Optical Glass: Substitutes Versus Equivalents

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This paper details the motivation for selecting alternate optical materials within an established design and offers considerations when doing so.

EXCHANGING OPTICAL MATERIALS

Selecting the material from which a lens is to be made is a fundamental design consideration[1]. A chosen material represents the optimum balance of optical and physical attributes going far beyond index and dispersion. Thermal and mechanical effects and index over the wavelength range used must be considered.

Considering all of the factors that influence material selection, the fabricator strives to honor the designer's selection. Occasionally situations may arise preventing the selected material from being used. The material may no longer be produced, or the material may be unavailable within the allocated manufacturing time. When these cases arise, an alternate material will need to be identified. The material may be an equivalent (within acceptable performance tolerance) or a substitute (outside tolerance for one or more attributes) material. Equivalents are able to be incorporated while keeping desired optical performance, and substitutes would likely require adjustment within the design.

SELECTION CONSIDERATIONS - OPTICAL

When switching materials, primary concern must lay with the optical performance. If the lens will no longer function as intended the material change cannot be made. When a material must be exchanged a replacement material with the same international (six-digit) code is a good starting point[2]. However, it is not sufficient to stop there[3]. Below are some additional considerations when switching.

Refractive Index

Partial dispersion is a key to identifying the possibility of equivalent materials. Glasses with large partial dispersions behave in an abnormal manner[4], and it is likely there is no equivalent for them. In the visible region $\Delta P_{g,F}$ is of specific importance because this represents the combination of shortest visible wavelengths, and the deviation from the "Normal Line" is most exaggerated. Consider the deviations shown in Figure 1, comparing abnormal (n-KzFS2) with normal (n-BaLF5) glasses of similar n_d and νd. The deviation in $\Delta P_{g,F}$ is 27x larger for the abnormal material. Accordingly, the abnormal material has no known equivalent, making availability an issue.

Deviation of Relative Partial Dispersions ΔP from the "Normal Line"	
$\Delta P_{C,t}$	0.0161
$\Delta P_{C,s}$	0.0066
$\Delta P_{F,e}$	-0.0007
$\Delta P_{g,F}$	-0.0004
$\Delta P_{i,g}$	

N-BALF5
547536.261

Deviation of Relative Partial Dispersions ΔP from the "Normal Line"	
$\Delta P_{C,t}$	0.0636
$\Delta P_{C,s}$	0.0280
$\Delta P_{F,e}$	-0.0044
$\Delta P_{g,F}$	-0.0111
$\Delta P_{i,g}$	-0.0440

N-KZFS2
558540.255

Figure 1

If a system is to be used over a range of temperatures the change in refractive index with temperature (dn/dT) needs to be evaluated as well. For example, on the basis of international code, the indices of Schott n-SF10 and Ohara S-TIH 10 at the traditional F-d-C lines and $\Delta P_{g,F}$ make these glasses appear to be equivalent. However, when one considers the difference in dn/dT it is clear the two glasses are not equivalent; the dn/dT can vary by up to a factor of five, changing sign in some cases.

Transmission

Depending on the wavelength range of use there may be shortcomings even between glasses of identical international code. The dense flint family of glasses (Schott SF, Ohara PBH) shows considerably more transmission in the blue and ultraviolet than the corresponding lead-free versions (Schott SFL or n-SF, Ohara S-TIH). For example, at 365nm a 10mm thick SF6 sample transmits ~25% of incident light, while n-SF6 transmits 4%. If performance in the blue and UV region is critical this material exchange cannot be made.

Poor transmission may be indicated indirectly. IR-grade fused silica (e.g., Infrasil), for example, has good transmission (low absorption) at 3.39 µm due to the lack of O-H bonds. Normal fused silica has O-H bonds and an absorption band (poor transmission) in the neighborhood of 3.39 µm and would be a poor substitute at this wavelength.

