Extracting More Light from LEDs

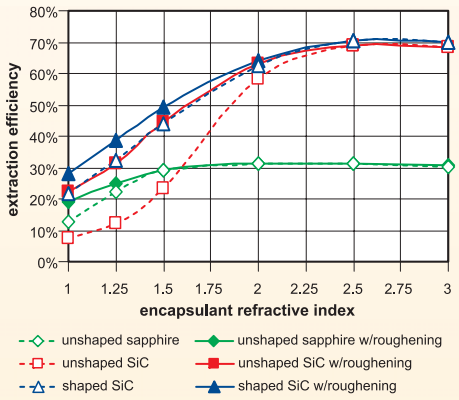
An LED's efficiency is limited by its inability to extract some of the light generated by the chip's active layer. One reason for this light loss is the refractive index mismatch between the chip and the surrounding medium. Some of the light bounces back rather than exiting the chip due to total internal reflection and Fresnel reflection. This light is then trapped and lost.

Several methods can improve the light extraction efficiency, including higher index encapsulants, shaping the LED chip, and roughening the LED's top surface.

The LRC conducted a two-part study. First, LRC researchers carried out an optical ray tracing analysis to understand what factors influence light extraction from an LED chip. Second, they conducted a laboratory study to quantify the refractive indices of commercial encapsulants commonly used in LED applications and how they vary with temperature.

Simulation setup

LRC researchers used LightTools® software to model a commercially available, high-power GaN LED chip and simulate its package conditions, such as the refractive index and position of the encapsulant, the chip's shape, the amount of surface roughening, and the substrate material. The LED's extraction efficiency was calculated under different conditions. The simulation results matched well with those from previous studies.



Extraction efficiency for three chips as a function of encapsulant refractive index with and without top surface roughening.

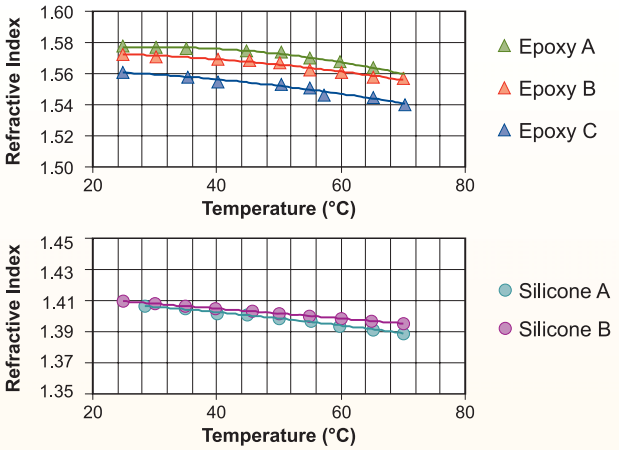
Sponsors

Corning Incorporated

New York State Foundation for Science, Technology and Innovation (NYSTAR)

Refractive index measurement setup

An Abbe Refractometer was used to study the refractive indices of three types of epoxies and two types of silicone materials. These commercial encapsulants are commonly marketed for LED applications.



Refractive index change as a function of temperature of several commercial epoxies and silicone materials commonly used as LED encapsulants.

Results

Optical ray tracing analysis showed:

- Using encapsulants with higher refractive indices, shaping the chip, or roughening the surface can improve extraction efficiency.
- Increasing the encapsulant's refractive index usually is more effective at improving extraction efficiency than chip shaping and surface roughening. However, in practice, it is difficult to find transparent encapsulants with a high index of refraction.
- LEDs with silcon-carbon (SiC) substrates show greater efficiency improvement than sapphire substrates when surface roughening and encapsulant refractive index changes are applied.

Measured values from the laboratory experiments showed that:

- Epoxies have higher refractive indices than silicone materials. While there are silicone materials on the market with higher refractive indices, the mechanical properties of these may not be suitable for LED packaging.
- Refractive index decreases with increases in temperature.

Rensselaer

View LRC Project Sheets at
www.lrc.rpi.edu/resources/newsroom/projectsheets.asp

Lighting Research Center

Lighting Research Center, Rensselaer Polytechnic Institute • 21 Union Street • Troy, NY 12180 • (518) 687-7100 • www.lrc.rpi.edu