Long Lasting Optics for LED Devices

Track Session: Advanced Materials For LED Lighting

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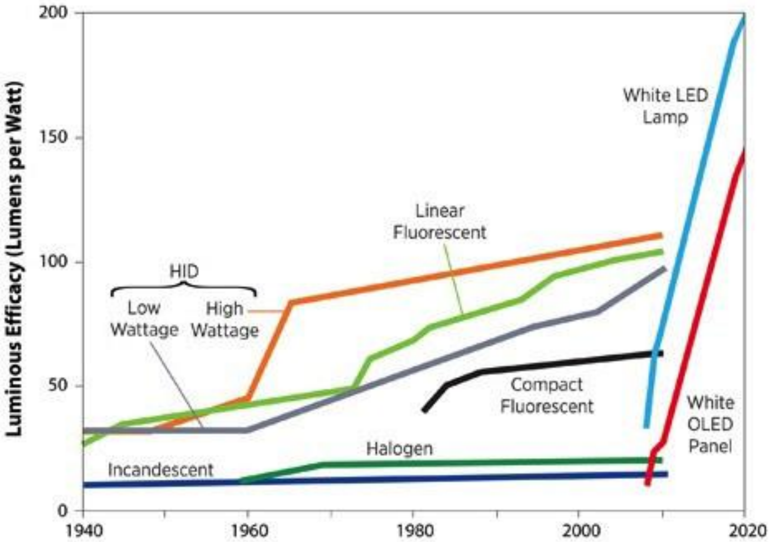
Overview

- Introduction
- Basics
- Material facts
  - Optical properties
  - Mechanical properties
  - Temperature dependences
- Conclusion

Introduction

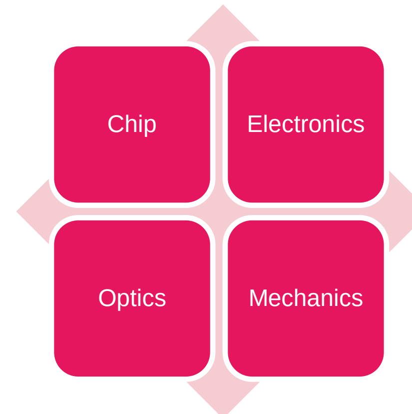
- LEDs started as small and “point-like” light sources mainly for signaling applications (long lifetime but low luminous output)
- But they are semiconductor devices → tremendous improvements over the last few years
- > 100 lm/W are commercially available; 300 lm/W are in the labs
- Chip temperatures and especially luminous flux have increased



- The optics didn’t follow the changing requirements and are still made from the same materials
- Especially true for “secondary optics” (lenses, TIR-collimators, reflectors)

Basics

- An “LED” is a closely packed system of components, where the weakest part determines the maximum performance (e.g. lifetime)
- And LEDs are not “cold” light sources, the heat (70-80%) will be concentrated on a small area
  → a path of low heat resistance has to be build
- Otherwise the whole system will stay at an elevated temperature
- Negative impact of temperature on the lifetime of **electronical** components are well known



Source: Energystar

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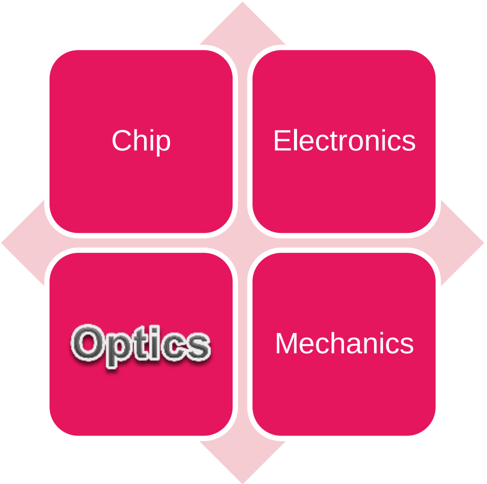
Basics

