Use of Heatable Glass in LED Lighting Products

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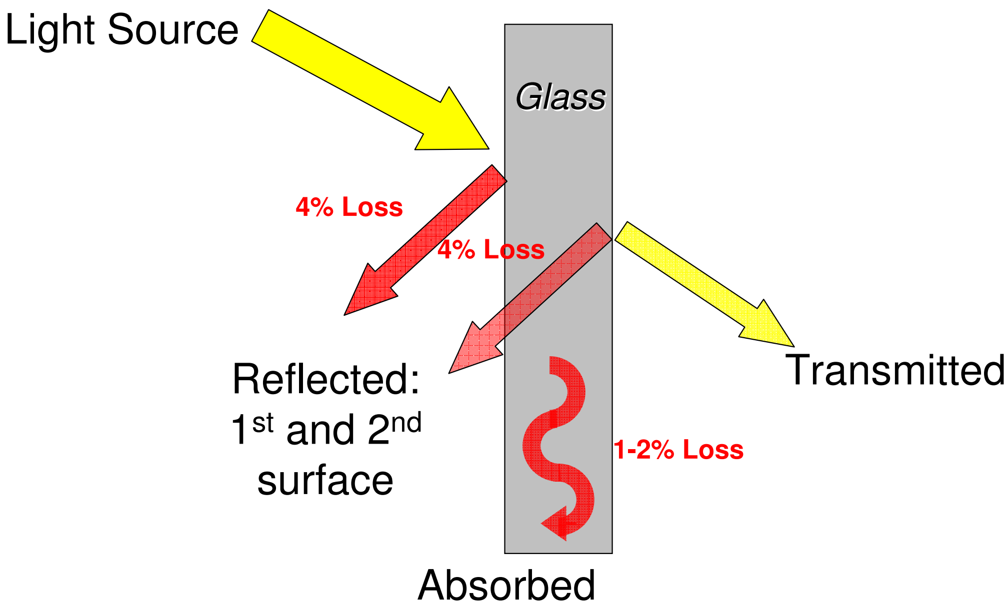
Historical Benefits of Using Glass in Lighting

- Mechanical Strength and Durability
  - Strengthened (tempered) glass has successfully been fielded in outdoor lighting applications for > 50 years to provide translucent properties as well as long-term mechanical strength and durability (thermal, chemical, and environmental)
- Environmental Protection
  - Glass has proved to be the best long-term material choice to protect the valuable components of a lighting fixture (light source, reflectors, electronics, etc.) from the elements in outdoor lighting applications
  - Unlike other materials, glass does not carry a static charge that attracts dirt
- UV Resistance
  - Unlike other lens materials, glass does not degrade to the intense and prolonged UV exposure seen in outdoor lighting applications
- Cost and Sourcing
  - Unlike other lens materials, glass is a low-cost and readily available material option
- Flexibility
  - Unlike other lens materials, glass can be easily and cost-effectively converted into end fabricated parts based on the lighting application's need

