Optical silicones advance new LED applications

Jake Steinbrecher and Gifford Shearer

October 2020

LEDs ARE CONTINUING TO REVOLUTIONIZE LIGHTING

The LED lighting market is expected to exceed $125B by 2027.

Lighting related energy consumption is expected to drop by 40% in 2030 thanks to LED penetration into general illumination.

Main growth drivers:

- High efficiency
- Reliability and robustness
- High brightness
- Condensed size and customized shapes
- Low power consumption

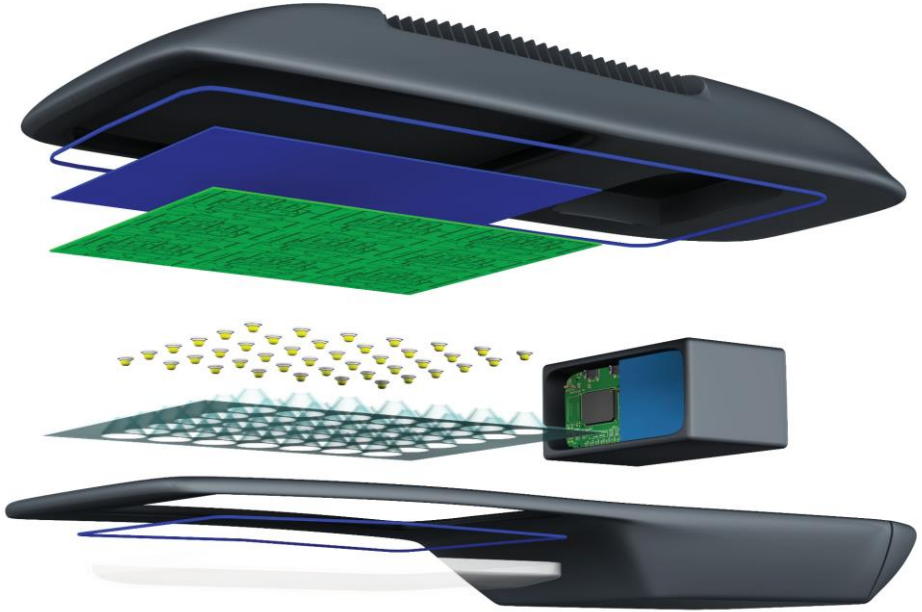
AGENDA

- **Benefits of silicones in LED lighting applications**
- **New applications enabled by silicones**
  - Automotive adaptive drive beam forward lighting
  - High-powered sport stadium lighting
  - LED purification and disinfection lighting
- **Processing and design benefits of silicone**
  - Liquid molding process
  - Complimentary white reflective silicones
  - Extruded silicones for linear lighting applications

Benefits of silicones in LED applications

SILICONES USED IN LED LUMINAIRES

- Adhesive and sealants
- Conformal coatings
- Thermal-interface materials
- LED Chip encapsulants
- Thermally-conductive pottants
- Secondary optics (lens)



MATERIAL OPTIONS FOR LED OPTICS

	SILASTIC™ Moldable Silicone	PC	PMMA	Glass
Light transmission (%)	94	88-90	93	95
Refractive index	1.42	1.58	1.49	1.52
UV resistance	High	Low	Medium	High
Chemical resistance	Medium	Medium	Low	High
Service temperature max. (C°)	>150	120	90	>200
Yellowing*	Low	High	High	Low
Micro detail replication	High	Low	Medium	Low
Ability to mold large/ thick parts	High	Low	Low	Medium
Minimum thickness**	<0.5 mm	2 mm	2 mm	—
Draft angle ° (manufacturing)**	<0	1 to 2	1 to 2	—
Weight	Low	Medium	Medium	High
Flexible material — integration	High	Low	Low	Low

* Yellowing due to high temperature, high lumen density, or UV exposure
** Injection molding process

Benefits of moldable optical silicones

- **High clarity** → Match LED efficiency
- **Stability** → LED lifetime/efficacy
- **Impact resistance** → Assembly
- **Consistent performance** → High and low temperatures
- **Design flexibility** → LED integration

Aging	Silicone (1)	PC (2)	PMMA (3)
Initial			
Sunlight UV			
Heat 125°C			
Heat 150°C			NA
85°C/85%RH			

1. **SILASTIC™ MS-4002 Moldable Optical Silicone**
2. SABIC Lexan 2180 (non-stabilized)
3. LUCITE Diakon CMG302 (non-stabilized)

WHAT SILASTIC™ MOLDABLE OPTICAL SILICONES ARE

An enabling technology that is both *clear and tough*

LIQUID SILICONE RUBBER (LSR) = Silica particle reinforced: ***hazy*** *material*

Silica and/or other fillers impart strength and stability.

- Fillers cause haziness due to optical differences in refractive index between silica and PDMS.

MOLDABLE OPTICAL SILICONES (MS) = Siloxane resin reinforced*:* ***clear*** *material*

- **Molds like LSR**
- **Transmits light like glass**

Silicone resins impart strength and stability.

- **Benefits of resin/polymer molecular backbone**
  - Moisture resistance and thermal stability
  - Physical property variations
  - High purity and clarity
  - Injection molding properties

What SILASTIC™ Moldable Optical Silicones do

- Injection moldable for unique applications, including lenses (TIR, free-form), light guides, diffusers, reflectors, etc.
- Precisely control light, ‘bend’ light, replicate nano-scale optical features, uniformly diffuse or reflect light, be used in harsh environments/applications, enable high ingress (IP) and impact (IK) protection ratings, and more…

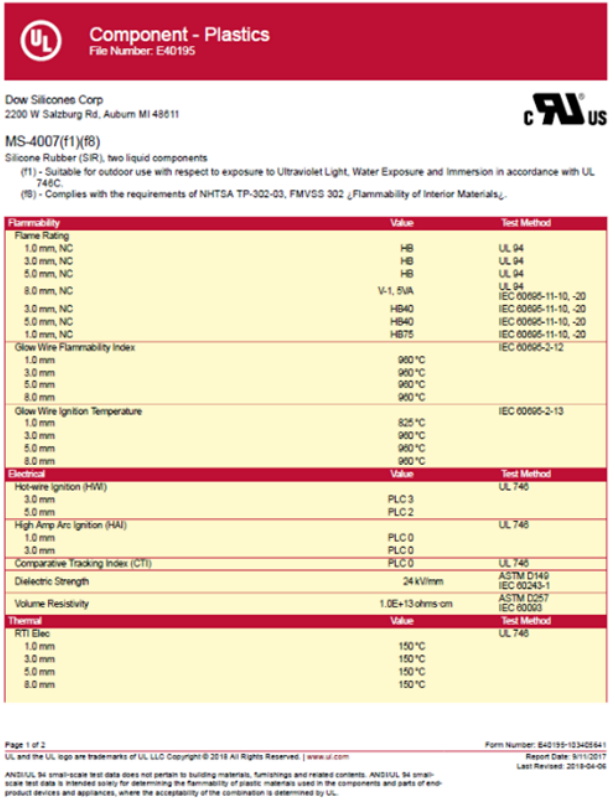




SILASTIC™ MS-2002
White Reflector

WHY CHOOSE SILASTIC™ MOLDABLE OPTICAL SILICONES?

- **Use in harsh environments**
  - Photo-thermal stability, UV heat, humidity, …
- **Ingress (IP) and Impact (IK) protection**
- **UL recognition for all products**
  - UL94, UL746C(f1)(f8)
- **Automotive recognition**
  - AMECA (outdoor weathering), FMVSS (abrasion), SAE (impact), GMW (chemicals), fogging
- **Efficient liquid injection molding**
- **Design flexibility in tooling and form factor**
  - Undercuts, trapped features
  - Near perfect replication of optical surfaces and features



Component - Plastics
File Number: E40195

Dow Silicones Corp
2200 W Salzburg Rd, Auburn MI 48611

MS-4007(f1)(f8)
Silicone Rubber (SIR), two liquid components
(f1) - Suitable for outdoor use with respect to exposure to Ultraviolet Light, Water Exposure and Immersion in accordance with UL 746C.
(f8) - Complies with the requirements of NHTSA TP-302-03, FMVSS 302 „Flammability of Interior Materials„.

