White Paper: Low Chromatic Aberration Nanocomposite

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Abstract

Abbe number is a parameter for understanding the degree of visual spectrum dispersion in optical materials. While Abbe number has typically been used to understand the range of effective refractive indices for glass materials, there is increased interest in replacing glass materials with transparent polymers due to their physical flexibility and ease of chemical modification. In this paper, the Abbe numbers of Pixelligent ZrO_2 nanocrystal containing composites were determined for two acrylic and two silicone based polymer systems. The effect of nanocrystal loading on transparency and Abbe number are examined and compared to similar materials from literature.

Introduction

Abbe number is an indicator of chromatic dispersion, or the wavelength dependence of a material's refractive index. Materials with high refractive indices and low chromatic aberrations are valuable for traditional optical components such as lenses, prisms, waveguides, and diffraction gratings. These properties are also important for polymer based systems such as display and flexible electronics applications.

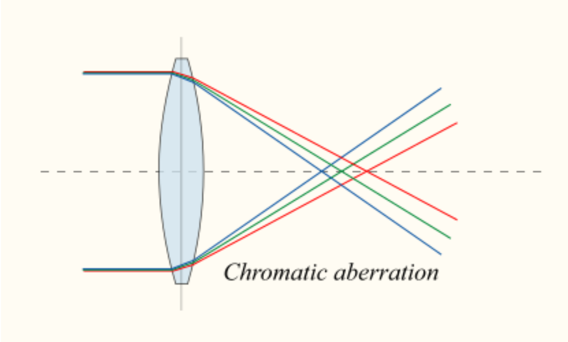

Figure 1. Chromatic aberration of a single lens causes different wavelengths of light to have distinct focal lengths.

Since the refractive indices of glasses and resins change with wavelength, engineers seeking to extract the most light from two different transparent and interfaced materials should match not only the refractive index at one part of the spectrum, but also the Abbe number. Abbe number can be modified in glass materials by adding traces of ionic, inorganic, or metal oxide compounds. Interest in reducing chromatic aberration has extended to transparent polymer systems, which offer many benefits over brittle, inert inorganic glass materials. Different approaches to reducing the chromatic aberration of polymers include hybridization with other polymers and integration with filler materials to convey superior optical performance.[1] The calculation for Abbe number is [2]:

$$V_D = \frac{n_D - 1}{n_F - n_C}$$

n_D: refractive index at 589.3 nm, n_F: refractive index at 486.1 nm, n_C: refractive index at 656.3 nm

Materials with high refractive indices generally have a lower Abbe numbers. Also, in general glass materials tend to have lower Abbe numbers compared to organic materials with similar refractive indices. Abbe numbers for typical moldable glass materials and organic materials are shown in Figure 2.

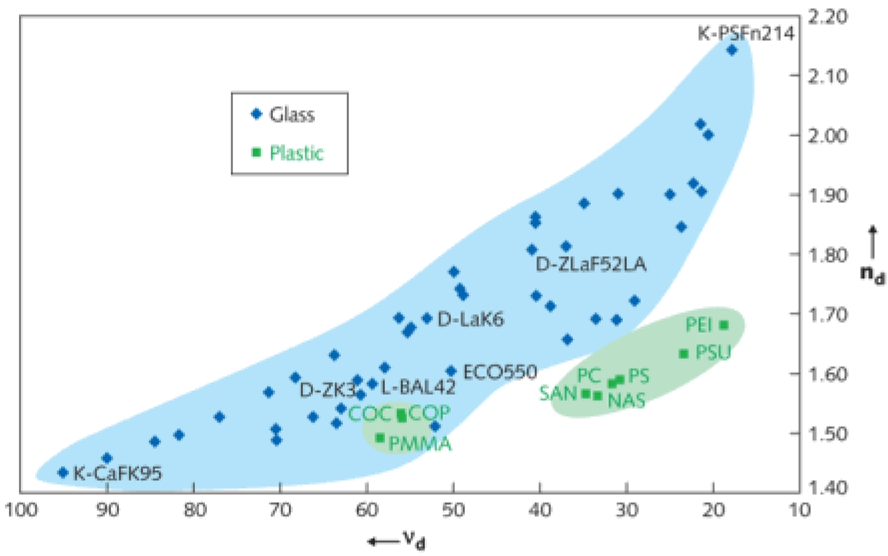

Figure 2. Abbe numbers for typical glass materials and polymeric materials [3]

Experiments

Pixelligent nanocomposite PixClear® PB was dispersed into a bisphenol dimethacrylate (BPA), and PixClear® PN was dispersed into a tri-functional methacrylate (BMT). Two experimental nanocrystal materials were dispersed into silicones. NM17 was dispersed in a commercial polymethylphenyl silicone (PMPS) and NM27A in a commercial polydimethyl silicone (PDMS). These polymers were chosen due to the relevance of acrylics and silicones in light management components. Additional details on these PixClear® materials are available at www.pixelligent.com.