- But also the optical materials used in such systems are sensitive to temperature
- LED manufacturers are trying to drive the devices with higher junction temperatures
- Lumen packages of LEDs become more powerful
- This leads to higher thermal load of the system and especially the optics, typically Polymethylmethacrylate (PMMA) or Polycarbonate (PC)

- The lifetime of those materials is already limiting the performance of optical systems (automotive, entertainment, outdoor)



Basics

(Secondary) Optics have to

resist

- environmental influences (rain, chemicals, dust/dirt, UV radiation)
- high temperatures (LED, ambient) and its fluctuation
- mechanical load

and **maintain**

- mechanical properties
- optical properties (efficiency, index of refraction, appearance)

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Rediscovering glass

- Low wattage lighting products were the first to be replaced by LEDs
- Now, LED products are targeting increasing power (and luminous flux) levels, further increasing thermal load on the optics
- Up to now, glass was not “necessary” for low power devices, apart from aesthetic and longevity reasons
- Being one of the oldest optical materials, its properties are unique, well understood and thus can provide substantial benefits also for LED applications

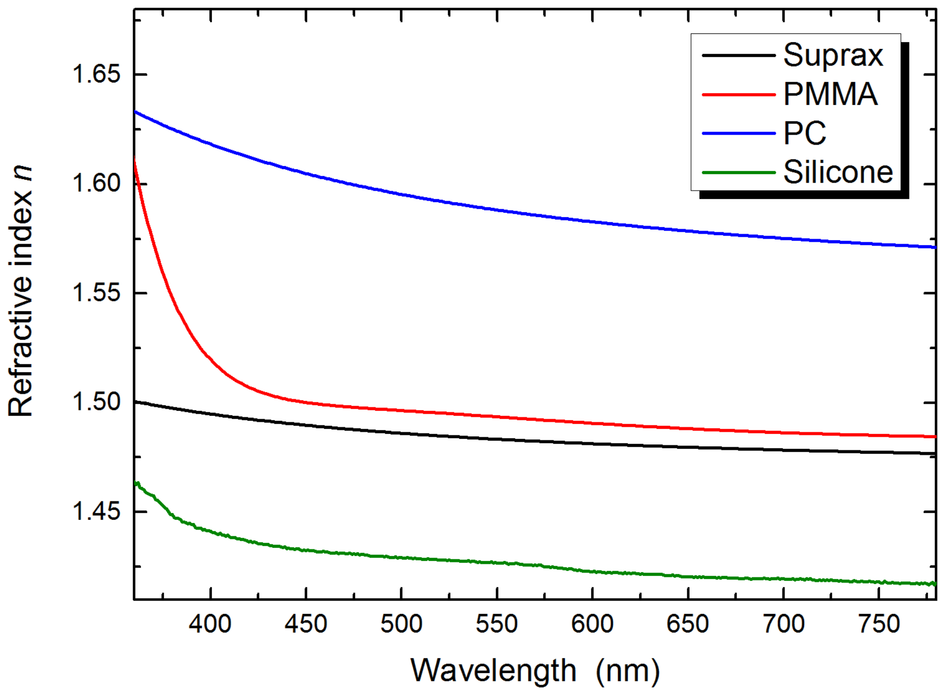
Material facts

Property	Glass (here: Suprax)	PMMA	PC	Silicone	Remarks
Density (g/cm^3)	2.31	1.18	1.20	1.02	
Water absorption (weight %)	No	0.6 – 2.0	0.1 – 0.3	0.2	acc. to ISO 62
Thermal expansion coefficient ($10^{-6}/K$)	4.1	80	70	250 – 345	
Thermal conductivity (W/(m K))	1.20	0.19	0.21	0.31	
Heat capacity (J/(g K))	0.80	1.20	1.17	1.37	@ 25 °C
Flammability (mm/min) (class)	No	25 (HB)	2.5 (V0)	HB…V1	UL 94
Chemical resistivity	++	-	0	+	
Short Time Operating Temperature (°C)	450	93	130	260	
Permanent Operating Temperature (°C)	400	<80	<110	<150	
Light Transmission (%)	92	92	89	91	D = 3 mm
Refractive Index	1.482	1.492	1.585	1.410	n_d @ 25 °C
Fresnel losses (%)	3.8	3.9	5.1	2.9	One surface
	7.5	7.6	9.9	5.7	Two surfaces
Thermo-optic coefficient dn/dT ($10^{-4}/K$)	~0	-1.1	-1.1	-5.0	
Abbe number	65	59	31	50	ν_d
Coatability	++	0	0	-	
UV resistivity	++	0	-	+	
Cleanability	++	-	-	0	
Possible feature size	0	+	+	+	
Yellowness index	0	8	9	1	30 years ASTM E313