Flammability	Value	Test Method
Flame Rating		
1.0 mm, NC	HB	UL 94
3.0 mm, NC	HB	UL 94
5.0 mm, NC	HB	UL 94
8.0 mm, NC	V-1, 5VA	UL 94 IEC 60695-11-10, -20
3.0 mm, NC	HB40	IEC 60695-11-10, -20
5.0 mm, NC	HB40	IEC 60695-11-10, -20
1.0 mm, NC	HB75	IEC 60695-11-10, -20
Glow Wire Flammability Index		IEC 60695-2-12
1.0 mm	960 °C	
3.0 mm	960 °C	
5.0 mm	960 °C	
8.0 mm	960 °C	
Glow Wire Ignition Temperature		IEC 60695-2-13
1.0 mm	825 °C	
3.0 mm	960 °C	
5.0 mm	960 °C	
8.0 mm	960 °C	
Electrical	**Value**	**Test Method**
Hot-wire Ignition (HWI)		UL 746
3.0 mm	PLC 3	
5.0 mm	PLC 2	
High Amp Arc Ignition (HAI)		UL 746
1.0 mm	PLC 0	
3.0 mm	PLC 0	
Comparative Tracking Index (CTI)	PLC 0	UL 746
Dielectric Strength	24 kV/mm	ASTM D149 IEC 60243-1
Volume Resistivity	1.0E+13 ohms·cm	ASTM D257 IEC 60093
Thermal	**Value**	**Test Method**
RTI Elec		UL 746
1.0 mm	150 °C	
3.0 mm	150 °C	
5.0 mm	150 °C	
8.0 mm	150 °C	

Page 1 of 2
Form Number: E40195-103405641
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Last Revised: 2018-04-06
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New applications enabled by silicones

CASE STUDY – ADAPTIVE DRIVE BEAM LENS

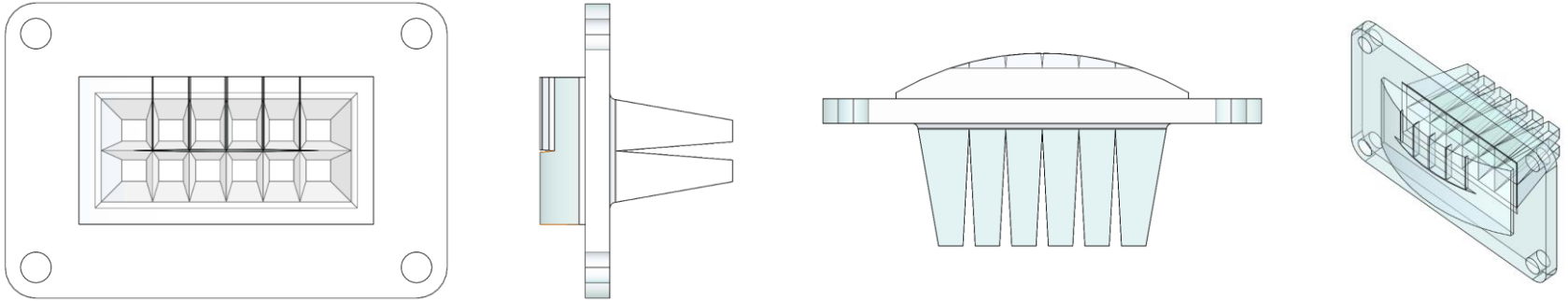
Dark or low-lighting conditions increase likelihood of a collision[1]

Dark driving = 25% of automotive travel, but 52% of driver fatalities and 71% of pedestrian deaths

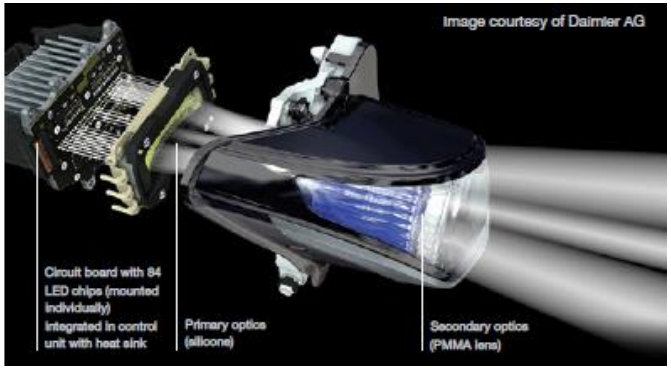
Potential solution	Limitations
Increase roadway illumination	Glare and reflections, infrastructure needed
Increase high beam usage by drivers	Glare and concern for oncoming drivers
Adaptative driving beam (ADB) implementation:	Long-range visibility without causing discomfort, distraction or glare

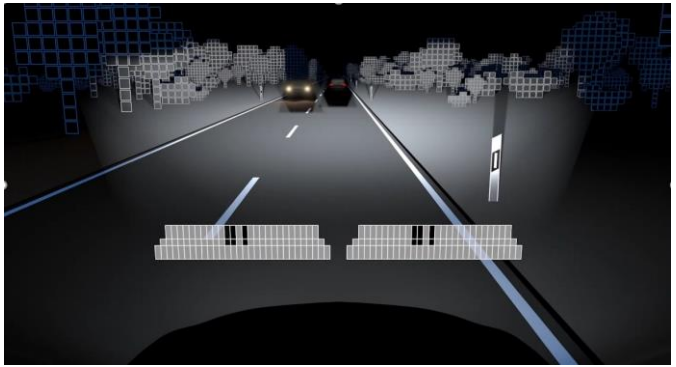
1. AAA "Comparison of European and U.S. Specification Automotive Headlamp Performance" April 2019.

SILASTIC™ MS-1002 SILICONE ENABLES COMPLEX ADB LENS



*Designs are for reference only and are not meant to duplicate or infringe on any other design.





Link to case study

ADVANCES IN MOLDABLE OPTICAL SILICONES

As the pioneers of moldable optical silicones, we're leading silicone technology in lighting with more than 10 years of optical performance.

In response to market feedback Dow has commercialized the next generation of moldable optical silicones to provide benefits beyond the performance of MS-100X.

- **Higher light transmittance** for better optical clarity and longer path length applications.
- **Higher hardness options with reduced surface tack** to enable tougher more rigid molded parts.

Ideal for high-power LED general / specialty lighting and automotive lighting applications

- **SILASTIC™ MS-400X Silicones** deliver better optical and aging performance in applications like stadium lighting and automotive lenses.