Sample preparation

Each formulation was spin-coated onto glass microscope slides at corresponding spin speeds to yield 1 to 2 micron-thick films.

Instrumentation

The films were measured on a Woollam M2000 Ellipsometer over a broad range of wavelengths (190 – 1000 nm). Refractive index values were obtained at the specific wavelengths relevant to the Abbe number calculations (e.g. 486.1, 589.3 and 656.3 nm).

Results and Discussion

In general, higher nanocrystal loading leads to a lowering of the Abbe number. For the NM17 and NM27A silicone nanocomposite systems studied, the difference in Abbe number between pure polymer and 80wt% loaded nanocomposites is ~ 20%. The BPA composite showed a very small variation with increasing nanocrystal loading, while the BMT composite showed a more significant decrease in Abbe number. PCPN-BMT exhibited a 25% drop in Abbe number when nanocrystal loading was increased from 20wt% to 80wt%. The PCPB-BPA nanocomposite showed a very minor change in its Abbe number when loading was increased from 50% to 95%. While PCPB-BPA with 50% loading had an Abbe number of 35, this value decreased by only 5% at 95% loading (Figure 3.).

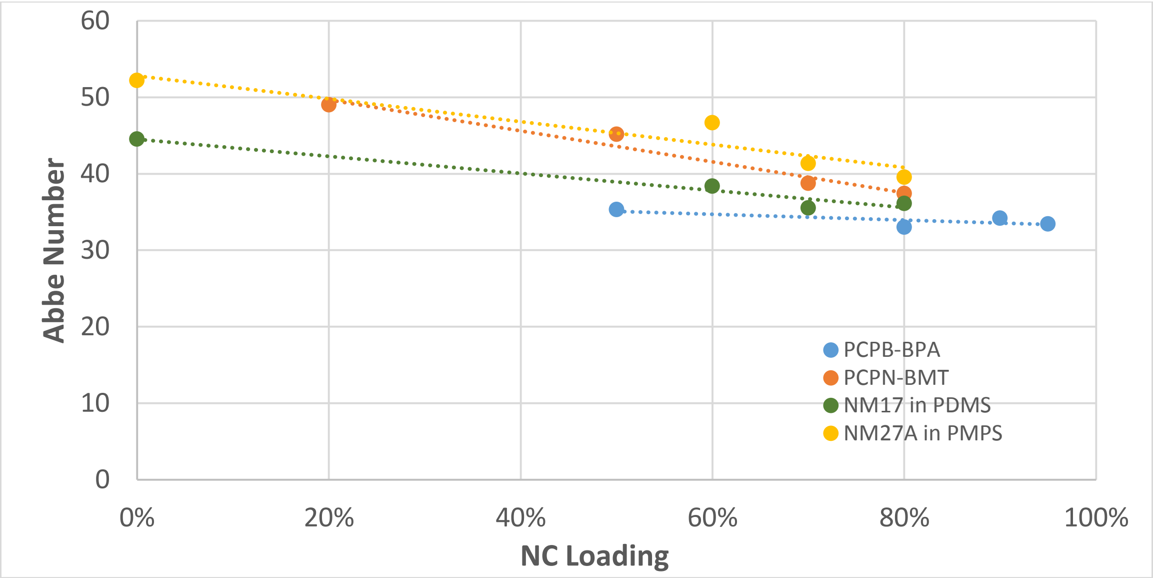

Figure 3. Abbe number was measured for four nanocomposites in different polymer systems at loadings up to 95wt% zirconia.

A study of titania nanocomposites in poly(glycidyl methacrylate) (PGMA) by Tao *et al.* found that the addition of functionalized nanofillers also caused a decrease in Abbe number. [2] While this result is generally in agreement with our study, the Pixelligent nanocomposites show less of an Abbe number decrease with higher loading compared to that observed by Tao *et al.* Their matrix material, poly(glycidyl methacrylate), was calculated to have an Abbe number of 58 in its native form, and the addition of 5nm

TiO_2 to 60wt% caused a decrease to 13.8. In Figure 4. we show the refractive indices of our four nanocomposites at the wavelengths used to calculate Abbe number.