Refractive index

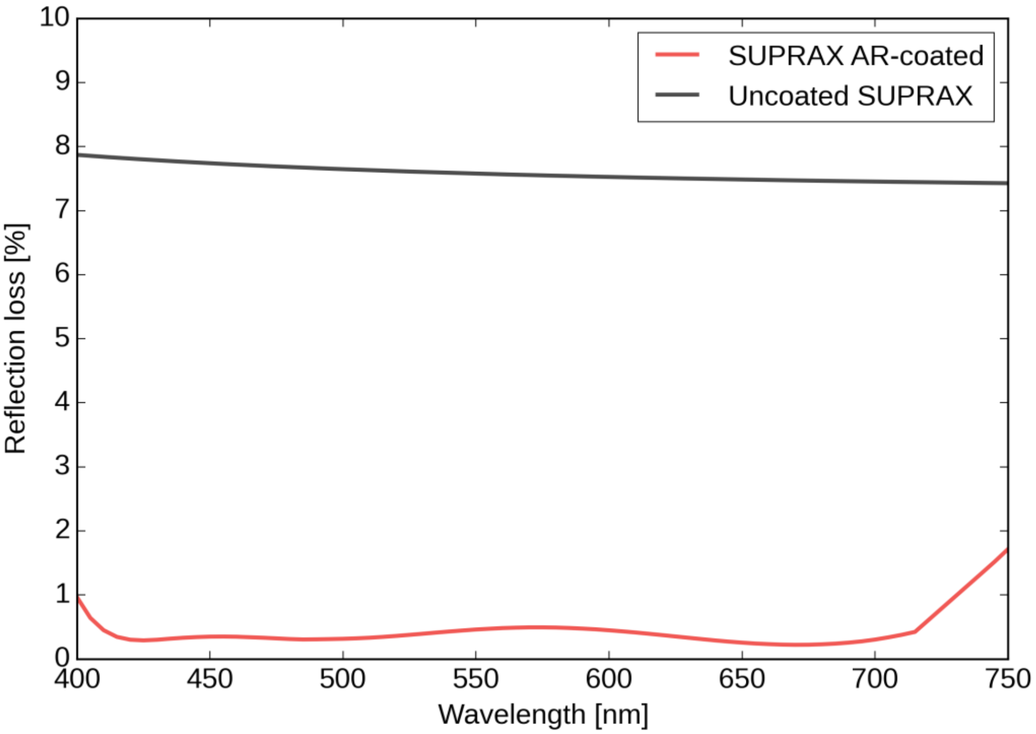
- Refractive index of glass (Suprax) and PMMA similar → optical designs interchangeable

- Dispersion (variation of refractive index with wavelength) is highest for PMMA, lowest for glass ⇨ less chromatic aberration (rainbow effect)



