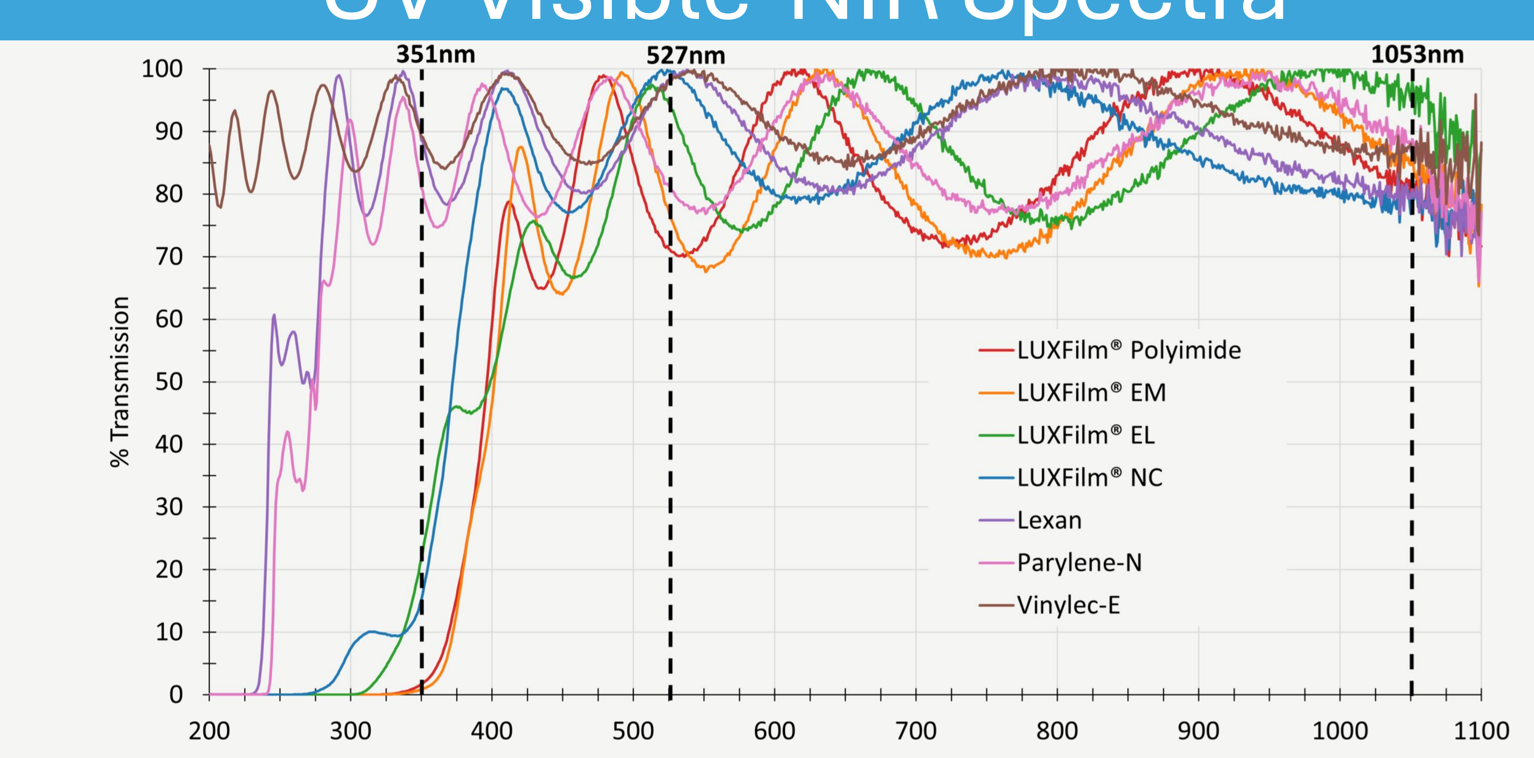


Figure 2: UV-Visible-NIR Transmission @ 500nm Thickness
Selected Sandia and NIF laser frequencies overlaid for reference. Films are transparent across the visible bandpass, but thickness-dependent interference fringes can affect transmission.

