Sintec Optronics Pte Ltd
新加坡新特光电技术有限公司

电光 Q 开关

Pockels Cells

Technical Overview

The Electro-Optic Effect

The linear electro-optic effect, also known as the Pockels effect, describes the variation of the refractive index of an optical medium under the influence of an external electrical field. In this case certain crystals become birefringent in the direction of the optical axis which is isotropic without an applied voltage.

When linearly polarized light propagates along the direction of the optical axis of the crystal, its state of polarization remains unchanged as long as no voltage is applied. When a voltage is applied, the light exits the crystal in a state of polarization which is in general elliptical.

In this way phase plates can be realized in analogy to conventional polarization optics. Phase plates introduce a phase shift between the ordinary and the extraordinary beam. Unlike conventional optics, the magnitude of the phase shift can be adjusted with an externally applied voltage and a λ/4 or λ/2 retardation can be achieved at a given wavelength. This presupposes that the plane of polarization of the incident light bisects the right angle between the axes which have been electrically induced. In the longitudinal Pockels effect the direction of the light beam is parallel to the direction of the electric field. In the transverse Pockels cell they are perpendicular to each other. The most common application of the Pockels cell is the switching of the quality factor of a laser cavity.

Q-Switching

Laser activity begins when the threshold condition is met: the optical amplification for one round trip in the laser resonator is greater than the losses (output coupling, diffraction, absorption, scattering). The laser continues emitting until either the stored energy is exhausted, or the input from the pump source stops. Only a fraction of the storage capacity is effectively used in the operating mode. If it were possible to block the laser action long enough to store a maximum energy, then this energy could be released in a very short time period.

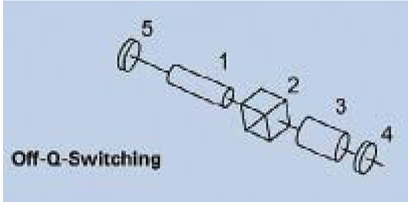
A method to accomplish this is called Q-switching. The resonator quality, which represents a measure of the losses in the resonator, is kept low until the maximum energy is stored. A rapid increase of the resonator quality then takes the laser high above threshold, and the stored energy can be released in a very short time. The resonator quality can be controlled as a function of time in a number of ways. In particular, deep modulation of the resonator quality is possible with components that influence the state of polarization of the light. Rotating the polarization plane of linearly polarized light by 90°, the light can be guided out of the laser at a polarizer. The modulation depth, apart from the homogeneity of the 90°

rotation, is only determined by the degree of extinction of the polarizer.

The linear electro-optical (Pockels) effect plays a predominant role besides the linear magneto-optical (Faraday) and the quadratic electro-optical (Kerr) effect. Typical electro-optic Q-switches operate in a so called λ/4 mode.

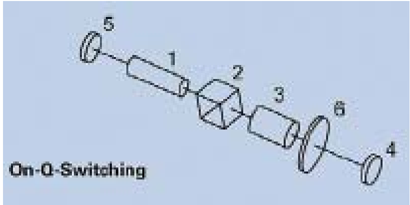
a) Off Q-Switching

Light emitted by the laser rod (1) is linearly polarized by the polarizer (2). If a λ/4 voltage is applied to the Pockels cell (3), then on exit, the light is circularly polarized. After reflection from the resonator mirror (4) and a further passage through the Pockels cell, the light is once again polarized, but the plane of polarization has been rotated by 90°. The light is deflected out of the resonator at the polarizer, but the resonator quality is low and the laser does not start to oscillate. At the moment the maximum storage capacity of the active medium has been reached, the voltage of the Pockels cell is turned off very rapidly; the resonator quality increases immediately and a very short laser pulse is emitted. The use of a polarizer can be omitted for active materials which show polarization dependent amplification (eg. Nd:YalO3, Alexandrite, Ruby, etc.).



b) On Q-Switching

Unlike off Q-switching, a λ/4 plate (6) is used between the Pockels cell (3) and the resonator mirror (4). If no voltage is applied to the Pockels cell the laser resonator is blocked: no laser action takes place. A voltage pulse opens the resonator and permits the emission of laser light.



