# White Paper:

# Lumen Gain with Zirconia-Silicone Nanocomposites for LED Encapsulation

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**Abstract**

Pixelligent's zirconia-silicone nanocomposite materials deliver up to 7% lumen output increase to packaged LEDs over a standard methyl silicone alone in a YAG-based phosphor layer. The nanocomposite combines the benefit of high-refractive index without the need for phenyl functional groups in a silicone system and is designed for use in either spray or dispense processes. Lumen efficiency gains over a standard methyl silicone and lumen equivalence compared to a methyl phenyl silicone can be achieved with a conventional LED chip architecture, a dispensable single phosphor-silicone mixture and a hemispherical lens.

**Introduction**

The introduction of zirconia nanoparticles into silicone has been shown to increase the overall refractive index of the resulting cured nanocomposite. This represents an increase from 1.41 to 1.49 – 1.58 for methyl silicones and from 1.55 to 1.59 – 1.64 for methyl phenyl silicones at 450nm, depending on the nanoparticle loading[1,2,3]. These gains have been greatly sought after in the LED industry to extend the refractive index of methyl silicone without needing to increase the molar content of aromatic functional groups, such as phenyl, in the overall polymer. Methyl phenyl silicones have a higher RI than methyl silicones, typically greater than 1.5, but often show yellowing during aging, which both reduces the light output and shifts the color point of the white light[4]. Nanocomposites without phenyl functionality could provide longer transparency retention under photo-thermal aging with equivalent RI values to methyl phenyl silicones.

Pixelligent has developed a methyl-based silicone with zirconia nanocrystals to demonstrate lumen efficiency improvements over low refractive index methyl silicones. For example, one material system design has a low viscosity (~800cP), is compatible with dispense processes, and has transmission values comparable to standard silicones under the visible light spectrum and a refractive index of 1.54 at 450 nm (increased from 1.41) at a loading of 68 wt% zirconia.

This white paper demonstrates the benefit of one of Pixelligent's zirconia-silicone nanocomposites, dispensed and cured from a nanodispersion named PCSF, on an LED package with a hemispherical lens as compared against a commercial methyl silicone with the same YAG phosphor volume loading and at the same color point.

**Experimental**

We dispensed both a commercial methyl silicone and methyl phenyl silicone and the Pixelligent PCSF material onto blue LED packages with a single YAG phosphor under the following conditions:

- Total dispense volume: $1.45 \pm 0.24$ mm$^3$
- YAG phosphor volume loading: 5.7 to 7.3 vol%

The dispense volume was held constant while the phosphor loading was adjusted within the range in order to color-match the LED packages to within ±100K over two CCTs. Hemispherical molded silicone lenses with a refractive index of 1.40 were glued to the dispensed area after cure with an index-matching silicone adhesive for each case, as shown in Figure 1 (an adhesive with RI = 1.41 for the methyl silicone; an adhesive with RI = 1.52 for methyl phenyl silicone and PCSF). Packaged, non-encapsulated, standard, blue LED chips from Prolight Opto were used for testing.



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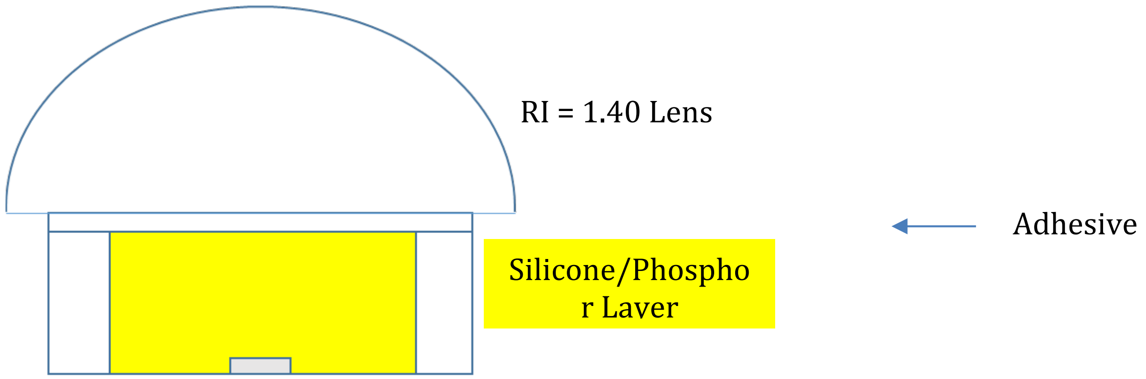