The Challenge of Using Glass in Lighting

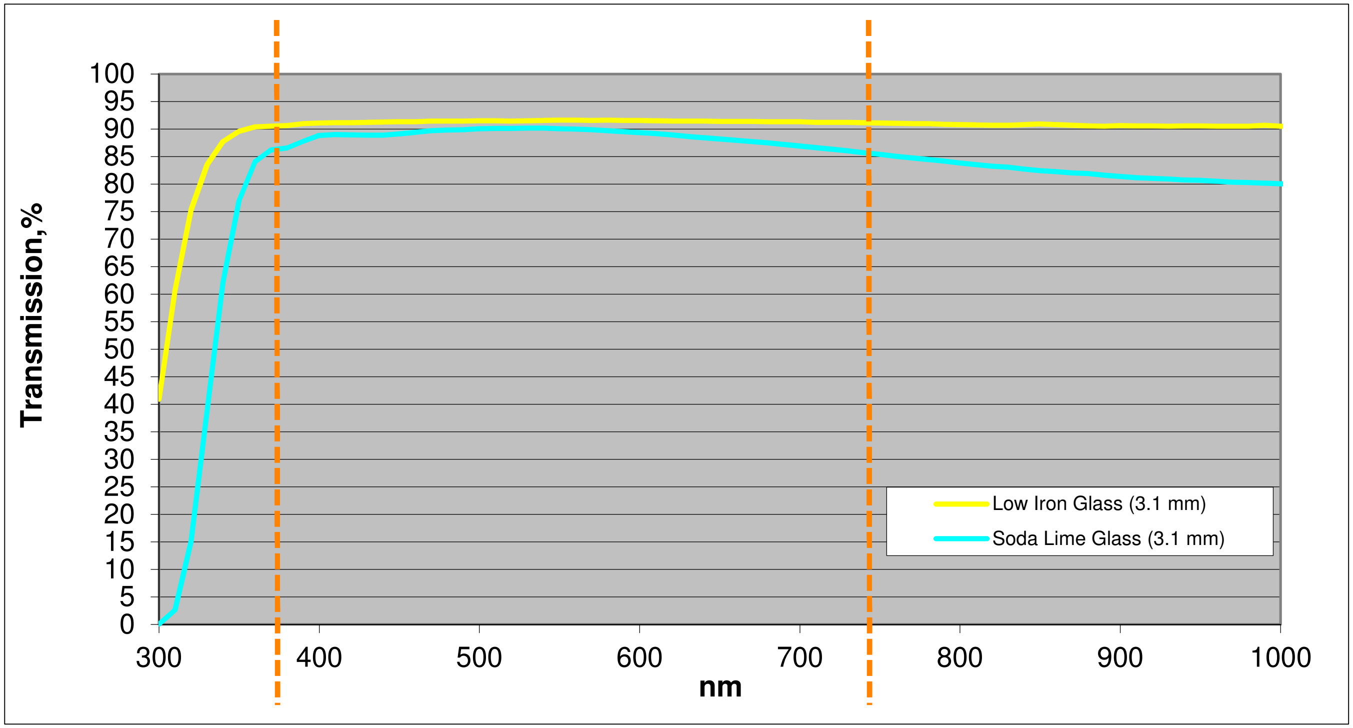
The historical challenge of using a glass lens in lighting applications has been with efficiency losses due to light reflection and absorption (shown in red below).



- Glass loses 9-10% of total light transmission by its material properties alone
- Therefore, you must **minimize absorption**, **increase light capture or transmission**, and **minimize reflection** on the glass to overcome this challenge and maximize the light going through the glass lens
- How? Through the use of **Low Iron glass and Anti-Reflective coatings**!