Pulse Picking

Typically Femto-Second-Lasers emit pulses with a repetition rate of several 10MHz. However many applications like regenerative amplifying require slower repetition rates. Here a Pockels cell can be used as an optical switch: by applying ultra fast and precisely timed λ/2-voltage pulses on the Pockels cell, the polarization of the Laser light can be controlled pulse wise. Thus, combined with a polarizer the Pockels cell works as an optical gate.

Selection Criteria

The selection of the correct Q-switch for a given application is determined by the excitation of the laser; the required pulse parameters, the switching voltage, the switching speed of the Pockels cell, the wavelength, polarization state and degree of coherence of the light.

Type of Excitation

Basically, both off and on Q-switching are equivalent in physical terms for both cw and for pulse pumped lasers. On Q-switching is, however, recommended in cw operation because a high voltage pulse and not a rapid high voltage switch-off is necessary to generate a laser pulse. This method also extends the life time of the cell. Over a long period of time, the continuous application of a high voltage would lead to electrochemical degradation effects in the KD*P crystal. We advice the use of an on Q-switching driver. Off Q-switching is more advantageous for lasers stimulated with flash lamps because the λ/4 plate is not required. In order to prevent the electrochemical degradation of the KD*P crystal in the off Q-switching mode we recommend a trigger scheme in which the high voltage is turned off between the flashlamp pulses and turned on to close the laser cavity before the onset of the pump pulse. The cell CPC and SPC series are recommended for diode pumped solid state lasers. These cells are ultra compact and will operate in a short length resonator: this is necessary to achieve very short laser pulses.

Pulse Parameters

The series LM n, LM n IM, and LM n SG cells are recommended for lasers with a power density of up to 500MW/cm². The LM n and LM n SG cells are used for lasers with very high amplification. The SG cells with sol-gel technology have the same transmission as the immersion cells and both are typically used when a higher transmission is required. At high pulse energies LMx cells are preferred.

Brewster Pockels cells are recommended for lasers with low amplification, such as Alexandrite lasers. The passive resonator losses are minimal due to a high transmission of 99%.

The CPC and SPC series cells are suitable for small, compact lasers and especially for OEM applications. They are available as dry cells and immersion cells.

The level of deuterium content in an electro-optic crystal influences the spectral position of the infrared edge. The higher the deuterium level the further the absorption edge is shifted into the infrared spectral region: for Nd:YAG at 1064nm, the laser absorption decreases. Crystals, which are deuterated to >98%, are available for lasers with a high repetition rate or a high average output power.

Pockels Cell Switching Voltage

Using double Pockels cells can half the switching voltage. This is achieved by switching two crystals electrically in parallel and optically in series. The damage threshold is very high and the cells are mainly used outside the resonator.

Electro Optic Material

The selection of the electro-optic material depends on its transmission range. Further on the Laser parameters and the application as well have to be taken into account.

For wavelengths from 0.25µm to 1.1µm, longitudinal Pockels cells made of KD*P and a deuterium content of 95% should be considered. If the deuterium content is higher the absorption edge of the material is shifted further into the infrared. KD*P crystal cells with a deuterium content >98% can be used up to 1.3µm.

KD*P can be grown with high optical uniformity and is therefore recommended for large apertures. The spectral window of BBO also ranges from 0.25µm to 1.3µm, but besides BBO also provides a low dielectric constant and a high damage threshold. Therefore BBO is recommended for Lasers with high repetition rate and high average powers. RTP, with an optical bandwidth from 0.5µm up to 1.5µm combines low switching voltage and high laser induced damage threshold. Together with its relative insensitivity for Piezo effects RTP is best suited for precise switching in high repetition rate lasers with super fast voltage drivers.

For wavelengths from 1.5µm up to 3µm we recommend LiNbO3.