**Figure 1. Diagram showing the LED package architecture**

**Lumen Gain in a Methyl Silicone**

LED packages with PCSF material demonstrated a 6.3% lumen gain over methyl silicone alone. Figure 2 shows a scatter plot of the lumen efficiency (lumens per optical watt) of the RI = 1.41 methyl silicone and PCSF material over multiple color points (approximately 4500 – 5800K corresponds to the CCx range shown). Two colored boxes represent the chosen color points to compare the lumen efficiency of the nanocomposite to the methyl silicone. For CCT higher than 5000K (i.e. lower CCx) a close linear relationship exists for both systems. The PCSF material maintains a higher efficiency, based on average lumen efficiencies, over the methyl silicone by roughly 7%. The calculated lumens gains of the PCSF material over the methyl silicone are 6.3% (325 vs. 306 lm/W) at a CCT of 5000K. Lumen efficiency decreases to 1.8% (321 vs. 315 lm/W) for CCT values around 4700K. As phosphor concentration increases, phosphor self-absorption occurs and reduces the amount of white light that leaves the device for both packages. Overall, the higher refractive index of the PCSF in addition to the presence of the hemispherical lens has led to better white light extraction from the LED chip over that of the methyl silicone.

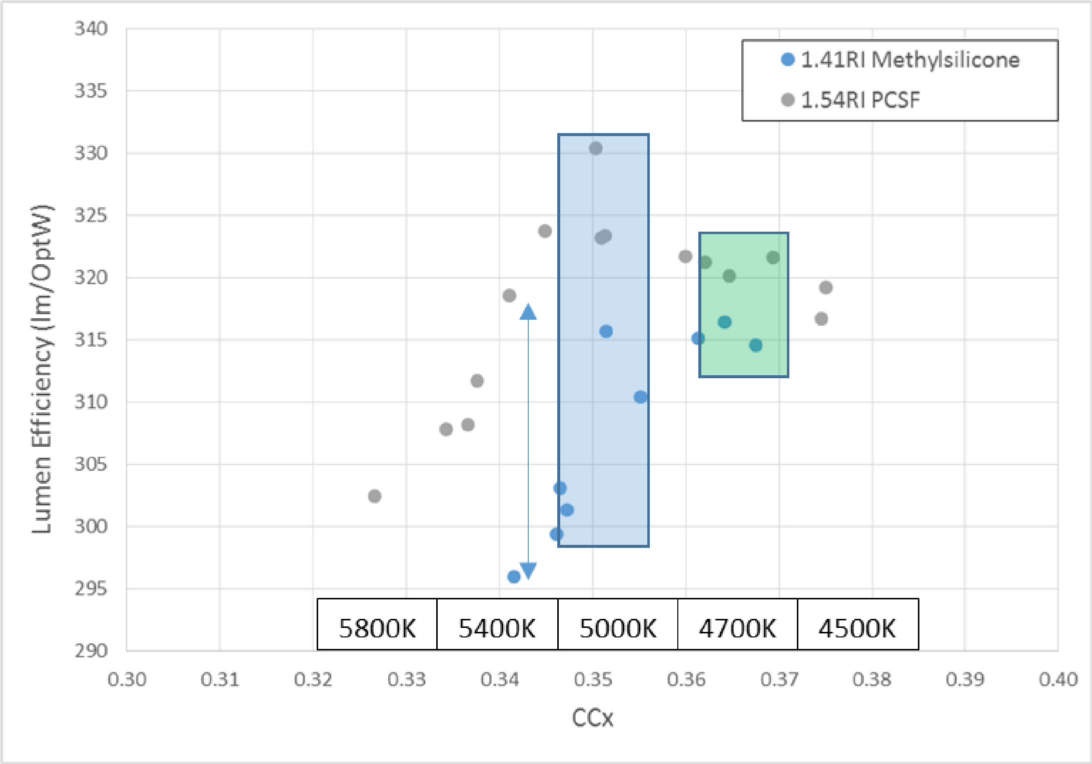


**Figure 2. Lumen efficiency versus CCx chromaticity coordinate for methyl silicone and PCSF material in a single phosphor system**