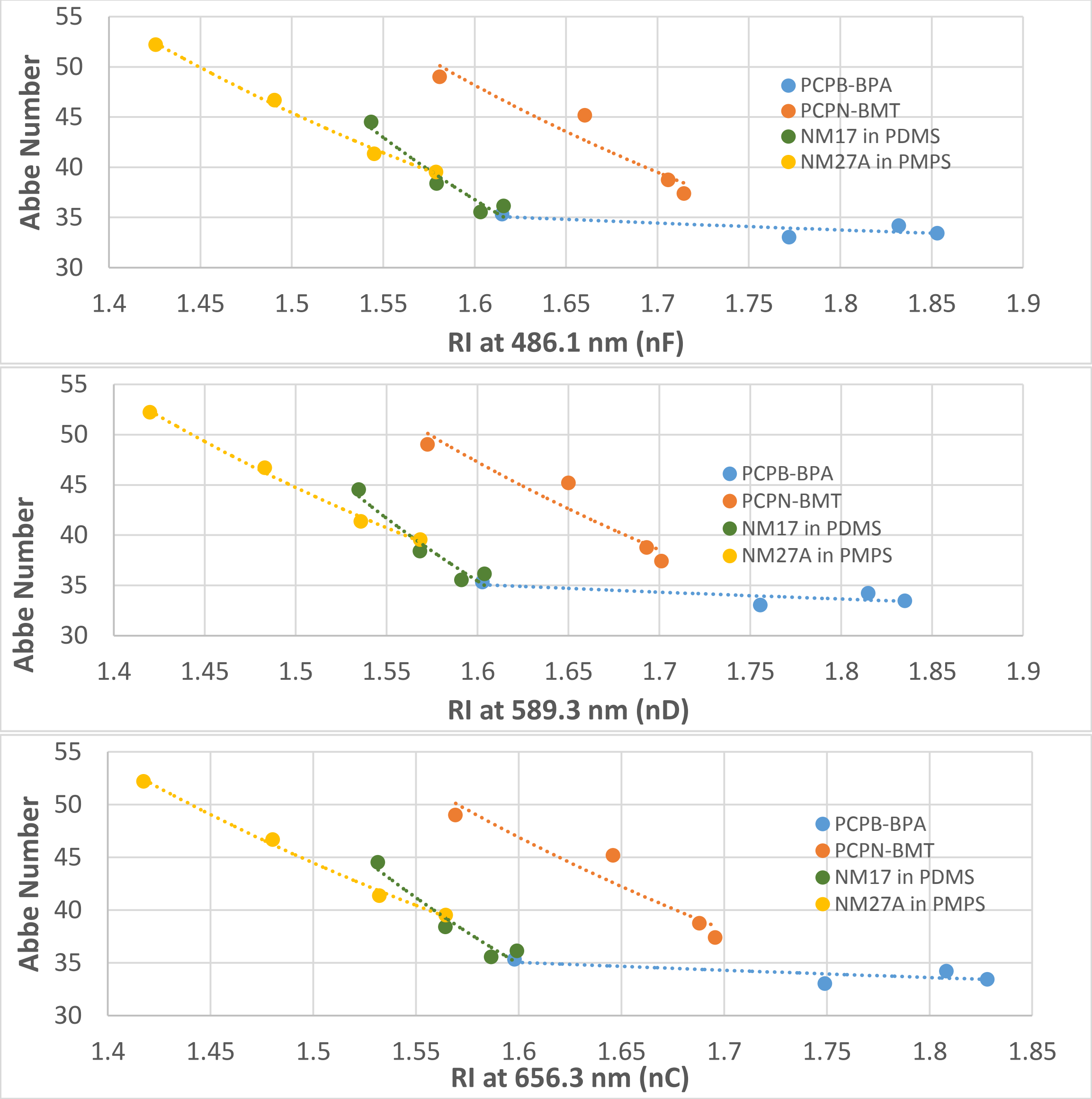

Figure 4. The Abbe number shown with respect to refractive index measured for each Pixelligent nanocomposite at three Fraunhofer spectral lines.