Coatings

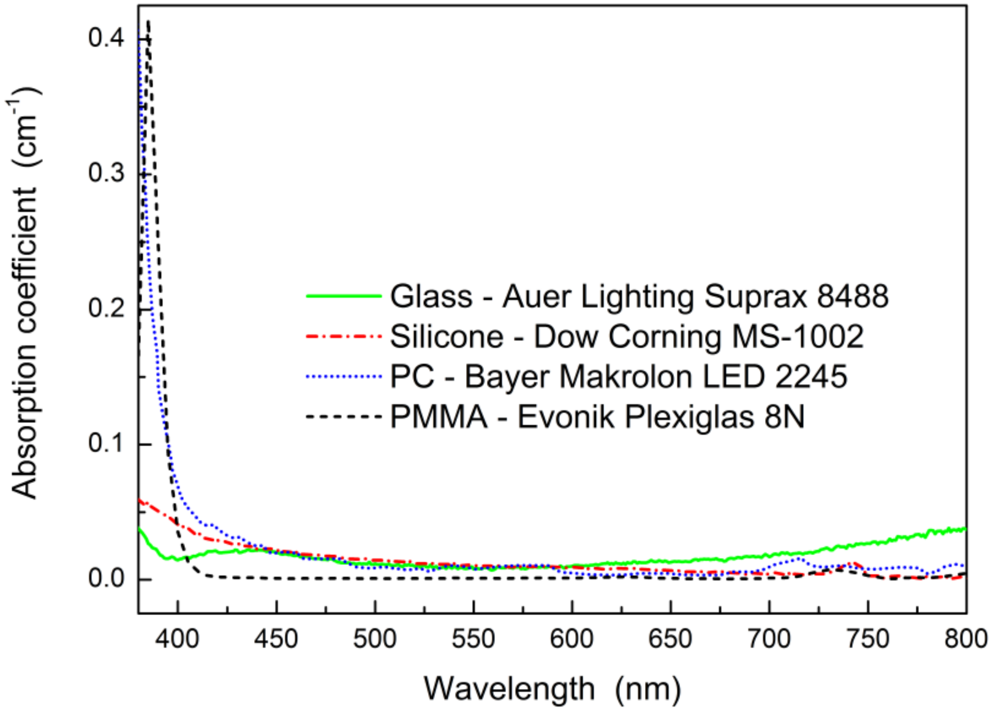
- Minimizing losses by coating the surfaces appropriately with an anti-reflective (AR) coating (transmission values of >99% are possible)
- This requires the material to be coatable
- For glass this is perfectly possible
- Coatings with a long-term stability like glass can be applied (e.g. SiO_2/TiO_2)



Absorption

- PC and especially PMMA show a strong absorption in the blue region

- Integrated over the whole visible spectrum this will lead to:



	Glass (here: Suprax)	PMMA	PC	Silicone	Remarks
Light Transmission (%)	92	92	89	91	D = 3 mm
Coatability	++	0	0	-	

Mechanical properties

Density:

- Plastics share a similar density of approx. 1 g/cm^3
- Glass: 2.3 g/cm^3 → known prejudice (heavy), but for real optics the absolute plus is often negligible

Mechanical stability:

- Glass can produce sharp edges when breaking, but provides a high surface hardness ↔ scratch resistance → easy cleaning
- Plastics can handle more force, usually no sharp edges when breaking, but show micro-scratches, e. g. when the surface is mechanically cleaned
- Hardness of glass is reason for lack of robustness against certain impacts (thermal or chemical toughening possible)

Chemical resisitivity

- Polymers are (partly) organic materials
  → less resistive against environmental stress (gases like ozone, nitric oxides, hydrogen chloride, nitric acid,..)
- Outgassing components can damage or degrade the plastics performance during production/operation of a lighting system
- Elevated temperatures promote the diffusion of aggressive chemicals into the material

Typical example for yellowing of plastics

- Many plastics show a considerable loss in their light transmission during use (yellowing/haze due to high-energy radiation (environment or LED))
- Resistivity against yellowing is inherent to glass

- Plastics absorb water up to 2% of their weight changing the mechanical properties
- No water absorption for glass

Thermal properties

Heat storage:

- Heat capacity for the materials is around 1 J/(g K) → higher density of glass leads to the ability to store more heat for a similar piece of optics

Heat conductance:

- Thermal conductivity is roughly similar for plastics; glass shows a four to six times higher conductivity → more heat can be transferred away from the source (possibility to use the optics as an auxiliary heat sink)

Thermal properties

- Thermal expansion coefficient reflects tendency of matter to change volume (e.g. length) as a function of temperature
- PMMA and PC closely together, Silicone four times higher ↔ big issue on optical performance e. g. for light guides: 70 mm long light guide would longitudinally expand by up to 1.3 mm for a 60 K temperature increase → focal point shift, mounting issues, etc.