Suppression of Piezo Effects

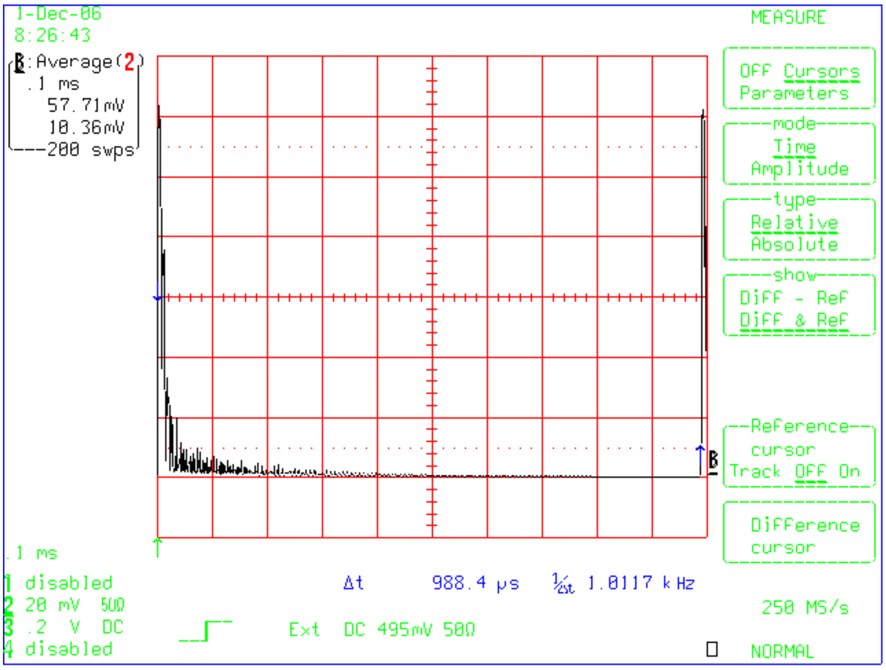
Like any other insulating material electro optical crystals show Piezo effects when high voltage is applied. The extend of the Piezo ringing depends on the electro optic material and usually its effect on the extinction ratio is negligible when used for Q-switching. However for pulse picking applications, which require highly precise switching behaviour, we offer specially Piezo damped Pockels cells which suppress these ringing effects efficiently.

