Photonics

Lecture 7

Modulation of light Birefringence

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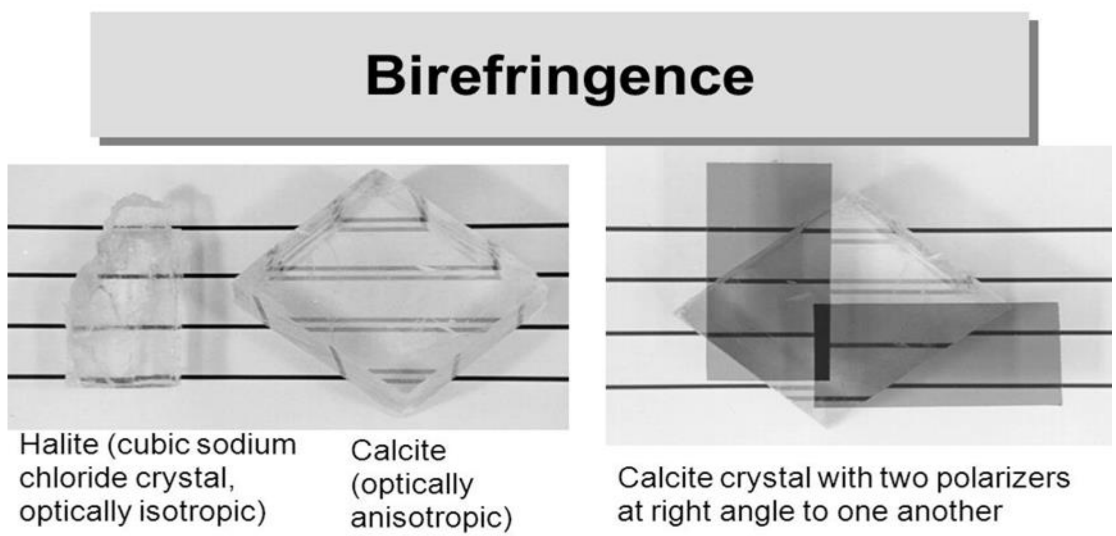
Birefringence

is the optical property of a material having a refractive index that depends on the polarization and propagation direction of light. These optically anisotropic materials are said to be birefringent (or birefractive). The birefringence is often quantified as the maximum difference between refractive indices exhibited by the material. Crystals with non-cubic crystal structures are often birefringent, as are plastics under mechanical stress.

Birefringence is responsible for the phenomenon of double refraction whereby a ray of light, when incident upon a birefringent material, is split by polarization into two rays taking slightly different paths.



Uniaxial materials

The simplest type of birefringence is described as uniaxial, meaning that there is a single direction governing the optical anisotropy whereas all directions perpendicular to it (or at a given angle to it) are optically equivalent. Thus rotating the material around this axis does not change its optical behaviour. This special direction is known as the optic axis of the material. Light propagating parallel to the optic axis (whose polarization is always perpendicular to the optic axis) is governed by a refractive index n_o (for "ordinary") regardless of its specific polarization.

For rays with any other propagation direction, there is one linear polarization that would be perpendicular to the optic axis, and a ray with that polarization is called an ordinary ray and is governed by the same refractive index value n_o However, for a ray propagating in the same direction but with a polarization perpendicular to that of the ordinary ray, the polarization direction will be partly in the direction of the optic axis, and this extraordinary ray will be governed by a different, direction-dependent refractive index. Because the index of refraction depends on the polarization when unpolarized light enters a uniaxial birefringent material, it is split into two beams travelling in different directions, one having the polarization of the ordinary ray and the other the polarization of the extraordinary ray.

The ordinary ray will always experience a refractive index of n_o, whereas the refractive index of the extraordinary ray will be in between n_o and n_e, depending on the ray direction as described by the index ellipsoid. The magnitude of the difference is quantified by the birefringence

$$\Delta n = n_e - n_o \, .$$

Biaxial materials

These are characterized by three refractive indices corresponding to three principal axes of the crystal. For most ray directions, both polarizations would be classified as extraordinary rays but with different effective refractive indices.

The two refractive indices can be determined using the index ellipsoids for given directions of the polarization. Note that for biaxial crystals the index ellipsoid will not be an ellipsoid of revolution ("spheroid") but is described by three unequal principle refractive indices $n\alpha$, $n\beta$, and $n\gamma$. Thus there is n_o axis around which a rotation leaves the optical properties invariant (as there is with uniaxial crystals whose index ellipsoid is a spheroid).

Additionally, there are two distinct axes known as optical ray axes or biradials along which the group velocity of the light is independent of polarization.

Positive or negative

Uniaxial birefringence is classified as positive when the extraordinary index of refraction n_e is greater than the ordinary index n_o. Negative birefringence means that $\Delta n = n_e - n_o$ is less than zero. In other words, the polarization of the fast (or slow) wave is perpendicular to the optic axis when the birefringence of the crystal is positive (or negative, respectively).

In the case of biaxial crystals, all three of the principal axes have different refractive indices, so this designation does not apply. But for any defined ray direction one can just as well designate the fast and slow ray polarizations.