Low-Iron Glass

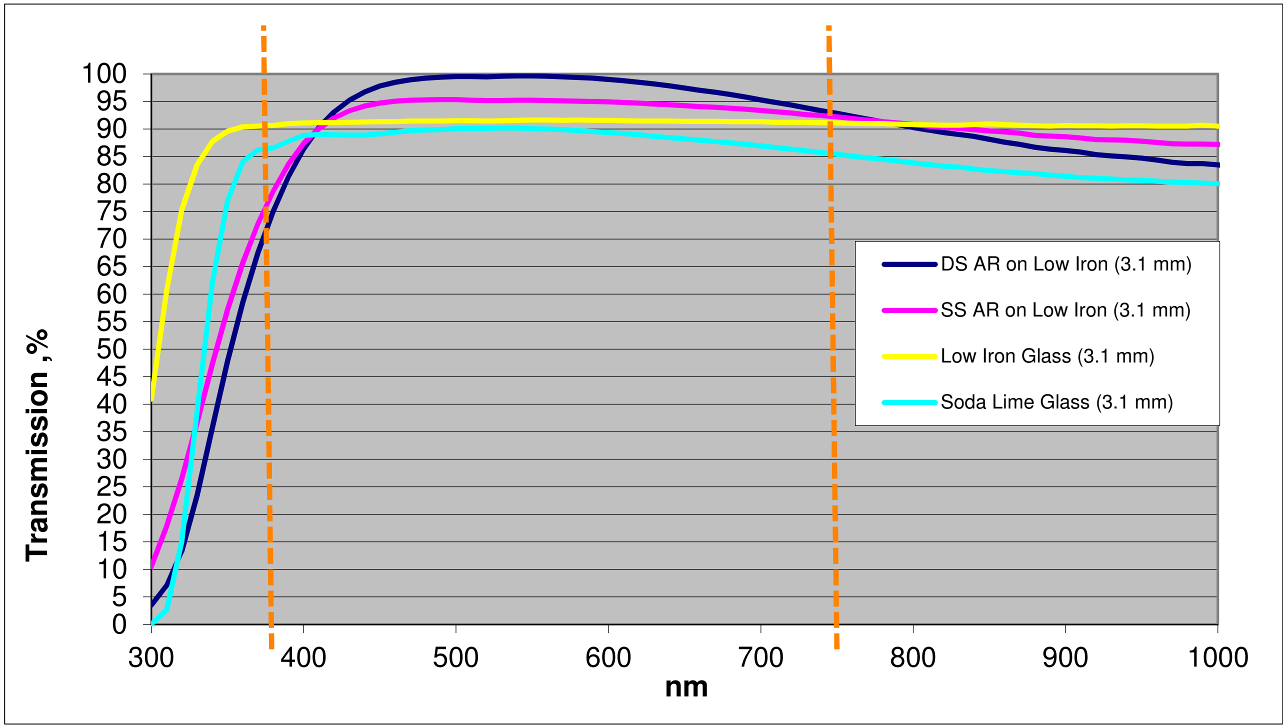
Standard soda lime float glass contains 0.11 – 0.08% Fe_2O_3 which allows 2% of visible light's energy to be absorbed and lost within the bulk material itself



In contrast, "Low Iron" glass contains only 0.02 – 0.03% Fe_2O_3 which **all but eliminates the absorption losses** in the visible spectrum typically seen with glass lenses

Anti-Reflective (AR) Coatings

Anti-Reflective (AR) Coatings minimize the interference of light traveling through a given material's surface by creating a filtering layer with a refractive index (n) as close to air (n= 1) and the lens material itself (glass n= 1.52)



AR coatings can reduce glass reflection losses to 0.5% per side and, when **coupled with low-iron glass** to reduce absorption losses, can **increase transmission levels of glass lenses from 89% (soda lime float glass) to 99%** (Double-Sided AR on Low Iron glass) in the visible range at NADIR

LEDs Change the Role of Glass in Lighting

- The adoption of LED-based lighting has triggered a major change in how optics are managed in lighting fixtures
  - With traditional Incandescent and HID-based light sources, light is illuminated from one single light source multi-directionally and directions/distribution patterns are managed with reflector assemblies
  - High levels of UV and IR energy generated especially at > 1,000W sources
- With LED-based light sources, light is illuminated from multiple (e.g., 60 – 120) light sources with individual primary optics required over each LED source to deliver light in the intended distribution pattern
  - Lower energy consumption and low levels of IR energy (heat) generated
  - PMMA Acrylic primary optic lenses are now fundamental and critical part of optical design

HID Fixture with Single Light Source and Reflectors

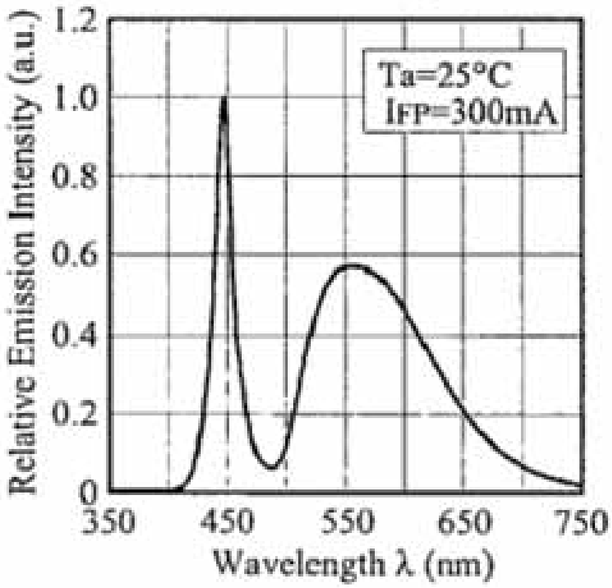
LED Fixture with Multiple Light Sources and Individual “Nano” Optics

