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Application Notes:
Dry Pockels Cells vs. Wet Pockels Cells

This note will also apply to SHG cells and doublers, triplers, etc.

The parameters of importance in laser application of these devices are:

1) Insertion loss
2) Damage threshold
3) Energy damage
4) Average power damage

The most common Pockels cells use KD*P and LN crystals.

KD*P is soft (M oh scale 2) crystal with excellent transmission from 250 nm to 1100 nm for 98% D crystals. Moreover, they are water-soluble and must be protected with windows or with good hard coatings. At 1064 nm, KD*P can handle energy densities up to 10J/cm^2. These are damage fluence levels at 1064 nm. LN is a hard crystal (M oh scale of 6) and is not hygroscopic. However it is pyro electric and develops a charge when heated. This charge attracts dust and therefore windows are required. As a comparison, fused quartz can handle 20J/ cm^2 and AR coatings can handle up to 5J/ cm^2 at 1064nm. Maximum energy a laser rod (Nd:YAG) can produce is about 2J/pulse. Pockels cells are used either inside the cavity (Intracavity) or outside the cavity (extra-cavity). For lowest loss intracavity application, it is vest to use Brewster face crystal or cell.

This discussion will focus on crystal KD*P cells, since KD*P has five times higher damage for CW power damage of 20 W at 1064 nm. LN is useful for lower power range finder applications. The intracavity loss depends upon two factors **(1)** Reflection loss **(2)** Intrinsic absorption loss, which is typically 0.5% per cm for 98% D crystals and increases dramatically to 2% per cm, for 90% D. Therefore good quality high D crystals of KD*P are required for intracavity work.

The most common Pockels cell is QC-10 with 10-mm aperture. The crystal is 10mm Dia and 20mm long, so typically the absorption loss is 1% in the crystal. This causes heating of the crystal and thereby degradation of the contrast ratio. Typically high contrast ratio of 1000:1 or more is desirable to have good hold off. When crystal heats up by 10ºC (100 watt circulation power-absorbing 1 watt in the crystal), the contrast ratio may degrade to 200:1 or less. This depends upon the beam diameter and tis number may be typical for a ¼ inch rod. The degradation of CR causes slow leakage of energy, causing uncontrolled pulse formation.

The cause of reflection loss is reflection due to crystal faces. Typically, this depends upon the refractive index (KD*P of 1.5) and is about 4% per surface which means an uncoated crystal in air will have 4+1+4 = 9% total loss. This makes the crystal useless without any AR coatings. A typical laser can tolerate a maximum of 2% total loss. So some techniques are used to reduce these effects.

The crystals must be protected with AR coated windows or must be protected with hard thin film coatings. For depositing hard coatings of materials like Silicon Dioxide or Titanium Oxide or fluorides of rare earth compounds, the boat temperature is around 2000ºC and the crystal substrate temperature should be around 250ºC to 300ºC. If the crystal substrate is below this temperature, there is a problem of poor adhesion of the coarting material i.e. it peels off or form wrinkles on the face. The problem is that crystal KD*P is soft and cannot be heated above 80ºC - 100ºC without decomposition in vacuum of 10^{-6} Torr. Therefore hard coatings cannot be deposited on the crystals. The closest deposition for protection as well as for AR requirement is a single layer coating. However, single layer-coating works reasonably well only at one wavelength, say 1064 nm with a reflection loss of about 1%. Triple layer hard coatings can be produced with reflection loss of ¼% and are called "V" coat. It can be double "V" coat at two wavelengths, say 1064nm and 532nm. Typically, hard coatings can handle 1GW/cm^2 peak power at 1ns pulse width (1064nm) or 100mW/ cm^2 at 10ns pulse width.

Quantum Technology has developed a proprietory coating called Polycoat, which consists of a special deposition of polymer material of single layer with a resulting in a loss of about 1%. In KD*P or about 0.02% for BBO it has a very high damage threshold of 27GW/cm^2 peak fluence level. This is the highest damage for any coating available. Even that of Sol-Gel, far exceeds that of most crystal materials and is comparable to fused quartz.

The second type of coating is magnesium flouoride single layer and works as partial AR (R = 1%) as well as protection against moisture (called P coat). The third type of coating is called Sol-Gel which is deposited by spinning the crystal in an organic solvent containing a polymer type material dissolved in it. The thickness is controlled by controlling the rate of spinning. All these three single layer films produce about 1% reflection loss per surface and these are also delicate as they cannot be touched or cleaned except with a gentle flow of dry nitrogen to remove dust or particles on these coatings. Sol-Gel coatings can have a very high damage threshold of 40J/cm^2 at 1064nm and 15J/ cm^2 at 355nm. This coating is sometimes called Hardened Sol-Gel (HSG) and can be deposited on glass, quartz, or crystals from 1.4 to 1.6 index of retraction. So with Sol-Gel or with polycoat, the crystal cell is filled with dry Nitrogen or Argon or simply dry air. The total loss now is about 3% (including absorption of 1% in the crystal). Then the cell is closed with two windows with "V" type AR coatings on both faces. The best "V" coatings have a reflection loss of 0.25% and four faces AR produce total R loss if 1% on the window faces. The total loss now is

1%	for windows (Two)
2%	for single layer coating (two faces)

1% for internal absorption
4% Total (max for a dry cell)

The other technique is to use fluids to index match the faces better to reduce the reflection loss further. The best pockels cells are made with a very close tolerance between window and crystal face, i.e. a very small gap of 0.5mm or less. The fluids that are used are:

1) Deuterated decalin n = 1.45
2) Decalin with n = 1.45
3) FC-43 with n = 1.3

With index matching, the reflection loss is much reduced. The best fluid is D-decalin with excellent transmission at 1064nm and good index match. The reflection loss is reduced to practically less than 0.1%. So the total loss now is:

0.5% R for windows – outside faces AR
0.1% R for D-decalin
1.0% absorption
1.6% Total

With non-deuterated decalin:

0.5% R for two windows
0.5% R for decalin
1.0% absorption
2.0% Total

With FC-43, the loss is:

0.5% R for two windows
1.0% R for FC-43
1.0% absorption
2.5% Total

It should be mentioned that fused quartz has about the same refractive index (n = 1.5) as that of a KD*P crystal (n = 1.48) and fluids index match both types of surfaces. However D-decalin is very expensive and carcinogeneous. So FC-43 is preferable. It has a damage threshold of $100 mW/cm^2$ and thermal blooming and carbon formation may take place for average powers in excess of 30 – 50 watts. It must be mentioned that damage is caused by several extraneous factors like dust particles and so on. So the assembly room should be class 1000 or better clean. The assembler must wear gloves and headgear, and dedication for this extra-careful work.

So for high powers (above cW 50 watt) dry cells are preferred since liquids damge. At the cost of higher reflection, there is longevity and improved reliability for dry cells.