OPTICAL SILICONES ADVANCE
NEW LED APPLICATIONS

JAKE STEINBRECHER AND GIFFORD SHEARER

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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
• 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

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

* 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

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**

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

• Molds like LSR
• Transmits light like glass
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…
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
NEW APPLICATIONS ENABLED BY SILICONES
**CASE STUDY – ADAPTIVE DRIVE BEAM LENS**

Dark or low-lighting conditions increase likelihood of a collision

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

<table>
<thead>
<tr>
<th>Potential solution</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase roadway illumination</td>
<td>Glare and reflections, infrastructure needed</td>
</tr>
<tr>
<td>Increase high beam usage by drivers</td>
<td>Glare and concern for oncoming drivers</td>
</tr>
<tr>
<td><em>Adaptative driving beam</em> (ADB) implementation:</td>
<td>Long-range visibility without causing discomfort, distraction or glare</td>
</tr>
</tbody>
</table>

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**

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

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

![Mechanical properties chart](image-url)
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)

\[ \text{CoF} = \frac{F_f}{F_n} \]

*Collagen simulates performance on skin*  
*Glass bead is a smooth steel surface*
# SILASTIC™ Moldable Optical Silicones: Optical Properties

<table>
<thead>
<tr>
<th>Thickness (mm)</th>
<th>SILASTIC™ MS-1002 Silicone</th>
<th>SILASTIC™ MS-1003 Silicone</th>
<th>SILASTIC™ MS-4002 Silicone</th>
<th>SILASTIC™ MS-4007 Silicone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refractive index $n_D$</td>
<td>-</td>
<td>1.4134</td>
<td>1.4088</td>
<td>1.4165</td>
</tr>
<tr>
<td>Abbe number</td>
<td>-</td>
<td>52</td>
<td>51</td>
<td>52</td>
</tr>
<tr>
<td>Luminous transmittance* (%)</td>
<td>10</td>
<td>90</td>
<td>92</td>
<td>93</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>84</td>
<td>89</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>75</td>
<td>85</td>
<td>86</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>59</td>
<td>77</td>
<td>79</td>
</tr>
</tbody>
</table>

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

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DOW Consumer Solutions - Lighting - Optical Silicones
SILASTIC™ MOLDABLE OPTICAL SILICONES: LIGHT PATH LENGTH EFFECT

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

(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*
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

Total spectral transmittance – 3 mm path length

- SILASTIC™ MS-1002 Silicone
- SILASTIC™ MS-1003 Silicone
- SILASTIC™ MS-4002 Silicone
- SILASTIC™ MS-4007 Silicone

Wavelength (nm):

200 220 240 260 280 300 320 340 360 380 400

Transmittance (%):

0 10 20 30 40 50 60 70 80 90 100
Moldable Optical Silicone: Optical Stability under UV Exposure

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

![Graph](image-url)

![Diagram](image-url)
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

**MDR Profile at 150°C**

- SILASTIC™ MS-1002 Silicone
- SILASTIC™ MS-1003 Silicone
- SILASTIC™ MS-4002 Silicone
- SILASTIC™ MS-4007 Silicone
**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
**Why is reflectivity important?**

It influences light output performance of lighting fixtures.

<table>
<thead>
<tr>
<th>Reflectivity of mixing chamber</th>
<th>Remote phosphor system improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>99%</td>
<td>30%</td>
</tr>
<tr>
<td>98%</td>
<td>22%</td>
</tr>
<tr>
<td>97%</td>
<td>19%</td>
</tr>
<tr>
<td>96%</td>
<td>15%</td>
</tr>
<tr>
<td>95%</td>
<td>11%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Material</th>
<th>Reflectivity</th>
<th>Designed process</th>
</tr>
</thead>
<tbody>
<tr>
<td>SILASTIC™ MS-2002 (LSR)</td>
<td>&gt;98%</td>
<td>Injection molding</td>
</tr>
<tr>
<td>SILASTIC™ ES-3001 (HCR)</td>
<td>&gt;98%</td>
<td>Extrusion molding</td>
</tr>
<tr>
<td>SI-2001 (Ellsworth ResinLab)</td>
<td>&gt;96%</td>
<td>Spray / dip coating</td>
</tr>
</tbody>
</table>

Source: Intematix – Application Note: Mixing Chamber Design Considerations for Chromalit Remote Phosphor Light Sources
Thermal and UV Stability of SILASTIC™ MS-2002 Silicone

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

Thermally-aged reflection @ 150°C

UV-aged reflection @ 1W/m², 340 nm
Dow and Pathway Lighting developed tunable LED fixture with SILASTIC™ MS-2002 Silicone.

Link to case study
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)

1. **SILASTIC™ ES-3001** Extrudable white-reflective HCR
2. **Optical encapsulant**
3. ** Extrudable optically-transparent HCR**

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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
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.
GLOBAL TEAM READY TO COLLABORATE

Technical services and development (TS&D) support

• François de Buyl, Kevin Van Tiggelen, Martijn Beukema: Dow Silicones Belgium, Seneffe (EU)
• Jake Steinbrecher, Rachel Rademacher: Dow Silicones Midland, Michigan (US)
• Qing Shi: Dow Silicones China, Shanghai (CH)
• Osamu (Sam) Mitani: Dow Silicones Japan, Chiba (JP)
• Junghyun H. Lee: Dow Silicones Korea, Jincheon (KR)

Product development platform leader

• Vennesa Jansma: Dow Silicones Midland, Michigan (US)

Marketing

• Gifford Shearer: Dow Silicones Midland, Michigan (US)
• Mark Bradford: Dow Silicones UK Ltd. (UK)
• Yasuyuki Kubode: Dow Silicones Japan, Tokyo (JP)
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