- Glass shows an up to 84 times lower coefficient of thermal expansion

Thermal properties

Operating temperatures:

- PC and PMMA are only applicable for temperatures around and below 120°C
- Silicone’s permanent operating temperature is at 150°C (260°C for short time operation)
- Glass withstands temperatures up to 450°C for short time operation and 400°C for permanent use

The residue of a PMMA light guide after moderate thermal treatment

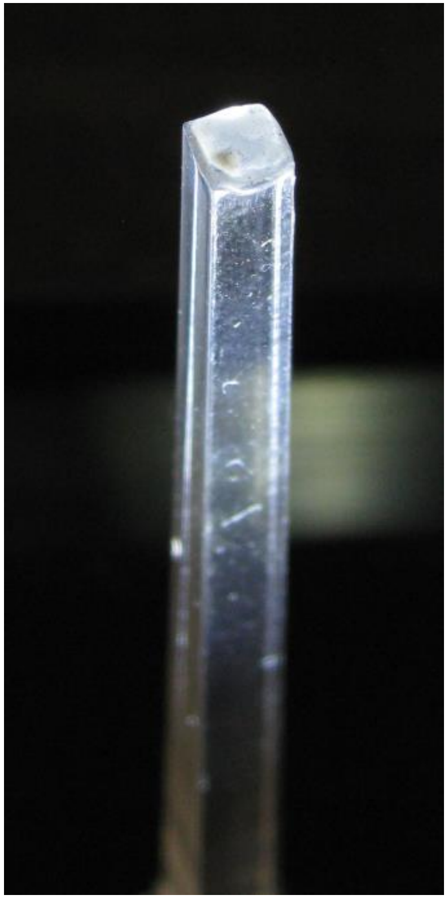
Flammability:

- Most plastics are flammable and result in a corresponding classification → not usable for certain kinds of applications
- Upon combustion, they can produce thick smoke and/or toxic gases
- Glass is not flammable

Temperature influences

"It's already there"

