

tons, 2nd ed. (Springer-Verlag New York, 1984), pp. 129–135, which is incorporated herein by reference,

$$\epsilon_{ij}(q, \omega) = \epsilon(\omega) \delta_{ij} + \sum_k \alpha_{ijk}(\omega) q_k q_l \dots \quad (1)$$

where δ_{ij} is Kronecker's δ . The product $q_k q_l$ and symmetry of ϵ_{ij} show that α_{ijkl} is symmetric under interchanges $i \leftrightarrow j$ and $k \leftrightarrow l$. Further, cubic symmetry reduces the number of independent components to the 3 familiar from elasticity theory of H. J. Juretschke, *Crystal Physics* (Benjamin, London, 1974), Sections 4.2 and 11.2, which are incorporated herein by reference. An isotropic system permits two independent tensor components. One component represents an inconsequential change in $\epsilon_{ij}(q, \omega)$ proportional to q^2 ; the other represents an isotropic longitudinal-transverse splitting. The third component that exists in a cubic system (but does not exist in an isotropic system) determines all observable anisotropies. Only this component need be considered. The related tensor elements, α_{1111} , α_{1122} , and α_{2323} , appear in the ratio 2:-1:-1, and this determines the angle dependence. For $\hat{q}=(1,1,0)/2^{1/2}$ the scaled eigenvalues of the contracted tensor $\sum_k \alpha_{ijkl} q_k q_l$ are 3/2 and -1 for the transverse $[\bar{1}10]$ and $[001]$ directions, respectively. Measuring the associated birefringence for one propagation direction determines the magnitude of the anisotropic response of the crystal for all propagation directions. The magnitude of the intrinsic birefringence in all directions is scaled by a single parameter. Nulling out this single parameter, eliminates the intrinsic birefringence for all propagation directions.

The x value of the mixed solid solutions $Ca_{1-x}Sr_xF_2$ and $Ca_{1-x}Ba_xF_2$ that nulls out the birefringence are predicted approximately by Equation 2:

$$i, x = \Delta n(CaF_2) / [\Delta n(CaF_2) - \Delta n(YF_2)], Y = Sr, Ba \quad (2)$$

The value obtained for $Ca_{1-x}Sr_xF_2$ and $Ca_{1-x}Ba_xF_2$ near 193 nm and 157 nm are shown in table 2.

As indicated above, these values assume a linear relation between the composition ratio and the birefringence parameter. Actually our calculations show that there is a small nonlinearity in this relationship, and thus a bowing in the composition/birefringence curves. Equation 1 is thus only approximately valid, and the exact nulling ratios must be determined by measurement on the prepared crystals. FIG. 2 shows calculations of the wavelength position of the birefringence null of $Ca_{1-x}Sr_xF_2$ for different values of Sr fraction x.

TABLE 2

Material	Nulls Intrinsic Birefringence at 193 nm	Nulls Intrinsic Birefringence at 156 nm
$Ca_{1-x}Sr_xF_2$	$Ca_{0.66}Sr_{0.34}F_2$	$Ca_{0.34}Sr_{0.66}F_2$
$Ca_{1-x}Ba_xF_2$	$Ca_{0.85}Ba_{0.15}F_2$	$Ca_{0.75}Ba_{0.25}F_2$

It has previously been shown that such mixed solid solutions of CaF_2 , SrF_2 , and BaF_2 can be grown as a single crystal. For example E. G. Chernevskaya and G. V. Anan'eva, "Structure of Mixed Crystals Based on CaF_2 , SrF_2 , and BaF_2 ," Soviet Physics-Solid State 8, pp. 169–171 (1966) and separately R. K. Chang, Brad Lacina, and P. S. Pershan, "Raman Scattering from Mixed Crystals ($Ca_xSr_{1-x}F_2$ and $(Ca_xSr_{1-x})F_2$)," Phys. Rev. Lett. 17, pp. 755–758 showed that $Ca_{1-x}Sr_xF_2$ formed single crystal solutions with the fluorite (CaF_2) crystal structure for all ratios of components and $Ca_{1-x}Ba_xF_2$ formed single crystal solutions with the fluorite (CaF_2) crystal structure at least when