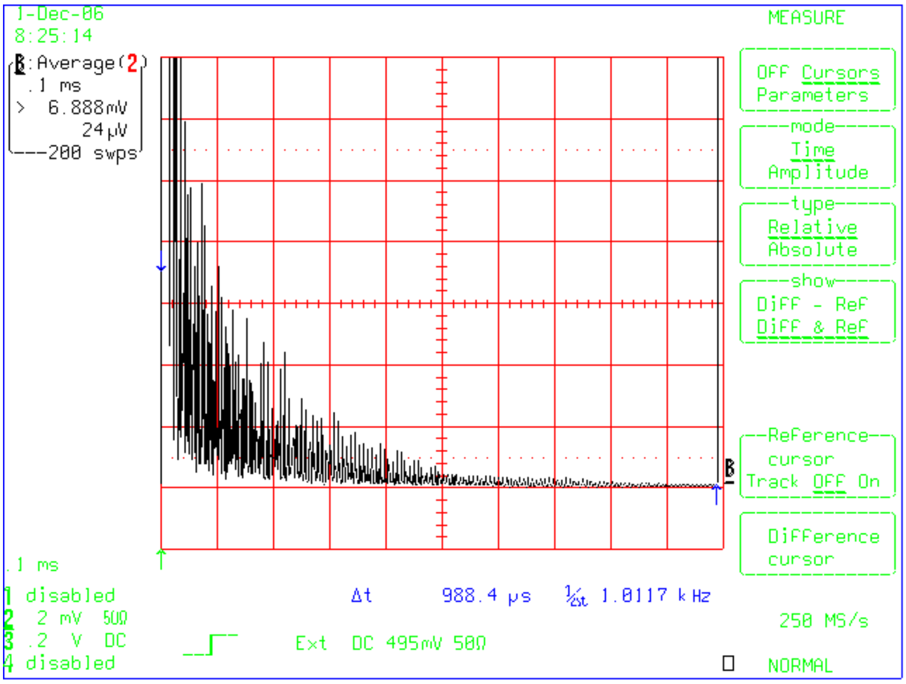
State of Polarization

The MIQS and CIQS series cells are supplied with an integrated polarizer: the alignment of the Pockels cell relative to the polarizer thus becomes unnecessary. The rotational position of the cell relative to the resonator axis can be chosen at will. However, should the polarization state of the light in the resonator be determined by other components, such as anisotropic amplification of the laser crystal or Brewster surfaces of the laser rod, then the rotational position of the cell will be determined by these factors. Thin film polarizers are used and the substrate is mounted at the Brewster angle. A parallel beam displacement of 1mm results from this configuration and can be compensated by adjusting the resonator.

1. How to Select an EO Q-switch to Meet Your Switching Frequency Requirement

The simple answer is that the IMPACT Pockels cells are recommended for operation at a maximum of 1-2kHz. This is not to say they will completely fail to operate at 5kHz. The contrast ratio will be sacrificed as the repetition rate is increased beyond 1kHz. The reason for this is contained within the nature of the DKDP crystal, When high voltage is applied, the crystal lattice is distorted, causing the desired Pockels effect. However, the longer that the voltage is applied, either in terms of electric pulse duration or in the repetition rate used, the distortion causes an acoustic resonance to develop. This is commonly referred to as “rining” in the crystal. This is true of any cell that uses KDP/DKDP as its crystal element. To illustrate this point, the following figures show several optical traces of the acoustic ringing from an IMPACT 8 Pockels cell when operated at 1kHz repetition rate. One trace (time stamp 8:26:43) allows the vertical (y-axis) to autoscale to a maximum of the signal from the electrical pulse. In the second trace (time stamp 8:25:14), we have collapsed the y-axis so that you don't see the maximum of the electrical pulse. Although the collapsed y-axis truncates the initial pulse maximum, it increases the visual appearance of the acoustic ringing following the initial pulse. In either case, you can see the acoustic ringing subsides after about 1millisec.





Although we generally recommend QX series Pockels cells for applications at >2KHz, whether or not the IMPACT 8 will work depends upon how much loss of contrast ratio their system can tolerate. But if you want a cut and dry answer, I'd recommend against operation at 5kHz. The QX and IMPACT cells use the same high quality DKDP crystal in similar sizes. The significant difference is the construction of the cell housing. The QX cell design is such that is provides some suppression of this ringing out to about 5KHz normally and is available in a damped version which will suppress this condition to <10KHz.

The BBO cell will operate into the 500KHz region and higher.

2. How to Select Aperture

In a Gaussian beam there will be ~10% of the laser energy present at a diameter of 2-3 times the 1/e^2 diameter. This will result is a significant loss of energy in the system and this energy can scatter inside of the cell and damage the cell. We would suggest that the aperture of the Q-switch is 2 to 3 times of laser beam diameter (1/e2). If the beam can be modified into something close to a "tophat" profile then the aperture requirement drops substantially.

3. What is maximum allowed laser energy? what is the maximum allowed peak power? What is the maximum peak power beam which can be switched off?

If you have a large, perfect beam you can get much more energy through the cell without damage than if you have a beam with hot spots and caustic retro-reflections, etc. In an 8.5mm beam, "typical" maximum wattages would range from 5-30W but, theoretically, DKDP can be used into the 50-75W region...but EVERYTHING has to be perfect. This is one of those situations where general rules just don't have much use.