SILASTIC™ Moldable Optical Silicones: Physical properties

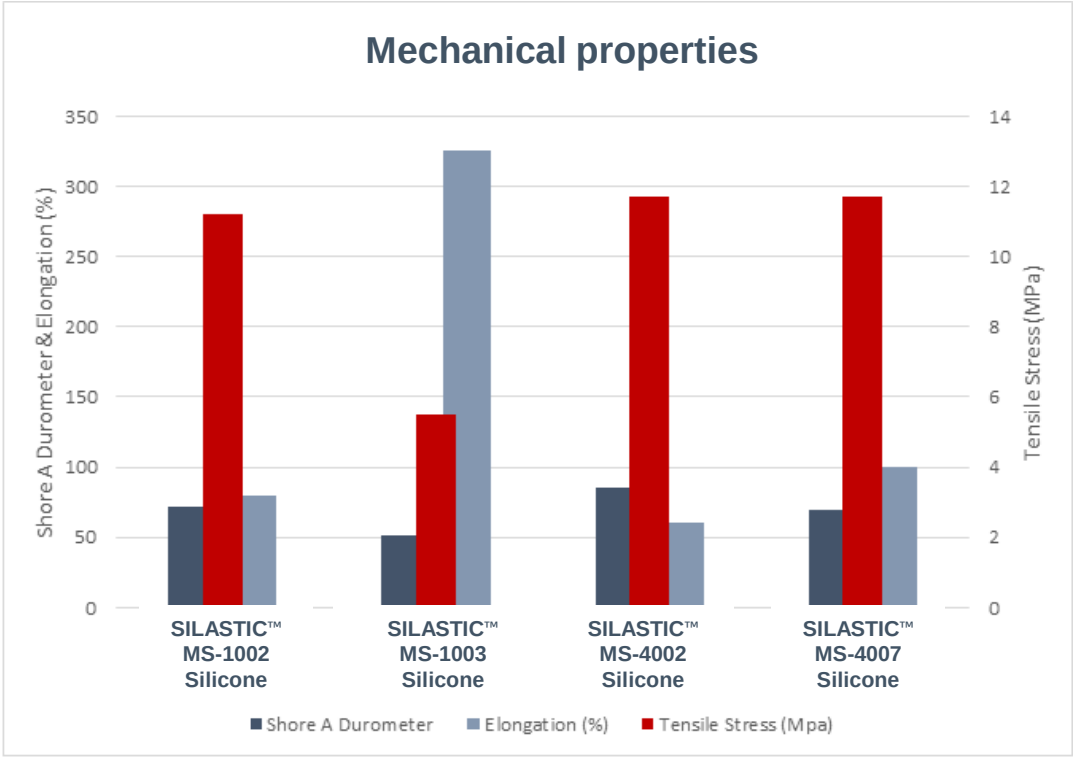
	SILASTIC™ MS-1002 Silicone	SILASTIC™ MS-1003 Silicone	SILASTIC™ MS-4002 Silicone	SILASTIC™ MS-4007 Silicone
Viscosity, Part A (Pa-sec)	40	52	47	28
Viscosity, Part B (Pa-sec)	18	37.5	20	9.5
Viscosity, mixed (Pa-sec)	26.3	42.3	25	10.5
Specific gravity (g/cc)	1.07	1.05	1.08	1.08
Durometer (Shore A) *	72	51	84	70
Tensile strength (MPa) *	11.2	5.5	11.7	11.7
Elongation at break (%) *	80	325	60	100
Linear CTE (by TMA) (ppm/˚C)	275	325	250	270

All SILASTIC™ Moldable Optical Silicones are UL94 / UL746 / UL746C(f1)(f8) certified (see appendix for details).
(*) Values after post-curing of parts at 150°C for 2 hours.

SILASTIC™ MOLDABLE OPTICAL SILICONES: MECHANICAL PROPERTIES

Expanding the product range from soft and pliable *to* firm and tough.

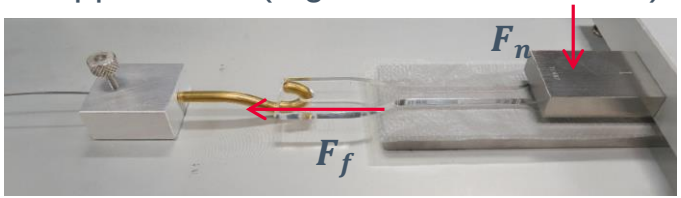
- High elongation and high Shore A durometer → impact and scratch resistance
- Range of hardness' and material toughness → accurate part fixation, high IP rating



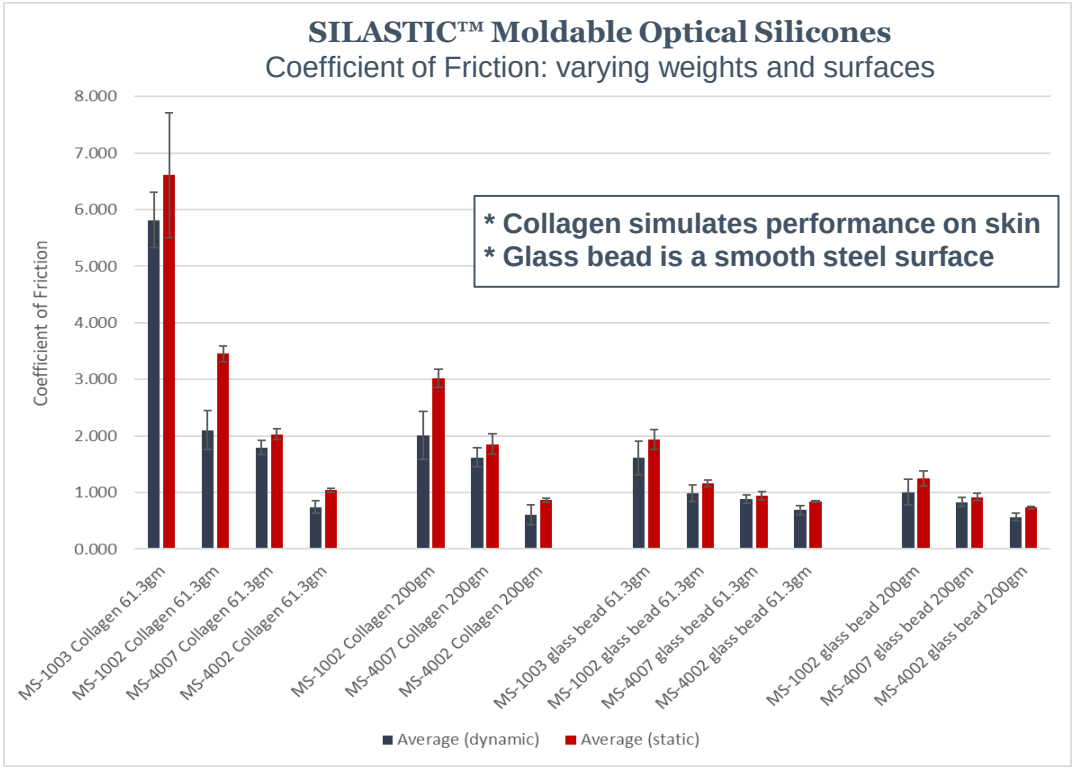
SILASTIC™ MOLDABLE OPTICAL SILICONES: 'FEEL'

SILASTIC™ MS-400X Silicone materials are designed to have a *slick,* plastic-like feel.

- Coefficient of friction (CoF) provides measure of surface tack.
- Higher number leads to more rubbery or tacky surface feel.
- Lower number can correlate to reduce dirt / dust depreciation of light output.
- Allows for more direct exposure applications (e.g., outdoor, industrial)



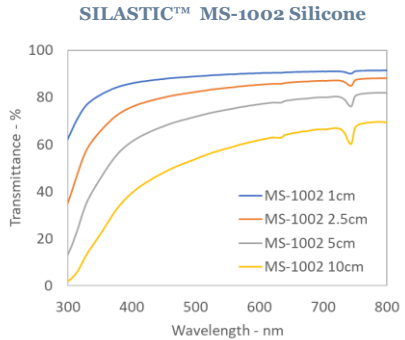
$$CoF = \frac{F_f}{F_n}$$

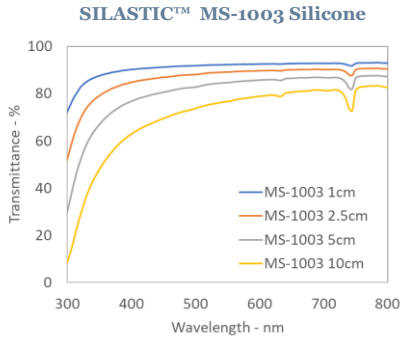


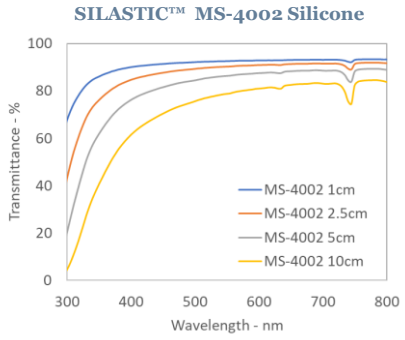
SILASTIC™ MOLDABLE OPTICAL SILICONES: OPTICAL PROPERTIES

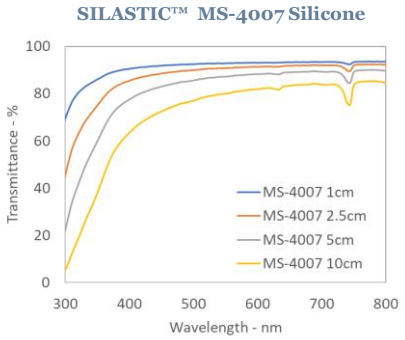
	Thickness (mm)	SILASTIC™ MS-1002 Silicone	SILASTIC™ MS-1003 Silicone	SILASTIC™ MS-4002 Silicone	SILASTIC™ MS-4007 Silicone
Refractive index n_D	-	1.4134	1.4088	1.4165	1.4125
Abbe number	-	52	51	52	51
Luminous transmittance* (%)	10	90	92	93	93
	25	84	89	90	91
	50	75	85	86	87
	100	59	77	79	80