**Lumen Equivalence with Methyl Phenyl Silicone**

LED packages with PCSF material showed comparable lumen output to packages with a methyl phenyl silicone. In Figure 3, PCSF and methyl phenyl silicone are compared within the same color point range as in Figure 1. For many parts, there is good agreement in lumen efficiency at multiple color points. Again, two CCT values were chosen in order to calculate an average lumen efficiency for each silicone material. The lumen efficiency values between the PCSF and methyl phenyl silicone are within 1.7% and 1.2% of each other at roughly 5400K and 4700K, respectively. Good agreement in lumen efficiency is expected because of the similar refractive index values of each material. By removing the need for phenyl functional groups within the silicone polymer, the PSCF material shows lumen equivalence to methyl phenyl silicones and is potentially more stable in long-term reliability as a methyl-based silicone.



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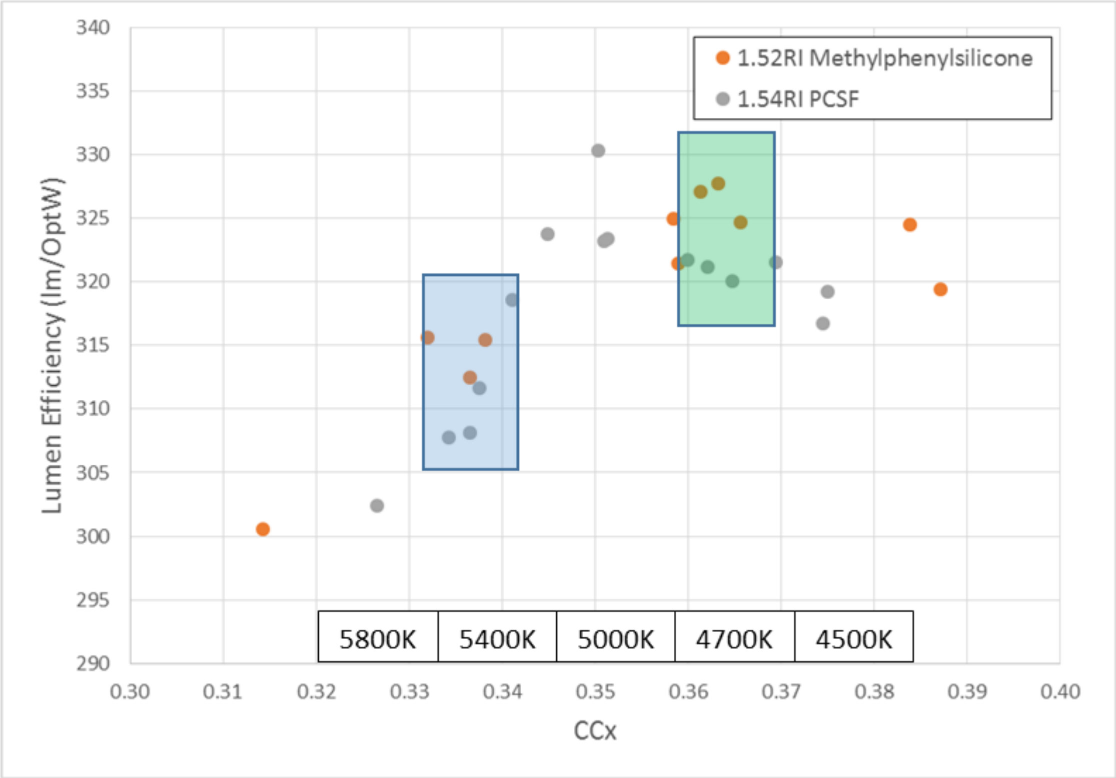


**Figure 3. Lumen efficiency versus CCx chromaticity coordinate for methyl phenyl silicone and PCSF material in a single phosphor system**