4. What is the laser beam pulse width and rise time?

The performance of the cell is directly related to the driver. The cell has a theoretical rise time on the order of 80ps...but the best drivers can only drive a rise time of 2-6ns. Pulse width and fall time are similarly affected. The electronics are fairly simple for a q-switch driver at 1/4 wave and a few Hz. Driver designs get MUCH more complicated for a region or a pulse picker at 10 or 100KHz and 1/2 wave voltage.

5. Do we need a waveplate?

Our cell does not contain a waveplate in it. If the customers application requires a 1/4 waveplate then he will have to add it into the system himself.

6. How to Select a Driver?

Any driver that produces ~3KV (2.6KV) will operate the cell to 1/4 wave. The driver that we offer at http://www.sintecoptronics.com/qswi tcheoDriver.htm should work.

7. How to Select Pulse Shape and Duty Cycle?

You can operate the cell with either a pull-up voltage or a pull-down voltage. Changing the polarity will only change the direction of the phase rotation. You should not, however, operate the cell with a constant applied voltage potential between the terminals, or a duty cycle greater than ~ 2%. "Pull-down" usually involves a constant applied or bias voltage. This type of operation is specifically not recommended. We have had customers that use this method to varying degrees of success. This type of operation usually results in dramatically reduced cell lifetimes. We offer no warranty coverage on cells that have been used in this manner.

8. How about Operation Environment?

Our recommended range would be in the 10-30 deg C range. Higher temps will seriously degrade performance. Voltage requirements will change with temperature as well. Also important is the rate of temperature increase. KDP is quite sensitive to thermal shock KD*P cells should never be warmed or cooled at a rate of more than 1-2 deg per hour.

9. How to Place an order for a QX cell?

Fluid filled cells are provided for legacy systems or special applications only. SolGel dry type cells are recommended for optimal performance in most systems. When you place the order for a QX cell, please define window wedge (0 deg or 1 deg) and endcap stype (DT, TK, TN).

If you would like us to make a Pockels cell and driver recommendation, we would like to know the following information about your application:

1. What is the beam diameter or radius (1/e2 value) - please specify if radius or diameter
2. What is the beam profile (Gaussian, pseudo-Gaussian, top hat, etc.)?
3. What is the wavelength of operation?
4. What is the repetition rate?
5. What is the laser peak power (extra-cavity)?
6. What is the energy-per-pulse?
7. What is the pulse width (FWHM)?
8. Do you require quarter-wave or half wave operation?
9. If using a laser cavity, what is the finesse or output coupler reflectivity?
10. Do you intend to use a bias or constant on voltage, switching to ground?

国产电光 **Q** 的主要问题：

1、脉冲频率低，一般用在 100Hz 左右。所以内雕机有八个头做内雕，提高内雕速度。现在用振镜做内雕，必须是高脉冲频率。灯泵内雕机就要用进口电光 Q 开关。在二极管端泵激光器里，有用声光 Q 开关（风冷），也有用电光 Q 开关。用电光 Q 开关的激光峰值功率更高，比声光 Q 开关的内雕效果更好。

2、使用寿命短：据做内雕机的人说，在重复率 200Hz 时，使用寿命也只有 1－3 个月。如果重复率更高，寿命就更短。也就是说总的脉冲数基本是固定的。

3、目前国产电光 Q 开关整体的损伤阈值是 450MW/cm2，其中晶体是不镀膜的，只是两端窗片镀增透膜，透过率是>90%的，当晶体两端也镀膜之后透过率可以到 96%以上，但是损伤阈值会降为原来的 1/3，很容易打环，这是由于目前 DKDP 晶体镀膜技术难度很高的原因.

4、国产电光 Q 开关优势：价格特别低。

进口 **Q** 开关的优势：

1、脉冲频率高：IMPACT 达 2kHz, QX 达 5kHz，BBO 达 500kHz

2、寿命长：不管用在什么频率，保修 12 个月，实际寿命远远长于一年。

3、进口的电光 Q 开关镀膜透过率大于 98%，损伤阈值大于 4000MW/cm2.

4、问题：价格高。