Chia-Liang Tsai and Guey-Sheng Liou present enhanced optical properties such as refractive index gains by inclusion of ZrO_2 nanofillers in their paper detailing the creation of polyimide/ZrO_2

nanocomposites. While showing slightly lower transmission properties and refractive indices similar to Pixelligent's at various loading, they reported Abbe numbers that were lower than Pixelligent's nanocomposites (Table 1.).[4]

Nanocomposite	Nanofiller Loading	Abbe Number	Transparency
PCPB-BPA	50wt%	35	>95%
PCPN-BMT	50wt%	45	>95%
NM17	60wt%	38	-
NM27A	60wt%	47	-
TiO_2/PGMA [4] Tao *et al.*	60wt%	14	90%
ZrO_2/PI [5] Tsai *et al.*	50wt%	32	89%
TiO_2/PI [5] Tsai *et al.*	50wt%	19	83%

Table 1. Comparison of Abbe number and transmission values for Pixelligent nanocomposites and similar materials from literature.

Pixelligent nanocomposites indicate less of an Abbe number decrease with increased nanoparticle loading, with the lowest calculated value being 33 for all nanocomposites. A potential explanation for the excellent performance of the Pixelligent materials could include the inherently high Abbe number conferred by ZrO_2. Thin films of pure ZrO_2 have an Abbe number of 38.2 while TiO_2 thin films have an Abbe number of 18.3. [4]

Pixelligent nanocomposites PCPN-BMT and PCPB-BPA were measured for their transmission across the UV/visible spectrum. Compared to literature values, the Pixelligent materials have a significantly better profile of light transmission.[4] At 450nm, Tsai and Liou report a transmission of 94% for their 50wt% loaded 500 nm thick polyimide/zirconia material. At the same zirconia loading, Pixelligent's PCPN-BMT material showed 96% transmission and Abbe number of 45, and PCPB-BPA showed a 98% transmission and Abbe number of 35. Both Pixelligent materials were measured to be 1µm thick.

Figures 5 and 6 show the visible transmission of the two acrylic nanocomposites at four loadings for films that are 1µm thick. The ripples are caused by interference between incoming and reflected light, commonly observed when measuring the transmittance of high quality optical thin films. Thin films of

Pixelligent nanocomposite materials PCPB-BPA and PCPN-BMT generally exhibit transmission over 95% in the range 400-800 nm in nanocomposites exceeding 80% loading by weight.

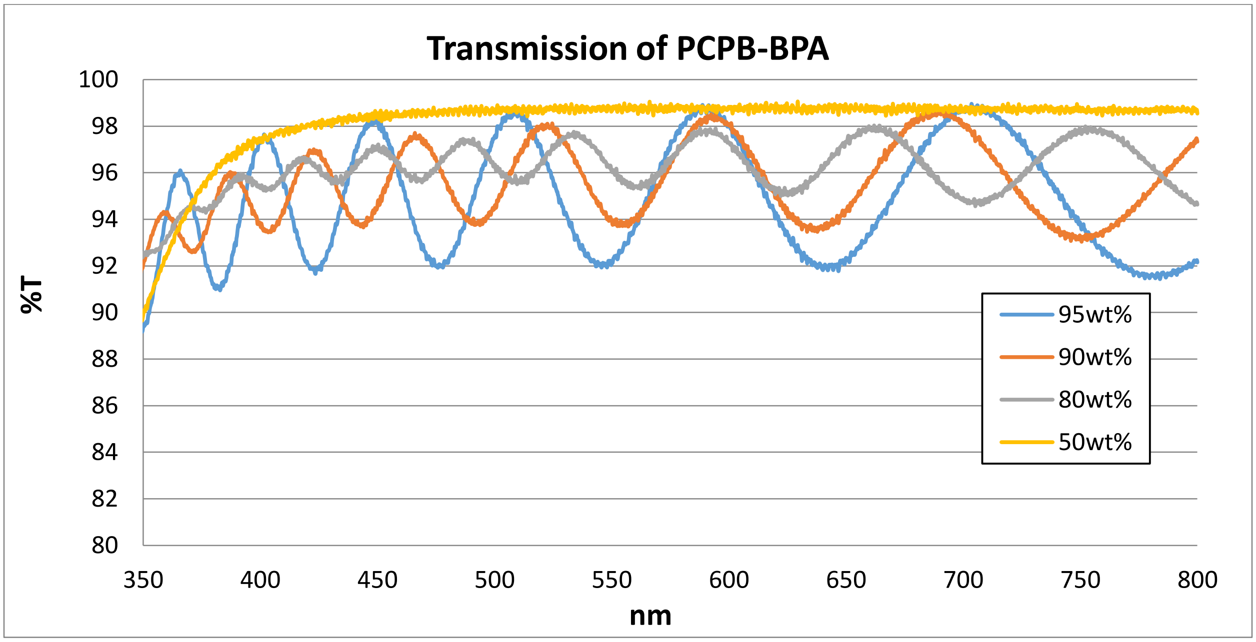

Figure 5. Transmission spectra of PCPB-BPA at various nanocrystal loadings.