Internal Quality

Optical materials may also have specifications covering internal quality. It may be impossible to get certified material and meet delivery deadlines. Stress birefringence, bubble content, striae and homogeneity all can be tested and quantified, but it adds cost and takes time. Homogeneity testing for example typically adds about a week to delivery. Also, even the highest grade materials may not be good enough to meet required material specifications, or material of the needed quality may simply be unavailable due to limited supply. In the latter case, it may be months for the next batch of material to be available.

SELECTION CONSIDERATIONS - PHYSICAL

Once the optical considerations have been accounted for, the physical properties may show a change in material is not possible. Below are some considerations about physical properties.

Raw Material Size Limits

Suitable material for large diameter (>200mm) or thick (>25mm) lenses may prove scarce. Manufacturers make raw materials in a variety of sizes, and large strips have more limited availability than smaller strip.

Switching between material manufacturers may also prove problematic. Equivalent materials come in different width or thickness depending on the manufacturer.

Density

Selecting on the basis of international code only, SF6 and SFL6 would appear interchangeable. However, SF6 is ~54% more dense. If weight is a consideration this exchange may not be possible.

Thermal Expansion

Thermal expansion can also vary significantly (>10%) when moving between materials of identical six digit codes. This is true for materials of different manufacturers (Schott n-SF10 versus Ohara S-TIH 10) and of the same manufacturer (Schott SF6 versus SFL6). Similar to dn/dT, thermal expansion can be an issue in systems that operate over a range of temperatures. A system which is athermal using the initial design may not be athermal once a material has been switched, and, depending on the lens mounting scheme, the result of introducing a lens element with different thermal behavior could be catastrophic.

Hardness/Abrasion Resistance

Materials with identical six digit codes may have distinctly different hardnesses or abrasion resistances. This will effect polishing times and may effect yields, both of which have direct influence on costs. The fabricator may propose switching materials to meet cost and delivery objectives by moving to more favorable materials.

OTHER SELECTION CONSIDERATIONS

There are still more considerations made when fine tuning a decision to exchange one material for another. Below are some final items for consideration.

Chemical Resistance

Similar materials can exhibit different resistances to chemical attacks like staining. Schott n-SK2 (607567) appears similar to Ohara S-BSM 2 (607568) on the basis of international code, but differs greatly when looking at chemical properties. S-BSM 2 offers improved climate resistance, but has a heightened acid sensitivity. Given the intended use environment this may influence preference.

Price

Glasses of similar or identical six digit code may offer tolerable or indistinguishable differences in performance, but price can differ drastically. In some cases a comparable material may be 3 to >10x in price per unit weight depending on the manufacture, and the difference in price can play a large role in considering a material exchange. However, remember the gains may be offset due to increased polishing time or a decrease in yield resulting from changes in other characteristics detailed earlier[5].

CONSIDERATIONS FOR THE OPTICAL DESIGNER

There will be situations where the optical material chosen in the design is no longer available or is not available in the time allotted, and the designer may be asked to exchange materials. The material may be an equivalent (within acceptable performance tolerance) or a substitute (outside tolerance for one or more attributes) material relative to the original selection. Looking at international codes alone is not enough, and considerations relative to optical and physical characteristics of the alternate material plus project requirements need to be examined.

Stating requirements on the drawing, “NO SUBSTITUTES ALLOWED or “n-BK7 or S-BSL 7 permitted” is a good way towards making intentions clear. Additionally, the manufacturer should seek permission before exchanging materials. Fully collaborating with the manufacturer and considering the implications of exchanging material in a system will allow the designer to make informed decisions that balance performance against constraints.

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[1] W.J. Smith, *Modern Lens Design*, Pg 31, McGraw Hill, New York City, 2005
[2] R.R. Shannon, *The Art And Science Of Optical Design*, Pg 143, Cambridge University Press, England, 1997
[3] R.E. Fischer, B. Tadic-Galeb, P. Yoder, *Optical System Design*, Pg 480, McGraw Hill, New York City, 2008
[4] T.S. Izumitani, *Optical Glass*, Pg 150, American Institute of Physics Translation Series, New York City, 1986
[5] R.E. Fischer, B. Tadic-Galeb, P. Yoder, *Optical System Design*, Pg 483, McGraw Hill, New York City, 2008