Numerical analysis of high-index nano-composite encapsulant for light-emitting diodes

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Revolution in LED Luminous Performance

![Graph showing luminous performance over time with different lighting types](image)

- Low-Pressure Sodium (18W)
- Fluorescent (40W)
- Metal Halide (70W)
- Mercury (400W)
- Halogen (30W)
- Incandescent (60W)
- Yellow Filtered
- Red Filtered

**White LEDs (Blue LEDs + Phosphor)**

LumiLeds Lighting - A Philips Lighting and Agilent Technologies joint venture
How to improve luminous efficiency

1. Improve crystal quality
   - Reduce the non-radiative recombination.

2. Improve electrical property
   - Reduce Joule heating

3. Improve optical extraction efficiency
   - Reduce the optical loss due to internal reflection.
Internal reflection in GaN

\[ \sin \theta_c = \frac{n_1}{n_2} = \frac{1.0}{2.4} \Rightarrow \theta_c = 0.43 \text{ rad} = 24.6 \text{ deg} \]

\[ \frac{P_{\text{escape}}}{P_{\text{gen}}} = \frac{1}{2} (1 - \cos \theta_c) = 4.55\% \]
Strategies for high extraction efficiency

- Increase the Aperture Ratio ($R_a$).
- Photonic crystal surface
- **Index match** the resin with GaN ($n=2.4$).

![High index resin diagram]
How to make high index resin

Mix low index resin (n=1.4) with high index nano-particle (n=3.0).

How small should the particle be to avoid significant scattering?
Optical behavior v.s particle size

- 1 µm
- ? nm
- 1 Å

Try FDTD (Finite Difference Time Domain) to simulate the situation.
Transmission efficiency as a function of the average radius of nano-particles($r_{av}$). $a_{av}$ is adjusted at every point so that the simple average index is 2.0.