Luxel Polymer Properties

- Luxel offers a wide selection of high strength and light element composition polymers. Mechanical properties were measured by pressurization to burst while measuring window deflection with a confocal microscope.
- The biaxial modulus (*Y*) is related to the window thickness (*t*), aperture radius (*a*), deflection (*n*), pressure (*P*), including offsets for the initial height (h_i) and pre-strain/slack of the film (A). Values of B were fit to the data for each polymer in the 0.2-1.0% strain range, to be comparable with previous studies [2].
- Tensile strength and max elongation are based on a thin membrane, spherical cap approximation [3].

$$P = \frac{4Yt}{a^2}(h_i+n)\left[\frac{2}{3a^2}(h_i+n)^2 + A\right]$$

Eq.2: Biaxial modulus adapted from Small and Nix (1992)

Table 2. Luxel Polymer mechanical properties

	LUXFilm® Poly	LUXFilm® EM	LUXFilm® EL	LUXFilm® NC	Lexan	Vinylec-E	Parylene-N
Modulus, Gpa *@ 0.5% Strain*	9.0 ± 2.0	10.5 ± 0.2	5.4 ± 0.5	5.1 ± 0.2	2.8 ± 0.1	3.2 ± 0.5	4.6 ± 0.2
Tensile Strength, Mpa	392 ± 57	463 ± 63	265 ± 24	110 ± 1	48 ± 2	48 ± 1	39 ± 2
Elongation at Break, %	32% ± 6%	46% ± 11%	66% ± 2%	74% ± 2%	73% ± 3%	43% ± 2%	4% ± 1%
Max % Hemisphere *(@ 90% of Burst)*	70%	75%	97%	100%	90%	73%	27%

Pressure-Deflection Behavior

- The plots below may be used as design guides for gas-filled targets. Window deformation can be estimated based on gas fill pressure.
- Luxel can pre-deform windows to a desired volume or geometry.
- The polymers offering the highest deformation capabilities are LUXFilm® El and NC, these can achieve up to 100% hemispherical shape.
- Coatings can be applied to pre-deformed windows for various experimental needs.