(*) Weighted total transmittance between 360 and 780 nm according to CIE Colorimetry 15:2004

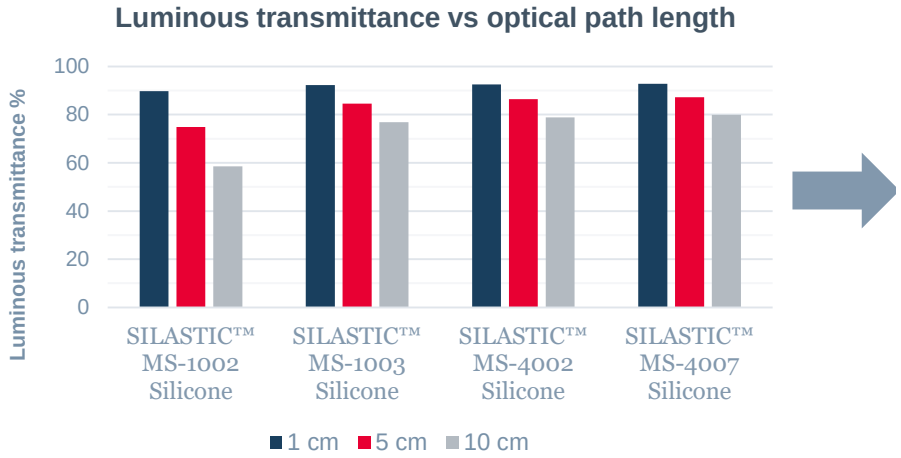


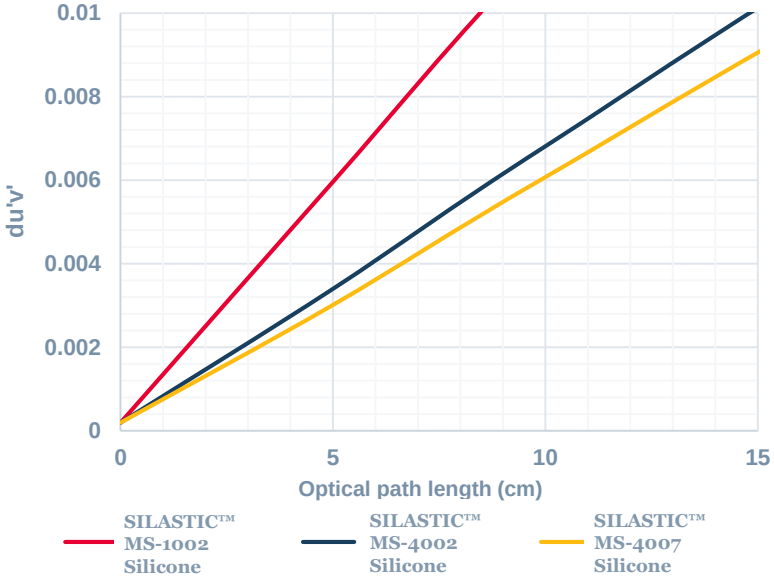




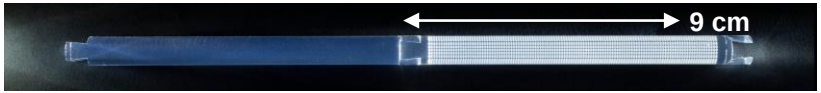


SILASTIC™ MOLDABLE OPTICAL SILICONES: LIGHT PATH LENGTH EFFECT





- **High luminous transmittance** [a]
- **Low chromatic dispersion** (Abbe Number ca. 50)
- **Low haze and scatter** (**SILASTIC™ MS-1002 Silicone**: <1% / 3mm) [b]



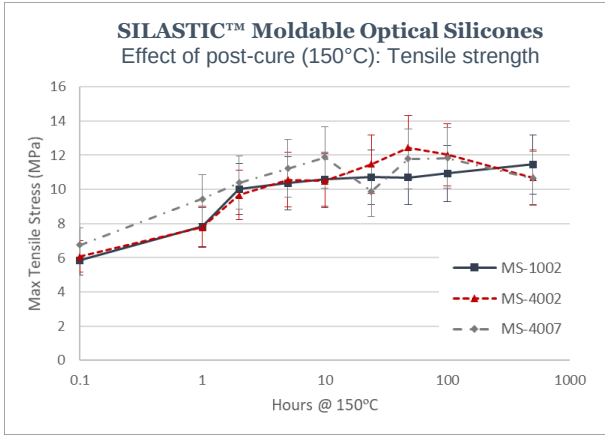
(a) Weighted total transmittance between 360 and 780nm according to CIE 15:2004
(b) Measured with haze-meter according to ISO14782

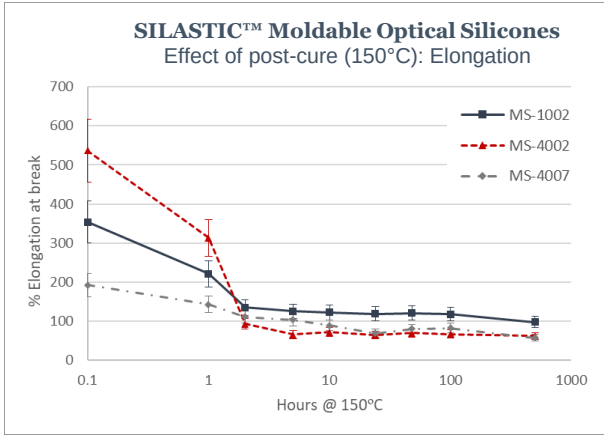
LED 4000K white light source

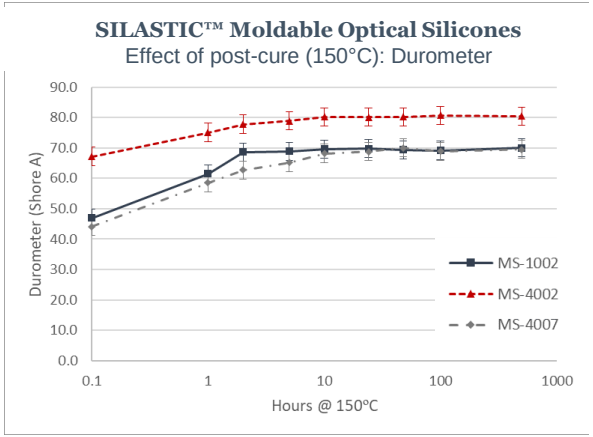
Significantly reduced color shift (du'v') for **SILASTIC™ MS-4002** and **MS-4007 Silicones** in comparison with **SILASTIC™ MS-1002 Silicone.**

PHYSICAL PROPERTIES (POST MOLDING → SHORT-TERM AGING)

After a recommended post cure of 1-2 hours at 150°C, the mechanical properties are very stable at elevated temperatures.







