Advanced Silicone Nanocomposites: Design, Functionalization and Applications

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Background

- **1. High refractive index \((n)\)**
  - Incorporate high-\(n\) nanoparticles (NPs) into LED encapsulants to increase light-extraction efficiency

![Image of light escape cone and graph showing extraction efficiency ratio vs. encapsulant refractive index.](image)

Courtesy: Prolight Opto Technology Corporation for providing un-capped LEDs

Background

1. High refractive index \( (n) \)
   - Incorporate high-\( n \) nanoparticles (NPs) into LED encapsulants to increase light-extraction efficiency

2. Good dispersion
   - Achieve homogeneous NP dispersion within silicones to ensure high optical transparency

\[
\frac{I}{I_0} = \exp \left\{ -\frac{32\pi^4 \phi_p x r^3 n_m^4}{\lambda^4} \left[ \frac{(n_p/n_m)^2 - 1}{(n_p/n_m)^2 + 2} \right] \right\}
\]

Background

- **1. High refractive index \( (n) \)**
  ✓ Incorporate high-\( n \) nanoparticles (NPs) into LED encapsulants to increase light-extraction efficiency

- **2. Good dispersion**
  ✓ Achieve homogenous NP dispersion within silicones to ensure high optical transparency

- **3. Color conversion**
  ✓ Introduce organic-phosphor-functionalized NPs into encapsulants to tune light color

Background

High-efficient, non-scattering, color-tuned, and environmentally friendly LED encapsulants
Approach & Theory

- High-\( n \) ZrO\(_2\) nanoparticle
  - \( n \approx 2.2 \)
  - \( r \approx 1.9 \) nm

- Polymer brush
  - Grafting-to

\[
\begin{align*}
\text{or} & \quad -\text{C}^-\text{OH} \\
\text{or} & \quad -\text{P}^-\text{OH}
\end{align*}
\]

polydimethylsiloxane (PDMS)

### LED encapsulation

#### Optical properties

- **Refractive index**
  - ZrO$_2$ 1k (79 wt% core)
  - ZrO$_2$ 10k 1k (55 wt% core)
  - ZrO$_2$ 36k 10k 1k (47 wt% core)
  - Neat PDMS

- **Transmittance (%)**
  - Neat PDMS
  - ZrO$_2$ 36k 10k 1k (a)
  - ZrO$_2$ 10k 1k (b)
  - ZrO$_2$ 1k (c)

- **Thickness** ~0.5 mm
LED performance

- Light output power

- Stability test
LED performance

![Graphs showing LED performance over time for different encapsulation methods.](image-url)
Incorporation of organic phosphor

NBD (7-nitrobenzofurazan) based

\[
\text{HOOC} \quad \text{H} \quad \text{N} \quad \text{C} \quad \text{O} \quad \text{NO}_2
\]

Grafted ZrO$_2$ in CHCl$_3$

Grafted ZrO$_2$ Dye in CHCl$_3$

\begin{itemize}
  \item Free dye
  \item \(~3 \text{ dye per NP}\)
  \item \(~5 \text{ dye per NP}\)
\end{itemize}

UV/vis absorption

Normalized PL Intensity

Weight (%) vs. Temperature (°C)

Concentration (umol/L)
Color conversion

[Graph showing UV/vis Absorption vs Wavelength (nm) and normalized PL Intensity. The graph includes peaks at different wavelengths for Free dye and dye per NP (3 and 5).]

[Color plots on CIE chromaticity diagram showing points labeled 1 wt%, 3 wt%, 5 wt%, and 7 wt% for Free dye and ~3 dye per NP and ~5 dye per NP.]
Future study

- Highly reliable dyes
  - Chemical structure modification
  - Dye molecule distribution

- Optical design
  - Refractive index engineering
  - Phosphor layer configuration
Summary

✓ **High-\( n \)** ZrO\(_2\) NPs have been uniformly dispersed (up to 80 wt%) within PDMS brush polymer, and a (up to 0.2) increase in \( n \) compared to neat silicone has been achieved.

✓ **Light extraction enhancement** of nanocomposite-encapsulated red and green LEDs was observed (up to 41 %) compared to neat-silicone-encapsulated ones.

✓ The **incorporation of organic phosphors** onto PDMS-grafted ZrO\(_2\) NPs was successful, and the **multifunctional** silicone nanocomposite exhibits desired fluorescent properties for **color-converting** in LED encapsulation.

✓ With optimized stability and optical design, it is expected that the prepared nanocomposites can be used as **High-efficient, non-scattering, color-tuned, and environmentally friendly materials** for **advanced LED encapsulation**.

**QUESTIONS?**
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