Glass and LED Lighting

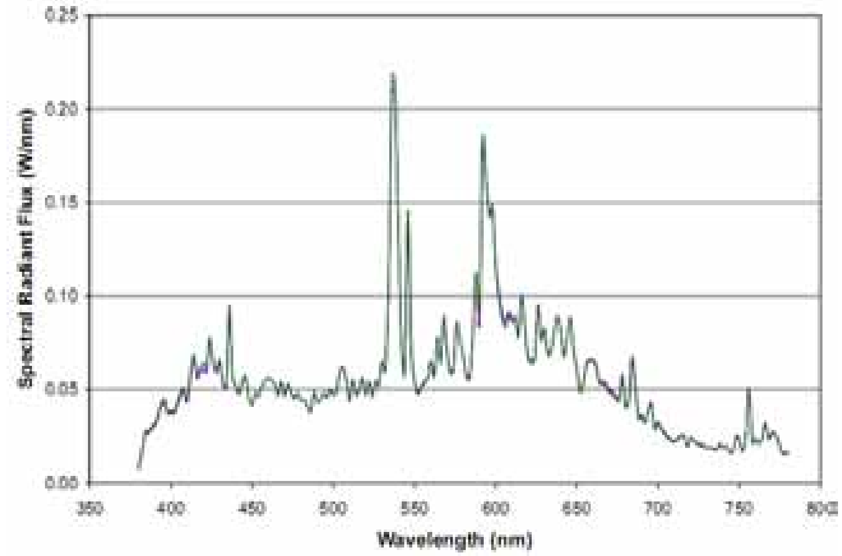
- The LED “revolution” in lighting in the past 5 years has forced new rules for luminaire design, performance, cost, and sourcing
- Plastic content, due to the optical needs of managing multiple light sources (LEDs), is now a functional need and not a choice
  - **Plastic primary optic is now needed** to reach needed light distributions
  - PMMA Acrylic material and its converters/manufacturers have improved quality and durability allowing it to be used as a standalone lens barrier
- **Glass** is no longer absolutely needed in traditional application areas of outdoor and industrial lighting – esp. when LEDs are increasingly being used
  - Now often a **“design option”** in LED luminaires
  - Primary use is in HID applications where glass is needed for UV resistance
- Does glass have a place of value in LED lighting?
  - **Glass creates value in areas where LED luminaires cannot provide the same functions that traditional lighting technologies did**
  - These areas include areas of harsh environments where exposure to UV or IR wavelengths are required to provide high levels of illumination and plastic materials cannot survive long-term without degrading and sacrificing light transmission

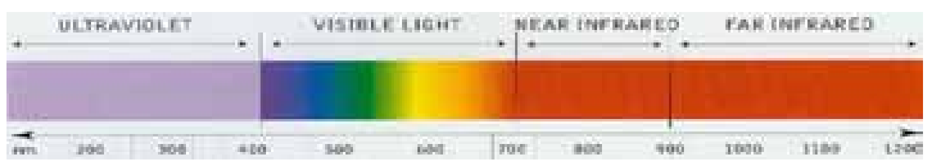
Limitations of LED Lighting for Outdoor Applications