*All materials tested were within acceptable QA limits

Award winning – Optic for sport stadium lighting

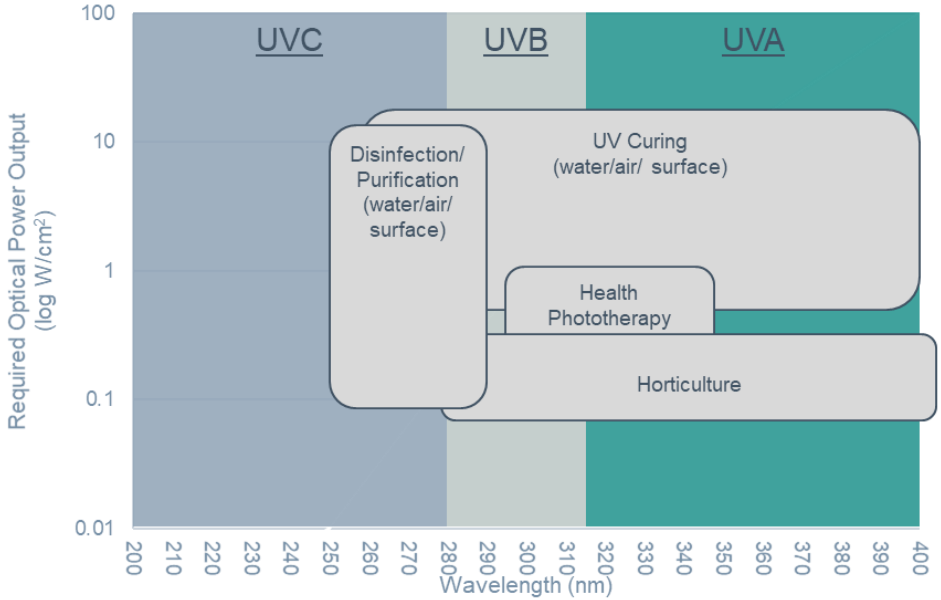
SILASTIC™ MS-4007 Moldable Optical Silicone was awarded a joint **2019 R&D Top 100** award for its use in sport stadium lighting.

SILASTIC™ MS-4007 Silicone enables high-lumen optical systems that enhance the viewing experience.

- **Excellent optical properties for large lens**
- **Design flexibility**
- **Ability to withstand long exposure to high density**
- **Excellent photo-thermal stability**

Growing market for LEDs in UV applications

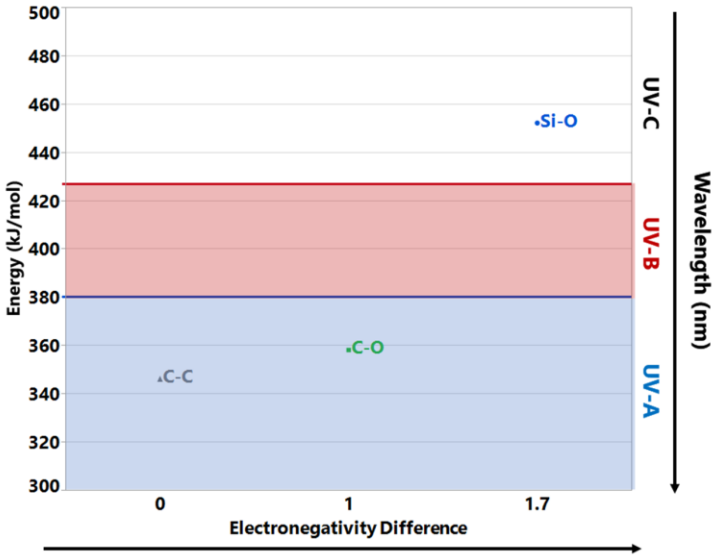
- LEDs for UV (A, B, C) applications are rapidly growing at 19% a year and expected to **exceed $1 billion by 2026.**
- Reduced costs and desire to eliminate mercury are propelling UV LEDs into more and more applications.
- COVID-19 has increased activity in UVC for disinfection and purification.



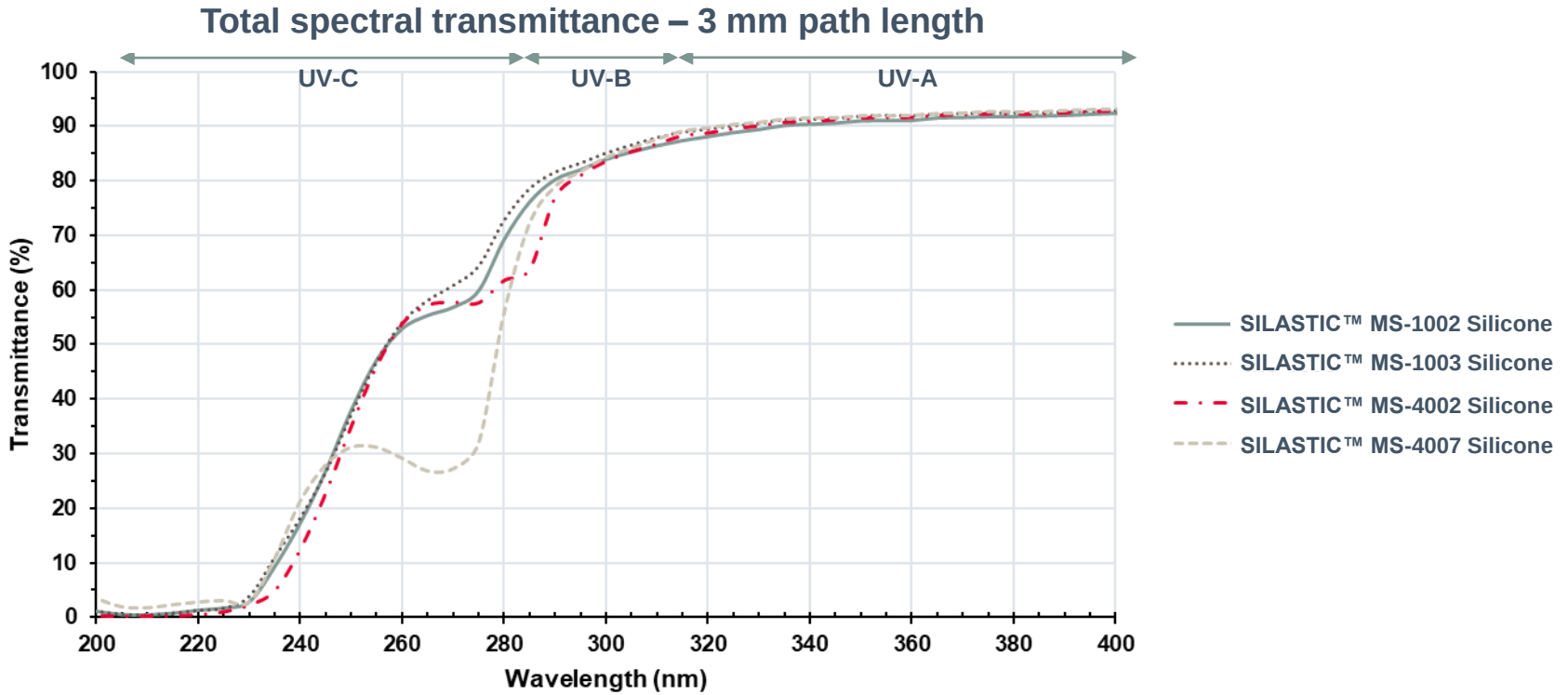
SILICONES FOR UV APPLICATIONS

Why silicone in UV applications?