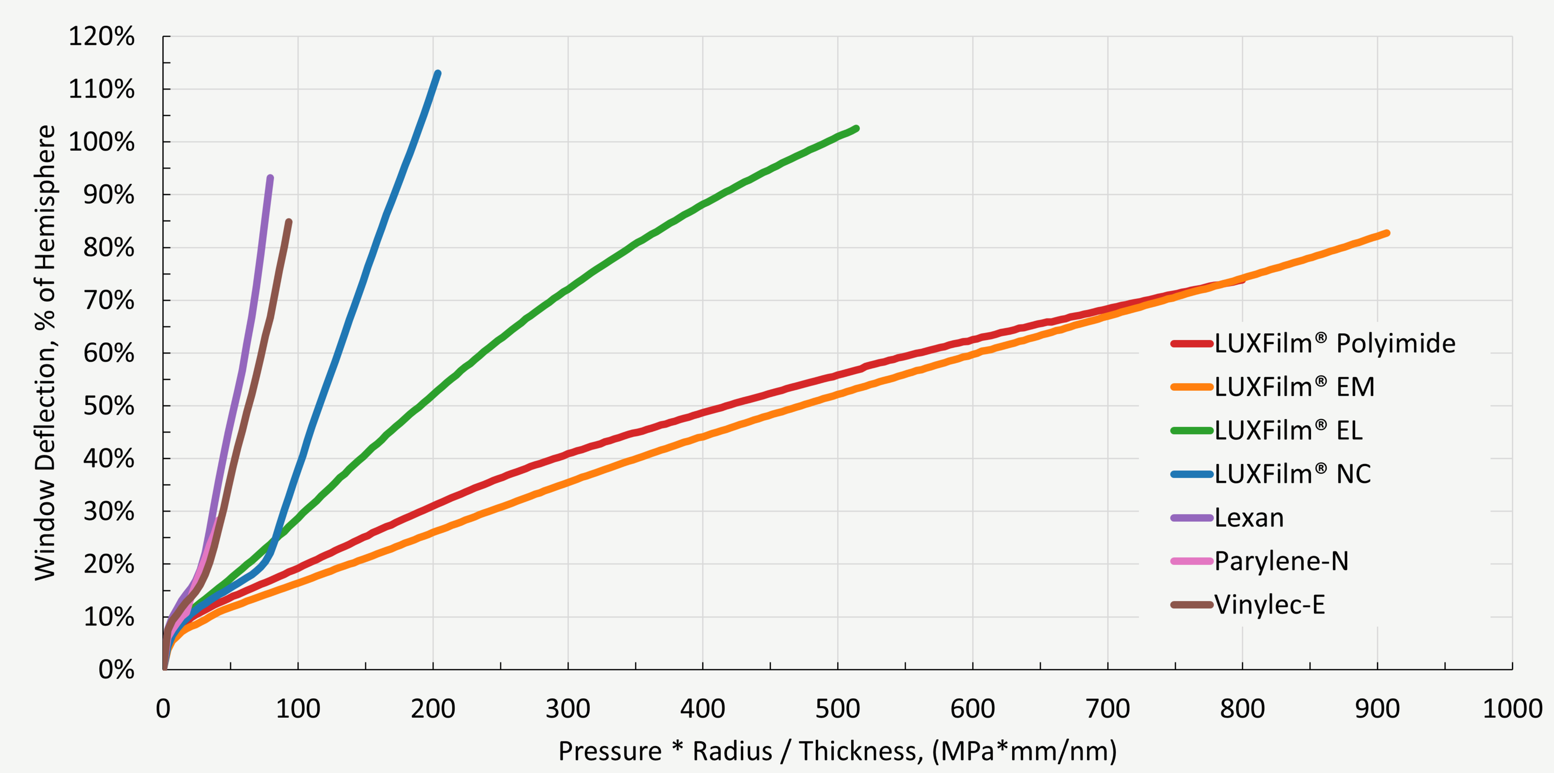


Figure 3: Deformation Behavior for Pressure*Aperture/Thickness
Polymers were mounted on 5mm ID circular apertures and pressurized at 50 Torr/min until failure, deflection was recorded with a confocal microscope.