LED Output



HID (Metal Halide) Spectra



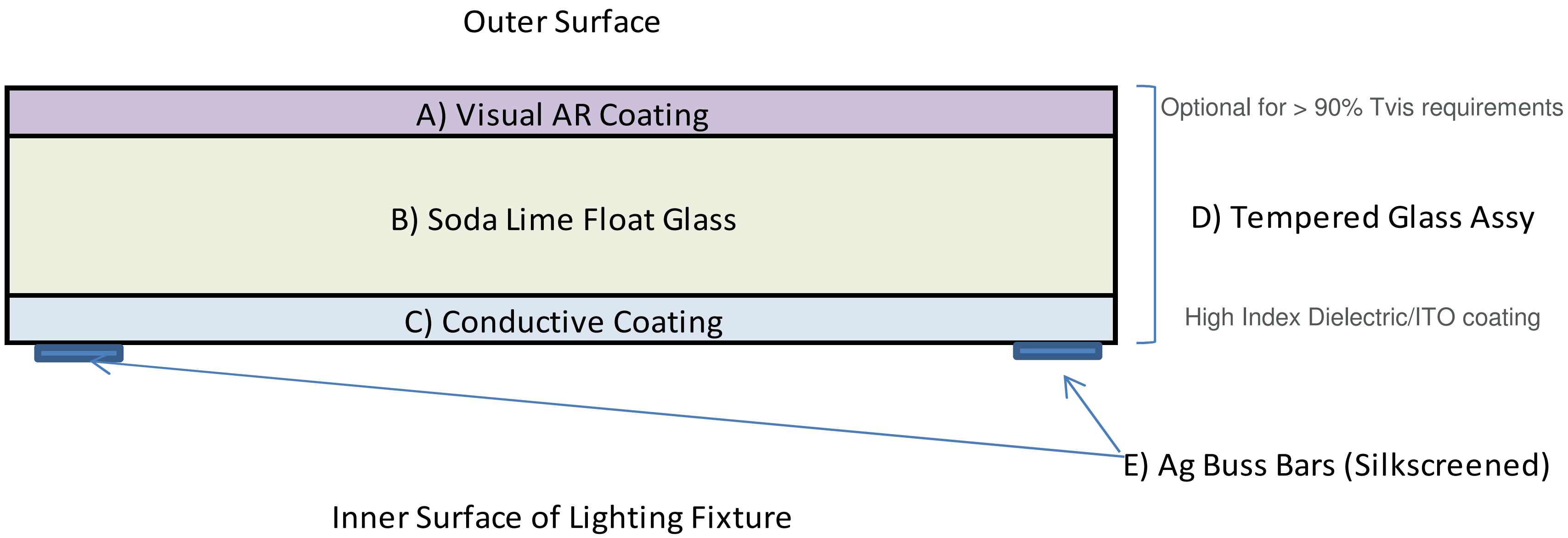


- LED source clearly **does not generate high levels of IR energy**
  - OK for luminaires that do not see harsh environments
  - **Not OK for luminaries <u>required to melt snow and ice off</u>** of them in harsh environments (as HID has done in the past)
- How can we bridge this gap? Through **heating the lens**!