**Overall Light Output Increase**

We have demonstrated that the PCSF material, when compared against a methyl silicone, shows gains in the number of lumens per optical power for the LED device type studied. We can also illustrate that compared against the methyl silicone, the blue portion of the white spectrum for PCSF is increased because of the higher refractive index of the PCSF nanocomposite. In other words, the higher refractive index and the attached lens help to reduce total internal reflection in the LED and extract more white *and* blue light. Figure 4 displays the linear relationship of the overall blue efficiency versus CCx for all three silicones mentioned in this paper. Again, the graph illustrates that the methyl phenyl silicone and PCSF agree very closely (similar fitted slopes and intercepts), as their refractive indices are nearly identical. The methyl silicone's line is lower than the other two lines. For CCx values ranging from 0.34 to 0.37 (5250 – 4550K) the overall blue efficiency is 5.4 to 3.8% higher for the higher RI silicones over the methyl silicone.

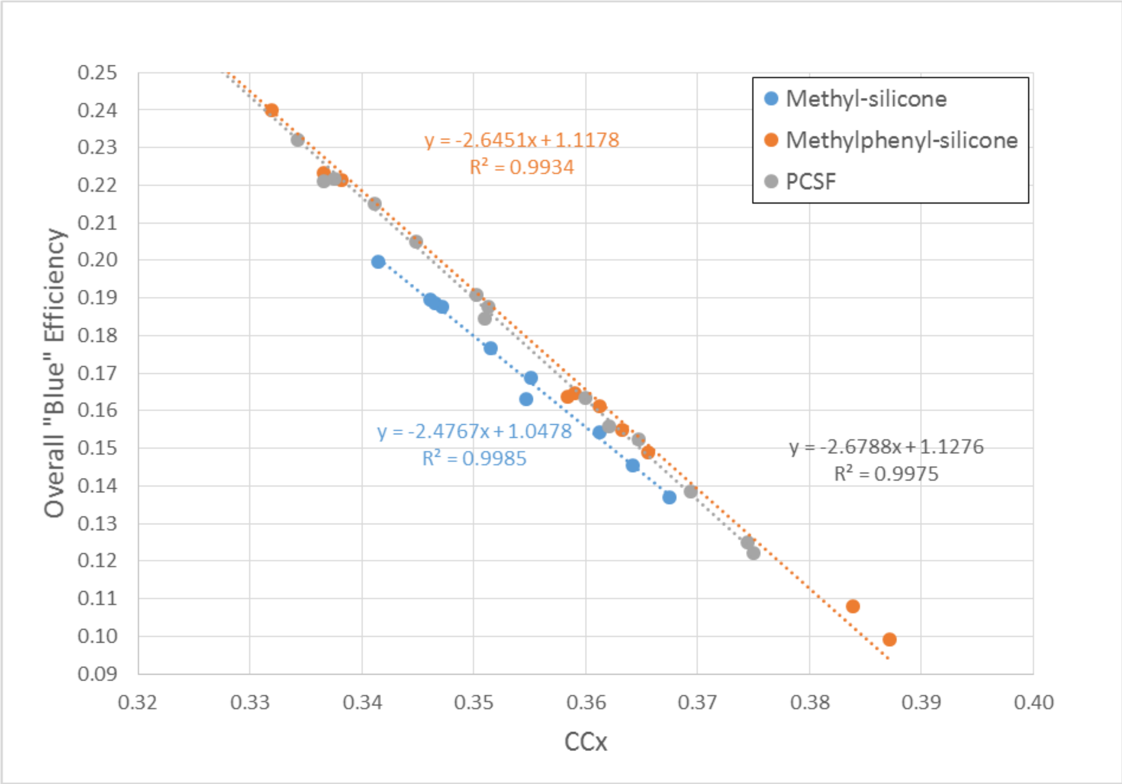


**Figure 4. Overall Blue efficiency (RF per optical watt) versus CCx chromaticity coordinate for three silicones evaluated**

**Conclusions**

Pixelligent's nanocomposite materials increase lumen efficiency and overall light output in LEDs. The PCSF material has shown comparable performance to a commercial methyl phenyl silicone in terms of lumen efficiency and overall blue efficiency over a broad color range (4200 – 5500K). Our material has also demonstrated, a significant improvement in lumen efficiency and overall blue efficiency over a commercial methyl-silicone. The lumen gains range from approximately 2 to 7%, and the overall blue efficiency were roughly 4 to 5% over the color range evaluated.

**References**

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