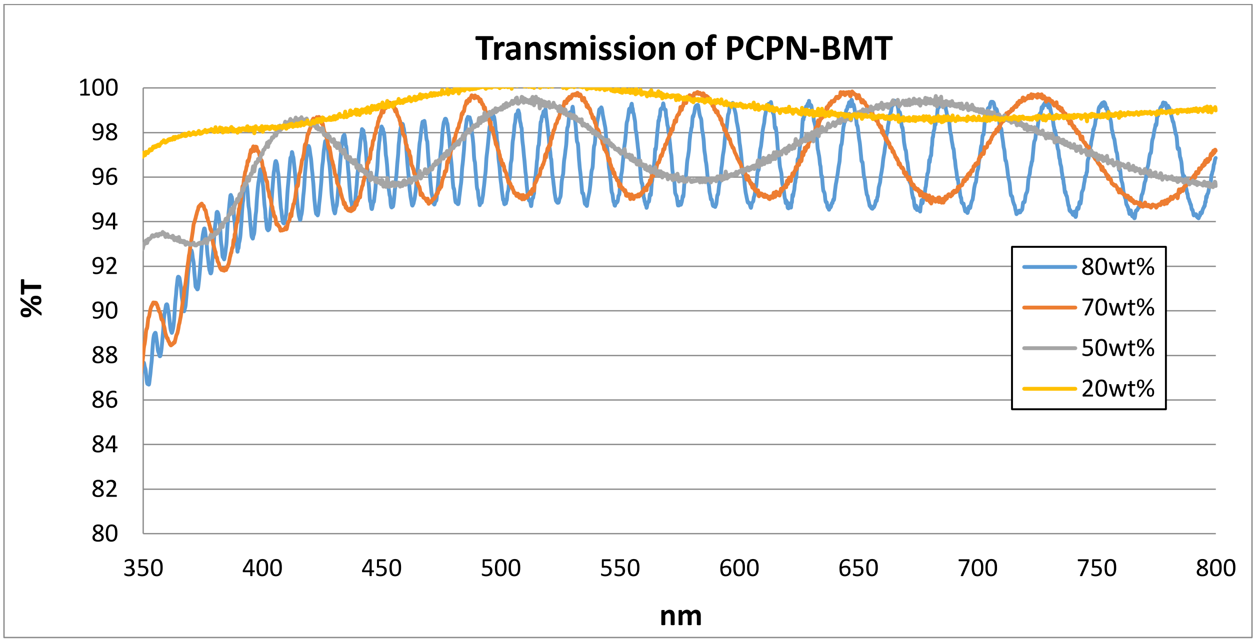

Figure 6. Transmission spectra of PCPN-BMT at various nanocrystal loadings.

Conclusions

In the Pixelligent nanocomposites that were tested Abbe number decreases slightly with increasing loadings of surface-modified zirconia nanocrystals. The silicone-ZrO_2 nanocomposites tested, NM17 and NM27A, have similar trends in decreasing Abbe number, with the dimethyl silicone-ZrO_2 nanocomposite NM17 showing the least chromatic dispersion of the two. PCPB-BPA, shows the least decrease in Abbe number with the addition of nanocrystals. The PCPB-BPA nanocomposite shows virtually no decrease in between 50wt% and 95wt% loading and corresponds to a refractive index range of 1.60-1.83. The 20wt% PCPN-BMT nanocomposite exhibited the greatest Abbe number of 45. This nanocomposite is more than 98% transparent and has a 1.57 RI at 589 nm.

Zirconia nanofillers are a promising additive for increasing the refractive index of polymeric materials, while maintaining transparency and minimizing the effect on native Abbe number.[5] Compared to commonly used titania containing nanocomposites and other zirconia nanocomposites from literature, Pixelligent's nanocomposites demonstrate high transmittance, low haze, and high optical clarity while increasing the refractive index with minimum impact on Abbe number.

Acknowledgements

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References

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