- **Stable under UV radiation exposure**: non-yellowing, non-hardening
- **High transmittance in UV** wavelength range down to ca. 270
- **Ease of fabrication** by liquid injection molding
- **Design freedom** to mold complex lens geometries
- Enables **water immersion**
- High **impact protection**

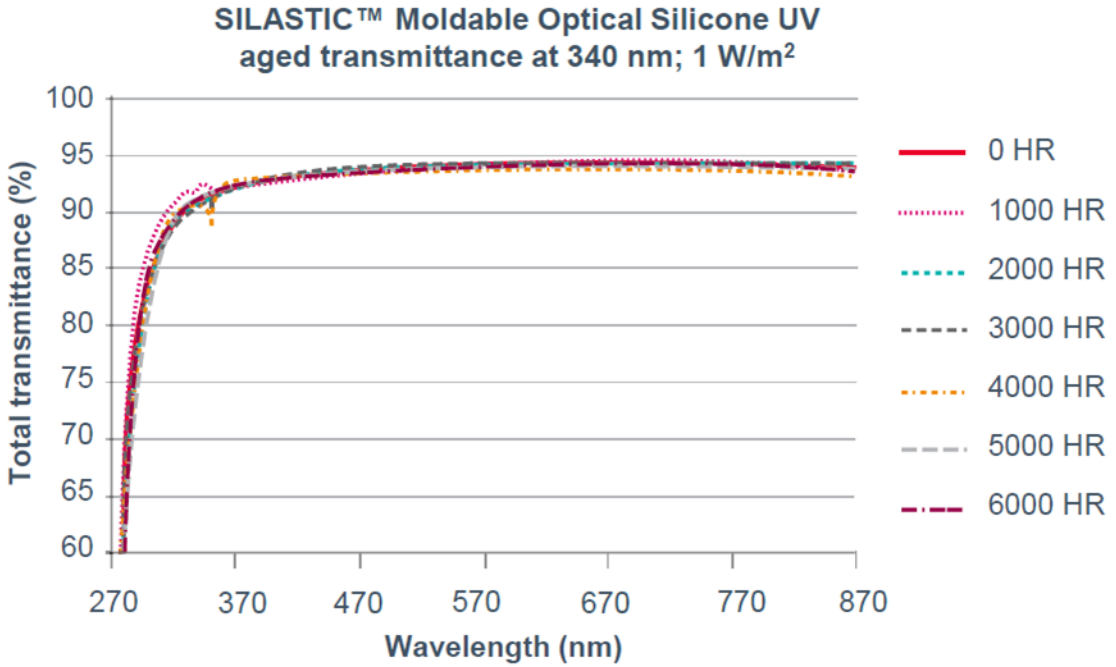


MOLDABLE OPTICAL SILICONE: OPTICAL DATA IN UV WAVELENGTHS



MOLDABLE OPTICAL SILICONE: OPTICAL STABILITY UNDER UV EXPOSURE

UL 746 C – F1 rated (Xenon / underwater immersion exposure), and non-yellowing under UV exposure

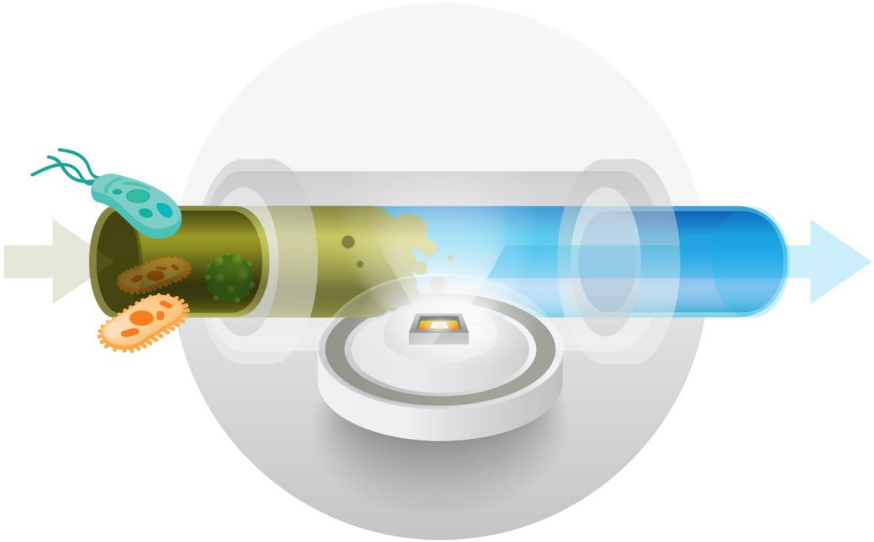


CASE STUDY FOR UV WATER PURIFICATION

SILASTIC™ MS-1003 Moldable Optical Silicone was used by Philips Lighting to design an UV purification system for drinking water.

- Certified to UL-746C(f1)(f8)
- Extensively tested in UV-A, UV-A+B, UV-C and sunlight
- One- piece lens that is water and dust tight (IP 68) as compared to quartz assembly

Dow and Philips Lighting Collaborate to change the future of UV purification.
Link to case study



Processing and design benefits

Benefits of liquid molding process

Traditional LSR

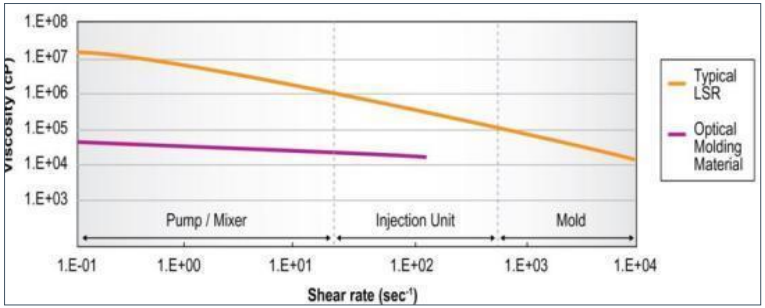
Silica and/or other fillers impart strength and stability.

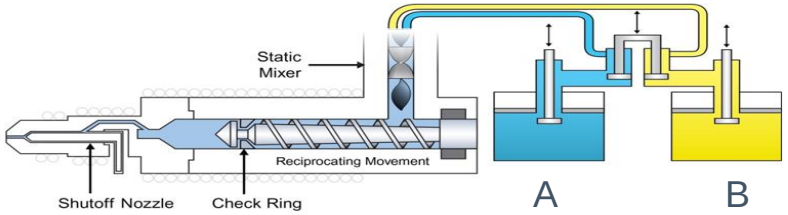
Moldable Optical Silicones

Silicone resins impart strength and stability.

Benefits of resin/polymer molecular backbone

- Moisture resistance and thermal stability
- High purity and clarity
- Very low viscosity to enable injection molding or complex parts





SILASTIC™ MOLDABLE OPTICAL SILICONES: VISCOSITY

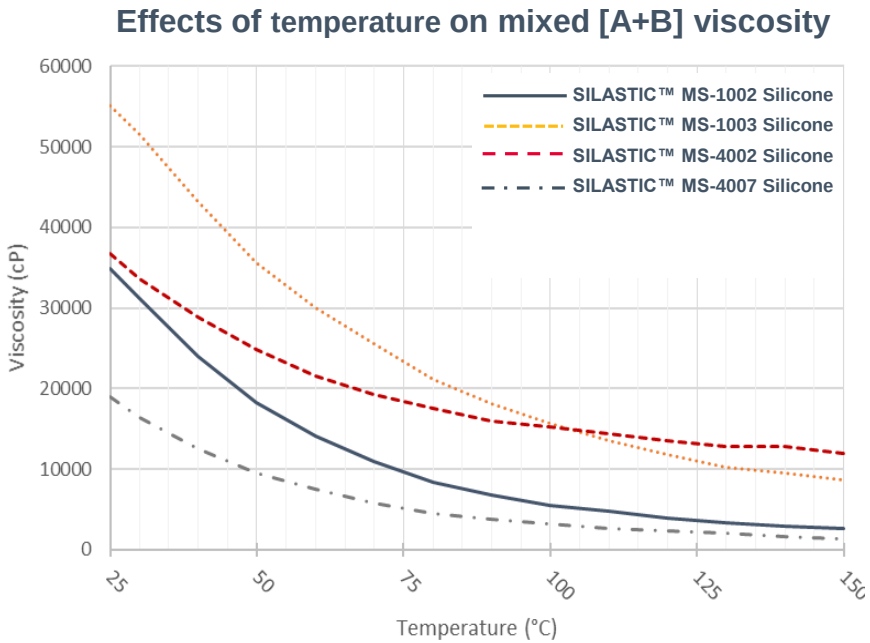
Heat influences viscosity of Moldable Silicone – very sensitive to temperature.