Material Options for Heatable Lenses

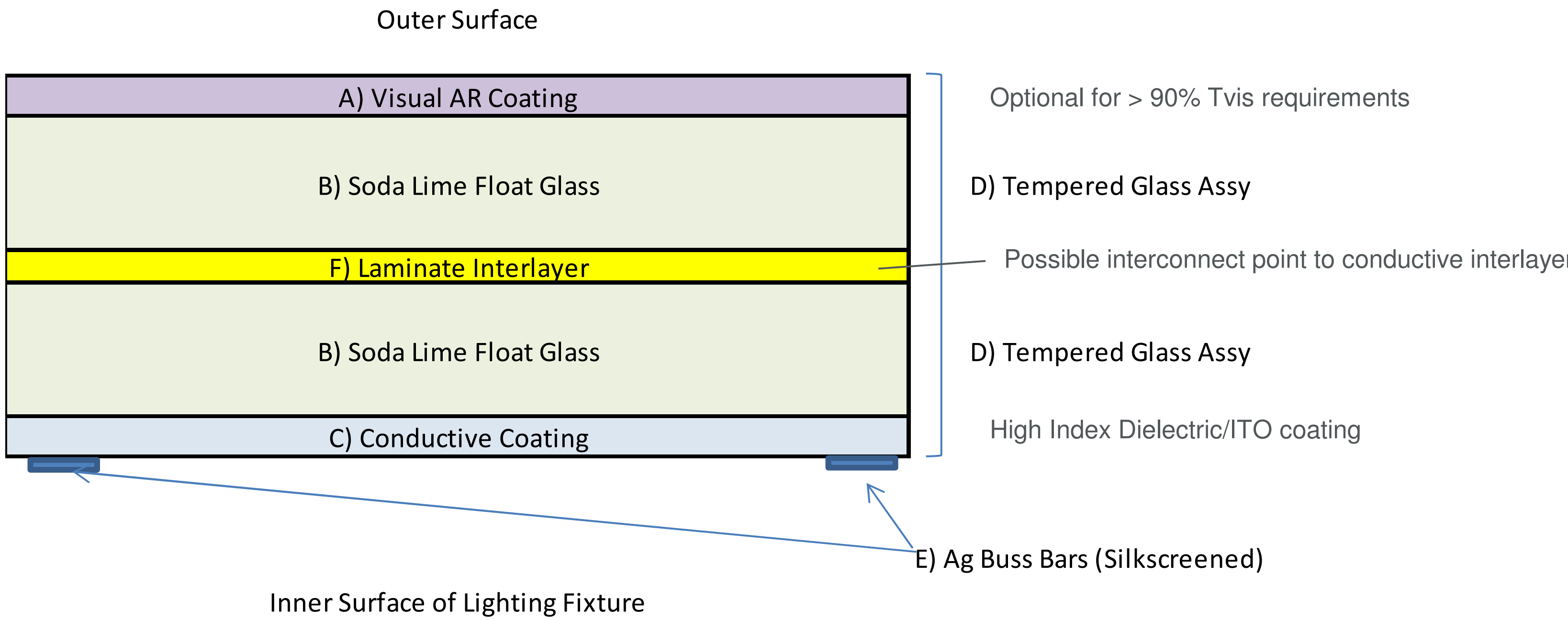
- Plastic?
  - **Plastics (PMMA or Polycarbonate) cannot be a cost-effective option** due to temperature limitations vs. material degradation
    - Would require costly dopants that would negatively impact efficacy and would still sacrifice transmission (efficiency) over lifetime
- Glass?
  - Al-Enriched or "Gorilla" glass is cost-prohibitive and typically very thin and susceptible to breakage (even when chemically strengthened)
  - Soda Lime and Borosilicate Glass are viable technical and economical options
    - Borosilicate glass is strong and inert but is costly with long lead-times and fabrication challenges (thermal or chemical strengthening)
    - **Soda Lime glass can cost-effectively meet the need using different technologies and fabrication options**
      - Transparent Conductive Coatings (TCC) can be applied via in-line pyrolysis (SnO_2:Fl) or MSVD (ITO) "Sputter" processes
      - Conductive Laminate Interlayer (coated with conductive layer or with embedded Tungsten "wiggle wire") can be used but can be costly and/or negatively impact efficacy and creates larger interconnect challenges

Heatable Glass Lens Concept (Monolithic)



- The **Monolithic Configuration** is used for applications where **thickness profile** is of concern and where **increased glass strength (thermally tempered to 25,000 psi) is needed for durability and blunt force** resistance
    - No exposure to projectiles

Heatable Glass Lens Concept (Assembly)



- **Assembly Configuration** is used for applications where lens with **exposure to projectile impact and where safety is required**
  - Keeps glass lens intact with **laminated interlayer to protect the light source and prevent broken glass fragments** (similar to automotive windshields)
- Laminated interlayer (index matching for high transmission) can serve as the safety layer with or without conductive agent within it
  - Coating in close proximity can also do the job and makes interconnect easier

