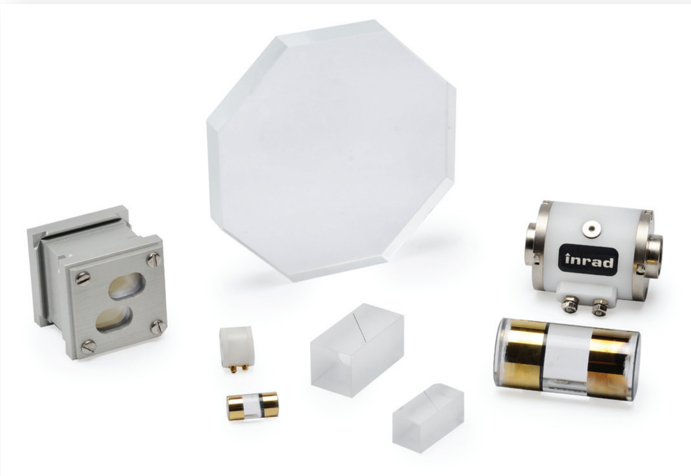
Inradoptics

Understanding Electro-optic Behavior



ELECTRICAL CONFIGURATIONS

The configuration of the Pockels cell can be such that the electrical field is applied either longitudinally along the propagation direction of the light beam or transversely to it. Because of crystal symmetry and the desire for the light beam to experience no birefringence in the absence of an electric field, most KD*P Pockels cells are longitudinal-field devices all $LiNbO_3$ and BBO Pockels cells are transverse-field devices.

Pockels cells can be configured to appear either as a capacitive load or as a portion of a coaxial transmission cable. Most INRAD Pockels cells are configured as capacitive loads with a typical capacitance of about 10 pF; the exact specifications can be found below. However, an impedance-matched design, the PKCM02, offers the advantage of being able to transmit a high voltage pulse or pulse sequence down a piece of transmission cable and have the voltage faithfully applied to the electrodes of the Pockels cell with subnanosecond rise and fall times.

PHASE RETARDATION

Pockels cell alters the polarization of a transmitted light beam when voltage is applied to the cell by causing a phase retardation between orthogonal polarization components of the beam.

In the absence of an applied field, there is no difference in the phase retardation between orthogonal polarization components of the light beam because the refractive index is the same for both polarization directions and so there is no polarization change in the transmitted light. However, an applied electric field creates fast and slow axes at 90 degrees to one another. The difference in velocity for beams with polarization components along these two directions, with voltage applied, retards the phase of one polarization component relative to the other thereby changing the polarization state of the emerging beam.

The relative phase retardation, Γ, is given by the following expression,

$$\Gamma = 2\pi \, \Delta n \, l / \lambda$$

Here, Δn is the birefringence (the difference in refractive index for the two polarizations of light), l is the crystal length, and λ is the wavelength of light that is being used.

LIGHT INTENSITIES

The emerging intensities of light with polarization directions along orthogonal directions is dependent on the size of Δn. For linearly polarized light that is incident at 45° to the fast and slow axes of the Pockels cell, the transmitted intensity with the same polarization direction as the incoming light, which is the intensity that would be transmitted through a parallel polarizer, is given by the expression for $T_{||}$; the intensity that would be transmitted through a crossed polarizer is given by the expression for $T_{\perp}$.

$$T_{||} = \cos^2 (\Gamma / 2) = \cos^2 (\pi \Delta n \, l / \lambda)$$
$$T_{\perp} = \sin^2 (\Gamma / 2) = \sin^2 (\pi \Delta n \, l / \lambda)$$

In general, the transmitted light is elliptically polarized. For the special case when the retardation Γ is $\pi/2$, or the quarter-wave value, the transmitted light is circularly polarized; when the retardation Γ is π, which is the half-wave retardation value, the polarization of the transmitted light is rotated by 90°.

The expression that relates Δn to the electric field for INRAD Pockels cells is of the form below.

$$\Delta n = r_{ij} E n_o^3$$

where r_{ij} is either the electro-optic coefficient r_{63} for KDP or the electro-optic coefficient r_{22} for $LiNbO_3$ or BBO, E is the electric field that is experienced by the crystal with the application of an applied voltage V, and no is the ordinary refractive index. Here, Δn is the induced birefringence due to the increase in refractive index for light polarized along the slow axis by $\Delta n/2$ and the decrease in refractive index for light polarized along the fast axis by $\Delta n/2$.

For the longitudinal configuration used with KD*P Pockels cells, E = V / l, where V is the applied voltage and l is the crystal length.

$$\Delta n = r_{63} E n_o^3$$

$$\Delta n = r_{63} V n_o^3 / l$$

$$\Gamma = 2\pi \Delta n \, l / \lambda$$

$$\Gamma = 2\pi r_{63} V n_o^3 / \lambda$$

At the half wave voltage, $V_{\lambda/2}$, $\Gamma = \pi$ and $V_{\lambda/2} = \lambda / (2 r_{63} n_o^3)$ — for KD*P.

For the transverse configuration used with $LiNbO_3$ and BBO Pockels cells, E = V/d, where V is the applied voltage and d is the electrode separation.

$$\Delta n = r_{22} E n_o^3$$

$$\Delta n = r_{22} V n_o^3 / d$$

$$\Gamma = 2\pi \Delta n \, l / \lambda$$

$$\Gamma = 2\pi r_{22} V n_o^3 l / (\lambda d)$$

At the half wave voltage, $V_{\lambda/2}$, $\Gamma = \pi$ and $V_{\lambda/2} = \lambda d / (2 r_{22} n_o^3 l)$ — for $LiNbO_3$ and BBO.

Note that the half-wave voltage for a transverse field Pockels cell is proportional to d/l , the electrode spacing divided by the crystal length. For the KD*P longitudinal Pockels cell, the half-wave voltage is independent of crystal length.

[KD*P Pockels cells also can be made using a transverse field configuration that uses the r_{41} electro-optic coefficient. In this configuration, a pair of crystals are used in order to compensate for the static birefringence of a single crystal. External cavity modulation applications require a second pair of crystals in order to compensate for the walk-off induced spatial displacement. Generally, with such multi-crystal transverse configurations, crystal lengths need to be well matched and the temperature must be controlled in order to null the overall static birefringence.]

DOUBLE-PASS CONFIGURATION

In order to lower the voltage requirement, Pockels cells often are used in a double-pass configuration that employs reflection off a mirror so that on the second pass through the Pockels cell the retardations are additive. Hence, with the quarter-wave voltage applied to the Pockels cell in a double-pass configuration, a 90° rotation of linear polarization is produced. Additional methods of lowering the half wave voltage include the use of two crystals in series or the use of long crystals in Pockels cells that use a transverse electric field.

The r_{63} coefficient of KD*P is largely independent of wavelength although it is sensitive to temperature changes. For Q-switch applications, the quarter-wave voltage at 1064 nm is about 3200 volts.

The r_{22} coefficient of $LiNbO_3$ varies with wavelength and with modulation frequency. For Q-switch applications, the quarter-wave voltage at 1064 nm with d = 9 mm and l = 25 mm is about 1650 volts.

The r_{22} coefficient of BBO is quite a bit smaller than either r_{63} of KD*P or r_{22} of $LiNbO_3$. BBO is useful when operation requires extremely high peak power or average power light fluences. For Q-switch applications, the quarter-wave voltage at 1064 nm with d = 4 mm and l = 20 mm is about 4350 volts.