Advantages

- Ease of fabrication through liquid injection molding
- Good flow allows for complex-part geometry
- Excellent reproduction of mold features

Challenges

- Easily turbulent
- Higher potential for flash in tooling



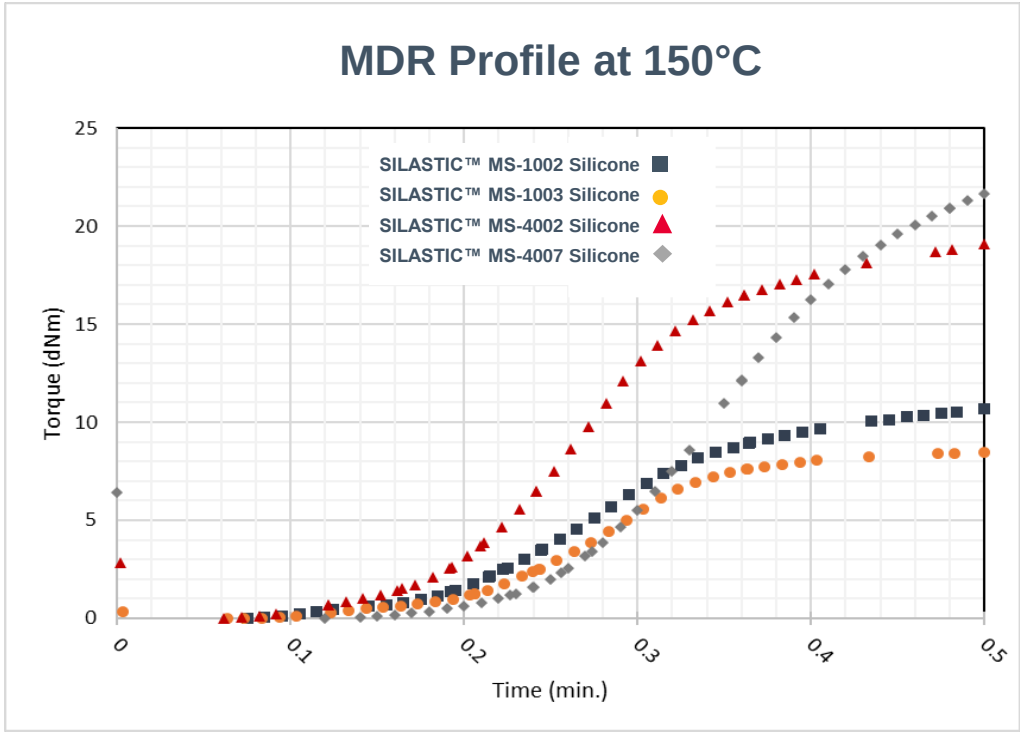
SILASTIC™ Moldable Optical Silicone: Cure rate

Cure properties tuned for optic and mold design

- Cure profile allows filling of complex geometry in liquid state
- Reduced gelation period can reduce cycle time and defects
- Quick to cured and handle-able part

SILASTIC™ Moldable Optical Silicones datasets are now available for the following Moldflow Analysis Software*:

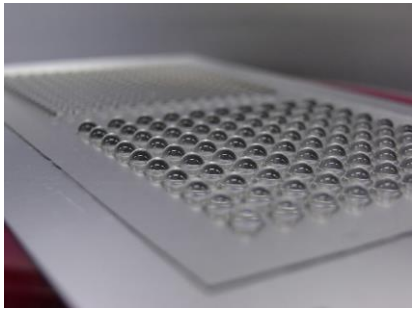
- SIGMASOFT
- Moldex3D

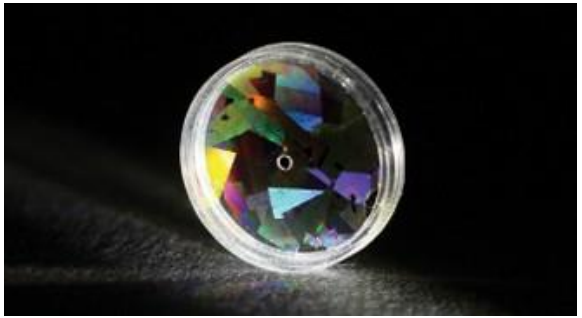


* SILASTIC™ MS-1002 Silicone available, SILASTIC™ MS-400X Silicones in progress

Design benefits enabled by silicones

- Mold shapes impossible in plastics or glass
- **One-piece Compound Lens** eliminates holder or alignment fixture
- Integrate optics with sealing features
- Simplify design – less components
- Replicate micro-surface features
- Create unique light effects





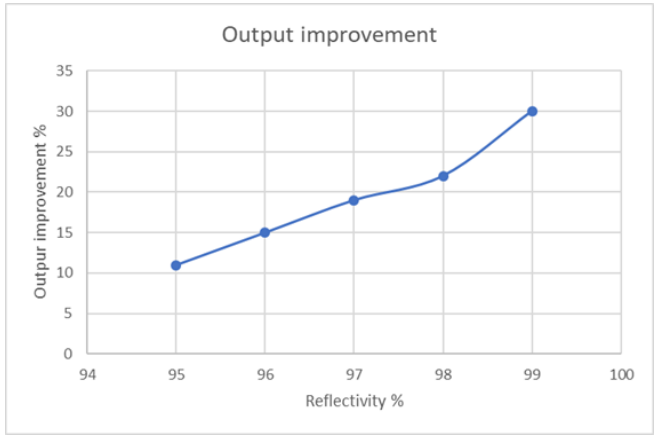
COMPLIMENTARY MATERIAL - WHITE REFLECTING SILICONE SOLUTIONS

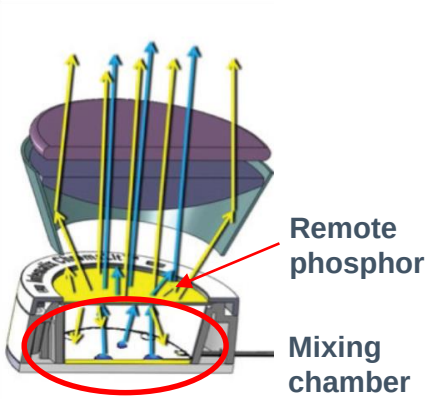
Why is reflectivity important?

It influences light output performance of lighting fixtures.

Material	Reflectivity	Designed process
SILASTIC™ MS-2002 (LSR)	>98%	Injection molding
SILASTIC™ ES-3001 (HCR)	>98%	Extrusion molding
SI-2001 (Ellsworth ResinLab)	>96%	Spray / dip coating

Reflectivity of mixing chamber	Remote phosphor system improvement
99%	30%
98%	22%
97%	19%
96%	15%
95%	11%