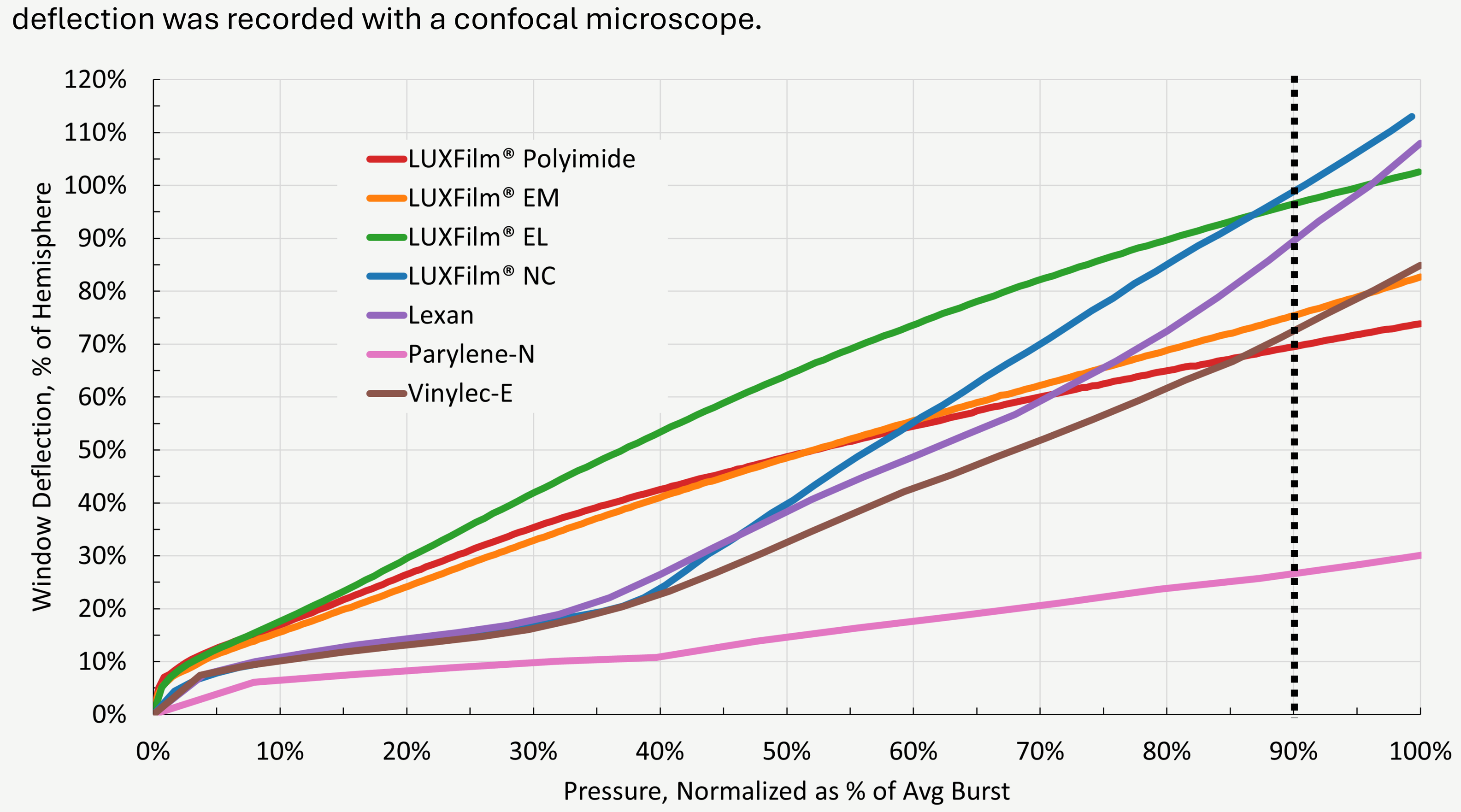


Figure 4: Maximum Window Deflection Guideline
The maximum deformation achievable for each Luxel polymer is indicated by the dotted line. Reasonable manufacturing yields can typically be achieved <90% of burst pressure.