Heatable Glass Options and Performance

Substrate Options and Performance

Glass	UltraWhite™ Low-Iron Glass Standard Clear Glass Acid-Etched Glass Textured Glass Single-Sided Anti-Reflective Glass
Visible Light Transmission (500-600nm)	Heatable Monolithic: 87% Heatable with AR Monolithic: 91% Heatable Laminated Assembly with AR: 93%
Thickness	3.0 – 6.0 mm (Monolithic) 4.0 – 8.0 mm (Laminated Assembly)
Sourcing	Temperable and laminated parts with availability 10 days from date of order for fabricated parts from a Guardian Select Fabricator

Durability

Adhesion	No delaminating in snap tape pull test
Abrasion Resistance	No visible change (< 1%Δ transmission) after 50 passes with 1,000 g load
Humidity Exposure	No visible change (< 1%Δ transmission) after 5 days at 85°C and 85% rH
Chemical Exposure	No visible change (< 1%Δ transmission) after 24-hour soak in DI water, acetone, IPA and Ethyl Alcohol

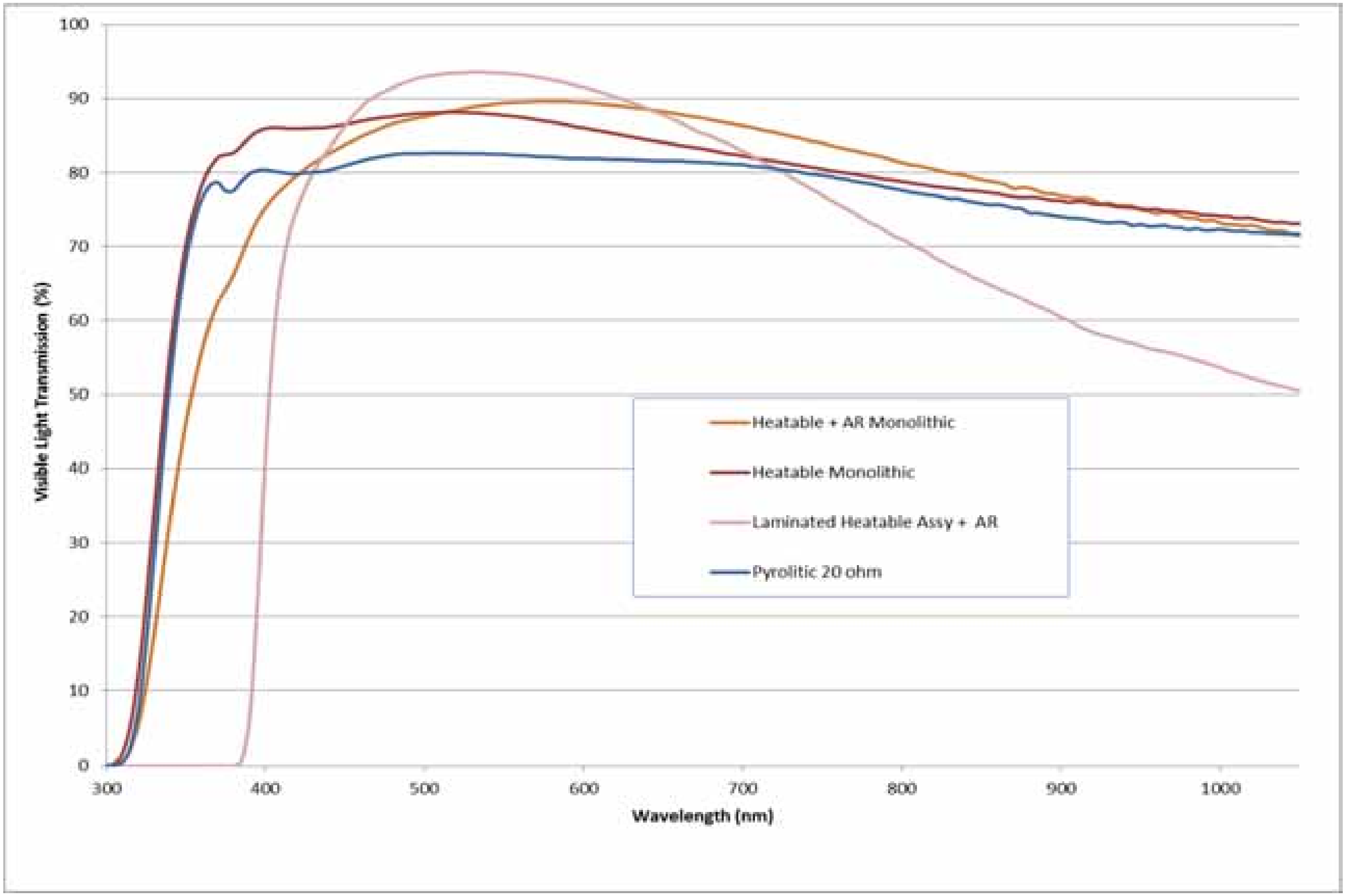
Power and Heating

Maximum Input Power	100 V AC/DC
Conductivity	15 to 20 Ω
Environmental Operating Range	-55° to +85°C
Maximum Glass Surface Operating Temperature	100°C
Operating Power Density	.1 to 9W/in.^{2}

Internal Strength

Thermal Tempering (Monolithic)	Meets ASTM C1048
Impact Resistance (Monolithic)	Meets ANSI Z97.1
Thermal Shock (Monolithic)	Meets MIL-C-7989
Maximum Internal Pressure Load (Monolithic)	10 psi (5 mm thickness)
Penetration Resistance (Laminated Assembly)	Meets ANSI Z26.1

Heatable Glass Optical Properties



Design Considerations for Heatable Lens LED Lighting

- What is the size and shape of the part?
  - The surface area is your "conductor" in this system and its overall area (sqft) and shape will determine the best path (buss bar locations, thickness, etc.) forward
- What is input or supply voltage?
  - – Determines proper conductive range for coating
- What is the desired maximum surface temperature and ramp rate?
  - – Buss Bar Location, Width, and Distance (Terminal Distance) are Driver
    - The shorter the distance between the buss bars (terminal resistors) the higher power density ratio (and higher possible surface temperature and ramp rate)
- What is the required light transmission or efficiency of the luminaire for the project or application?