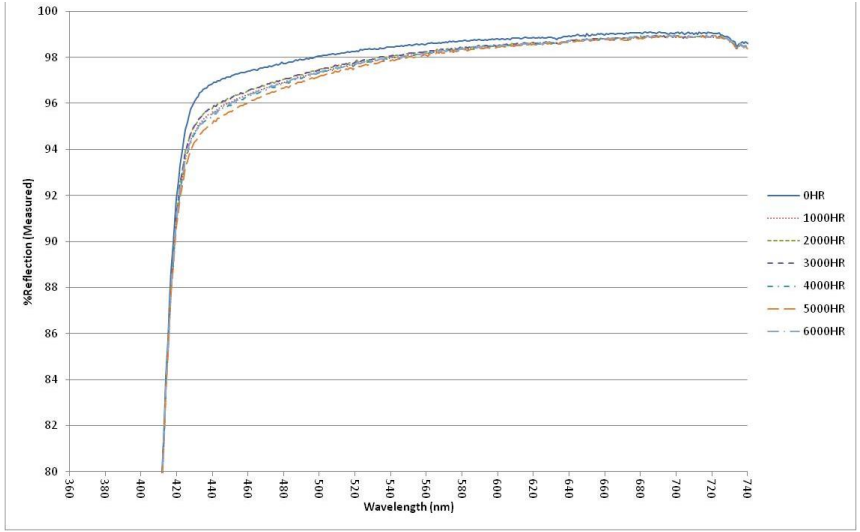




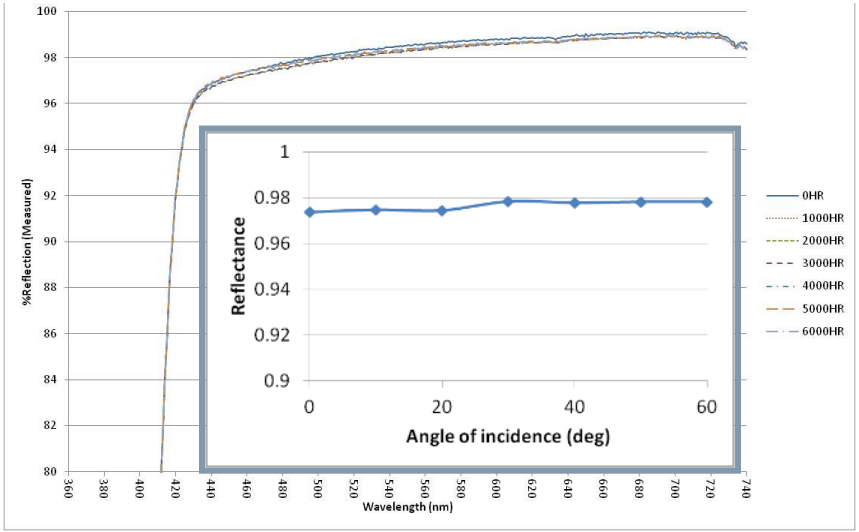
Source: Intematix – Application Note: Mixing Chamber Design Considerations for Chromalit Remote Phosphor Light Sources

THERMAL AND UV STABILITY OF SILASTIC™ MS-2002 SILICONE

Thermally-aged reflection @ 150° C



UV-aged reflection @ 1W/m^2, 340 nm



- **Outstanding stability against high heat and UV exposure**
- **Lambertian light diffusion pattern**

SILASTIC™ MS-2002 White Reflecting Moldable Silicone

SILASTIC™ MS-2002 Moldable Silicone	
Mixing ratio	1:1
Viscosity mix A+B (1 sec^{-1}; 25℃, mPa·s)	650,000
SG (g/ml)	1.44
Light reflectance (thickness = 3mm)	97%R (450 nm) 99%R (630 nm)
Hardness (Shore A)	84
Tensile strength (MPa)	8.6
Elongation (%)	86
CTE (ppm/ºC)	210
Pot life (hrs, 2X viscosity @25ºC)	48
UL recognition	UV94 / UL746C(f1)(f8)

Dow and Pathway Lighting developed tunable LED fixture with SILASTIC™ MS-2002 Silicone.

Link to case study

DOW

LIGHTING

CASE STUDY: PATHWAY LIGHTING PRODUCTS, INC.

Pathway Lighting Products develops new tunable LED fixture with SILASTIC™ MS-2002 Moldable Silicone

The challenge

Imagine a hospital or residential care facility in the early morning hours. Very warm lighting bathes the halls and common areas as residents and patients begin their day. As the day progresses, the lighting changes subtly, until it reaches a brighter white. Later, the lighting color begins to warm, and patients or residents feel the evening settle in.

Schools, restaurants, hotels and other locations can benefit from a changing spectrum of light to set moods. Other applications might impact health and wellbeing — sending signals of the day ebbing and flowing — and possibly supporting circadian rhythms.

Now, what if one LED light could achieve these different effects — changing from warm to cool and back again?

Pathway Lighting Products, a lighting fixture manufacturer located in Old Saybrook, Connecticut, wanted to create a tunable, white LED recessed downlight for applications like this. The downlight would feature a wide range of color temperatures: from 2100K to 4300K.

For the light's engine, they worked with LED Engin, Inc., based in California's Silicon Valley. For the reflector, Pathway Lighting wanted a material that would provide reflection across the light spectrum. They reached out to Dow for recommendations to consider.

The solution

Pathway Lighting could have used traditional reflective films or reflective coated metals, but they were interested in finding a better solution, including one that could be injection molded.

"We have used reflective films, and the biggest setback for us with films is the difficulty at installation," said Jeremy Mularski, solid state lighting engineer at Pathway Lighting.

"Working with the Dow lighting experts, we found that the performance specifications and the flexibility of our selected silicone really proved to be the deciding factor," he said.

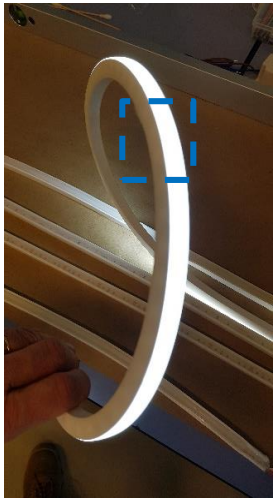
Pathway Lighting decided to make a parabolic reflector formed from SILASTIC™ MS-2002 Moldable White Reflector Silicone. This liquid silicone rubber (LSR) targets reflectivity up to 99 percent (at 630 nm), and it also delivers excellent thermal, mechanical and optical stability at temperatures as high as 150°C without yellowing or physical degradation.

"We looked at three primary areas when deciding. First, the thermal properties of SILASTIC™ MS-2002 Moldable Silicone were equal to or exceeded the temperature range of reflective films and coated metals. Second, the silicone's reflectance was the same or better than competitive reflective films and coated metals. But when it came to both flexibility of design and ease of installation, these were the silicone's main benefits on our end," said Mularski.

PATHWAY
The Lighting Source

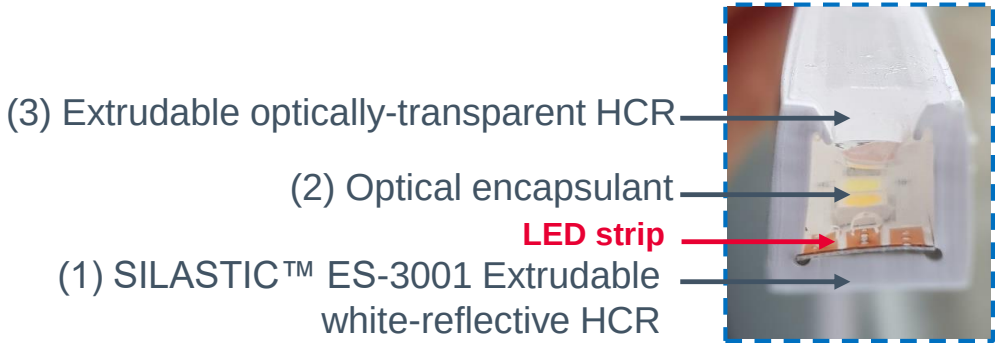
Silicones for extruded lighting applications

Novel design concept for a 3D flexible LED linear lighting device



All silicone solution

- High tensile and elongation, enabling 3D, flexible LED linear lighting design
- Heat / humidity / UV / flame resistant
- Extrusion / co-extrusion enabling continuous manufacturing (cost-effective)
- Reflectance: ≥ 97% (Lambertian distribution)



IMAGINE THE POSSIBLE APPLICATIONS WITH FLEXIBLE LINEAR LIGHTING

Targeted applications

- Flexible LED lighting fixtures
- High Ingress Protection (IP) and Impact Protection (IK) ratings
- Automotive lighting: rear-, front-, body-, interior / exterior
- Architectural lighting: RGBW LED’s colors mixing, warm to cold white
- Signaling lighting (outdoor): RGBW LED’s colors mixing, warm to cold white

FINAL REMARKS - SILICONES ADVANCE LED APPLICATIONS

Only silicones provide the design flexibility, optical performance and long-term stability in harsh environments.

SILASTIC™ MS Materials enable new lighting applications, providing many benefits:

- **Photo-thermal and environmental stability**
- **Ingress (IP) and Impact (IK) protection**
- **Design flexibility**
- **UL recognition for all products**
  - UL94, UL746C(f1)(f8)
- **Automotive recognition:**
  - AMECA (outdoor weathering), FMVSS (abrasion), SAE (impact), GMW (chemicals), Fogging
- **Efficient liquid injection molding**
- **Design flexibility in tooling and form factor**
  - Undercuts, trapped features
- **Near perfect replication of optical surfaces and features**

SILASTIC™ MATERIALS FOR OPTICS AND LIGHTING

Visit our website for more information including design examples, data sheets and case studies.

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THANK YOU

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