Thickness-Independent Behavior

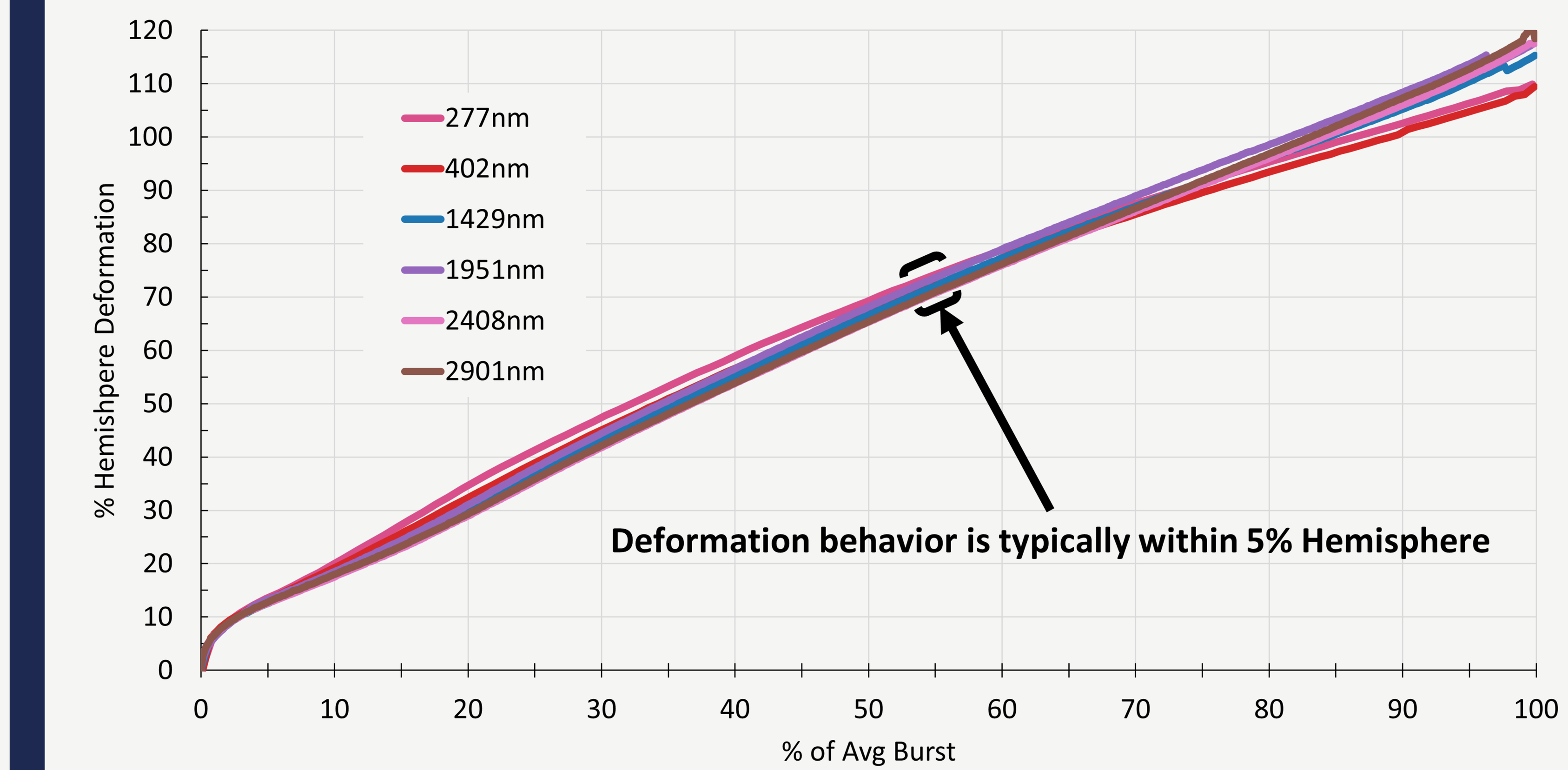


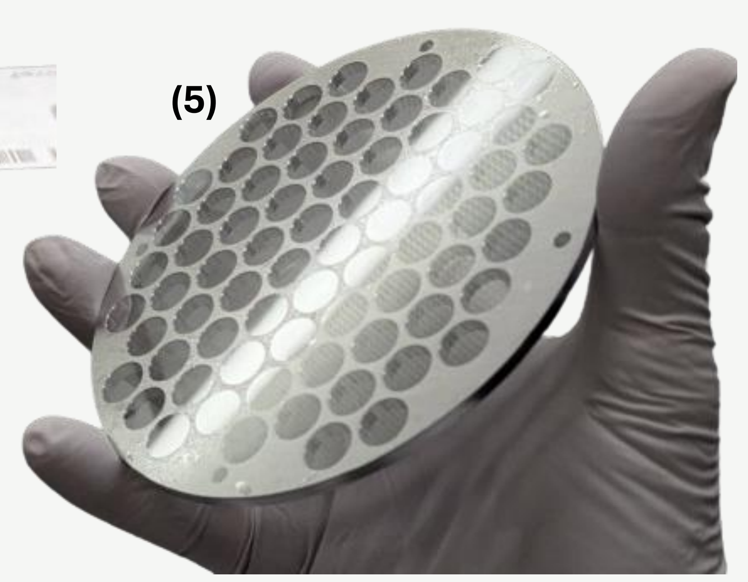
Figure 5: LUXFilm® EL Exhibits Similar Deformation Capability Across Wide Thickness Range

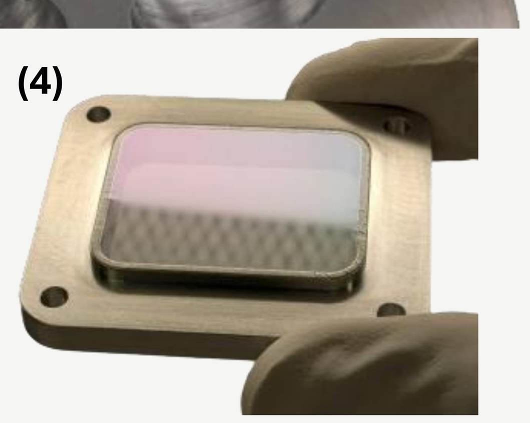
Applications

(1) Fully Hemispherical LEH window achieved with LUXFilm® EL

(2) Au coating over pre-deformed window (other coating examples include Co, SiO2, C)

(3, 5) Multi-aperture target designs can include multiple coatings or polymers on rigid or flexible (tape) substrates.





(4) Ultra flat film coatings

Figure 6: Example applications of the Luxel polymer suite
High modulus LUXFilm® Polyimide and LUXFilm® EM perform in applications involving high pressure differentials or mechanically stressful conditions.
High elongation LUXFilm® EL and NC is optimized for 3D window designs
Other polymer chemistries are available to limit contributions from N, O, and F

References

[1] Rabilloud, G. (1997). High-performance Polymers: v. 2. Polyquinoxalines and polyimides. Editions Technip.

[2] Bhandarkar, S., Betcher, J., Smith, R., Lairson, B., & Ayers, T. (2016). Constitutive models for the viscoelastic behavior of polyimide membranes at room and deep cryogenic temperatures. *Fusion Science and Technology*, *70*(2), 332-340.

[3] Small, M. K. & Nix, W. D. (1992). Analysis of the accuracy of the bulge test in determining the mechanical properties of thin films. Journal of Materials Research, 7(6), 1553-1563.