  - – If > 90%, then plan on adding AR coating to one surface to maximum light transmission (4% boost)

Design Considerations for Heatable Lens LED Lighting

- What is the position of the lens in the application?
  - Will it be susceptible to projectiles?
    - If yes, use a laminated assembly design approach for safety and increased service life
    - If no, use a monolithic tempered part for lower weight and profile while providing blunt force strength
- What type interconnect is needed between power supply and lens to maintain reliability and serviceability?
  - Terminals with wires, toggle pins, etc.
  - Needs to be durable to prevent dislodging but also easy to service
- Does heating need to be manual or automatic?
  - If automatic, then explore thermal couple on lens surface to trigger "proactive" heating of lens to prevent condensation before it occurs

Summary/Conclusions

- The continued push for widespread adoption of Solid State Lighting (SSL) across all market is creating both opportunities and challenges for all of us
- Although LEDs offer high efficacy, low TCO, and optical performance; they cannot provide levels of IR energy required to be effectively used in harsh outdoor environments
- In order for LEDs to successful penetrate into lighting applications that operate in these harsh outdoor environments (e.g., aviation lighting), the luminaires must have a lens that can be heated to provide the IR energy that incumbent technologies have historically provided
- A glass-based heatable lens provides an feasible (technical and economical) solution to meet the optical and environmental durability requirements of aviation lighting with LEDs with design flexibility based on application:
  - Monolithic or Laminated Assembly
  - Choice of different lens shapes, thicknesses, conductivity, power density, interconnects, feedback loops, and temperature thresholds and ramp rates
  - Conductive and AR coatings designed to maximize visible light transmission

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An overview of Guardian Industries' lighting solutions can be found on-line at:

http://www.guardian.com/GuardianGlass/glassproducts/TechnicalGlass/lightingproducts/index.htm

Thanks for your time and attention!