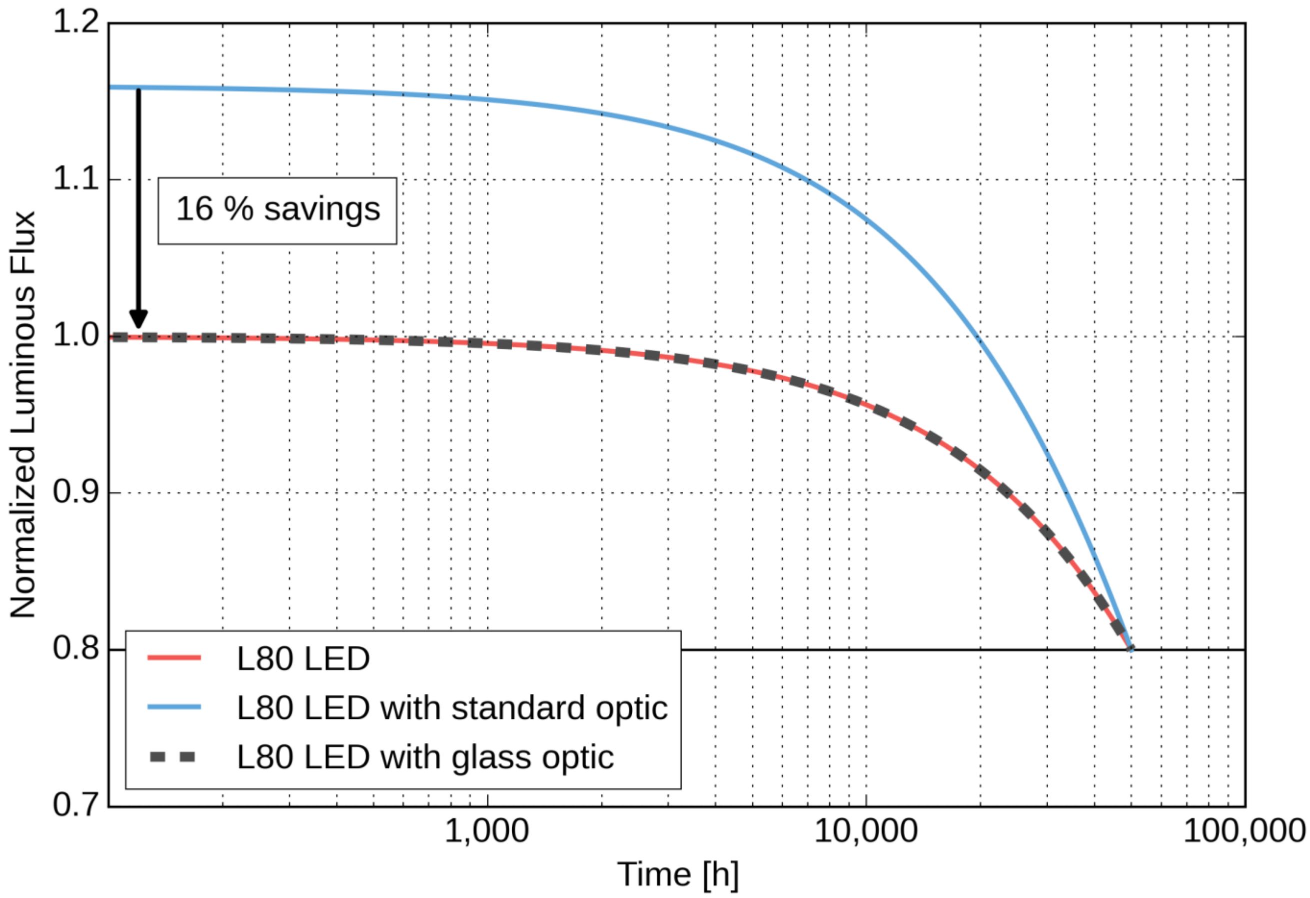
- Failing optics are more and more seen by manufacturers of such LED lighting fixtures
- Systems need to be dimmed to avoid potential damage
- Systems show degrading performance due to optical longevity issues
- The full potential of LEDs can't be used
- Improper optical materials are a limit already!



PMMA light guide after 10s in front of 14W RGBW-LED at 35 °C ambient temperature

Consequences

- Typical LED degradation over time (20% @ 50,000h)
- Standard optics add further losses (e.g. 20% @ 50.000h)
- Glass maintains its features
- Savings in
  - LEDs
  - heat sink
  - energy!



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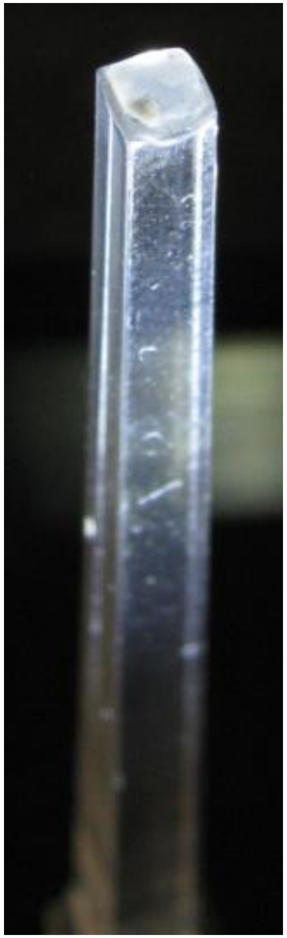
Summary

- LEDs have reached efficiency and flux levels that qualify them for high power applications
- Deploying them in advanced systems/luminaires requires appropriate material engineering
- Some materials show severe disadvantages like thermal aging, sensitivity to chemicals and environmental stress, power densities
  → they limit further enhancements in LED-systems
- Glass on the other hand: durable, versatile in shape and features, no temperature problems, easily coatable (to enhance initial performance) and cleanable (to keep initial performance)
- Glass can reach competitive pricing levels, especially for specialized and/or qualitative optics



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