the composition of the components is low. The indices of CaF_2 and SrF_2 are fairly similar, e.g., $n(CaF_2)$ near 157 nm=1.559 and $n(SrF_2)$ near 157 nm=1.576, a 1% difference as was demonstrated in John H. Burnett, Rajeev Gupta, and Ulf Griesmann, "Absolute refractive indices and thermal coefficients of CaF_2 , SrF_2 , BaF_2 , and LiF near 157 nm," Applied Optics 41, pp. 2508–2513 (2002). This means that the index of the mixture $Ca_{1-x}Sr_xF_2$ is relatively insensitive to unavoidable concentration gradients. Thus the material could have fairly uniform index, an important requirement for precision optics.

In addition to Ca, Ba, and Sr of the present mixed solid solution composition, some fraction of Mg can be introduced in the mixed solid solution to provide a composition having the form, e.g., $Ca_{1-x-y}Ba_xMg_yF_2$ or $Ca_{1-x-y}Sr_xMg_yF_2$, without altering the cubic crystal structure. As shown in FIG. 2, Mg makes a negative contribution to the intrinsic birefringence, as long as the concentration is low enough that the material retains cubic structure. This increases the range of alloys available for intrinsic birefringence compensation.

The introduction of Mg into the $Ca_{1-x}Ba_xF_2$ growth melt enables higher solid solubilities of Ba in $Ca_{1-x}Ba_xF_2$. The higher solid solubilities is provided by Mg having a smaller ionic radius compared to that of CaF_2 . Thus, Mg will compensate for the larger radius of BaF_2 compared to that of CaF_2 to thereby enable higher solid solubilities of Ba in $Ca_{1-x}Ba_xF_2$.

By introducing quaternary alloys, e.g., $Ca_{1-x-y}Sr_xBa_yF_2$ or $Ca_{1-x-y}Sr_xMg_yF_2$ or $Ca_{1-x-y}Ba_xMg_yF_2$, a broadband minimization of the intrinsic birefringence is possible. Appropriate values of x and y are chosen to minimize the intrinsic birefringence within the UV range such as, for example, the UV wavelengths of 193 nm and 157 nm. FIG. 3 shows calculations of the intrinsic birefringence of BaF_2 , SrF_2 , CaF_2 , and the quaternary mixed solid solution $Ca_{0.6}Sr_{0.3}Ba_{0.1}F_2$. The quaternary mixed solid solution shows a broadband minimization of the intrinsic birefringence, with an absolute maximum value of 1.85 between 157 nm and 193 nm.

Further, the freedom to null out the birefringence for different x and y values enables the creation of intrinsic-birefringent-free materials with different indices and dispersions. Optics with nulled birefringence from a family with distinct (x, y) values or for from different families can be combined for correction of chromatic aberrations (the minimizing the derivative of the index of refraction with respect to source wavelength) due to the different index properties.

Although the invention has been described above in relation to preferred embodiments thereof, it will be understood by those skilled in the art that variations and modifications can be effected in these preferred embodiments without departing from the scope and spirit of the invention.

What is claimed is:

1. A composition comprising a mixture of CaF_2 crystal and a second alkaline earth fluoride having spatial dispersion induced birefringence opposite to the birefringence of the CaF_2 crystal the CaF_2 crystal and the second crystal being present in amounts such that composition has minimal spatial dispersion induced birefringence at a selected wavelength within the UV range and said composition further comprising Mg.

2. The composition of claim 1, wherein the composition is in the form $Ca_{1-x-y}Ba_xMg_yF_2$.

3. The composition of claim 1, wherein said second crystal is SrF_2 .