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OPTICAL COATINGS
A brief encounter

A method of reducing unwanted losses in optical systems is the use of coatings on lenses and other transparent materials such as crystal, windows, and mirrors. *However, what do coatings do?* Coatings provide a method of reducing losses at a wavelength or a range of wavelengths to which they are placed so that reflections is minimized. In general, a glass plate for example will produce a reflection of ~4% on each surface as light is passed through it (figure 1).

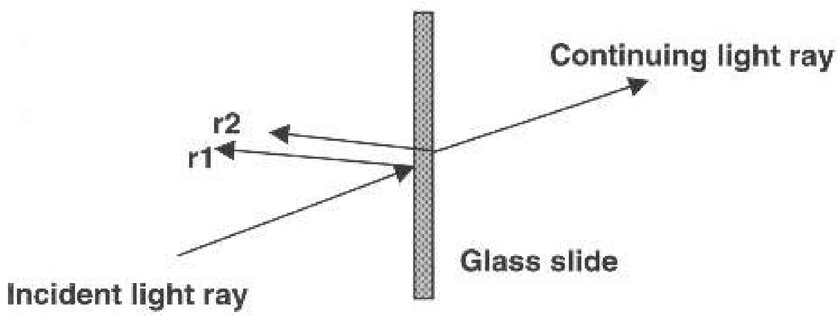


FIGURE 1

The incident light ray above is angled off center to more easily show the reflected beams, r1 and r2. This ray continues through the glass plate as shown. The two reflections, r1 and r2, contain approximately 4% of the light source each. Therefore, if we normalize the incident light ray as having 1 unit of light or 100% to start, then each reflection would have 4% each (8% total) of the original incident light ray. The continuing ray would have been reduced by 8%, or be 92% of the original incident ray. Other losses may occur in the material in which the light beam is passing. This varies by the light's wavelength and the material.

Many times this loss is not appreciable, but in laser systems, reflections can be a source of trouble or concern. For example, if the incident ray were represented by 100W of laser optical power, then each reflection would be 4 watts. This can be significant.

Enter the optical coating. The chemical coating is deposited on the clear surface by a number of methods: sputtering, electro-plating, vacuum depositing, etc.

When the coating inter-acts with the light ray, beam reflection is reduced. The reduction is in the range of 1% and less, and may be as low as <0.25%. Compare this to the original 4% per surface. Each coating is particular to a wavelength. Other wavelengths will not have their reflections reduced as much, if at all. There are also broadband coatings, and the most common of these are that found in photographic equipment such as cameras or tunable lasers. In the camera example, these coatings reduce the inter-lens reflections of the camera of its compound focusing lenses. This reduces light spots; especially those caused by reflections of the sun. Tunable lasers such as Ti: Sapphire also benefit by broadband coatings, since the reflections are kept minimal as the laser is tuned.

In general, the broader the bandwidth of the coating, the more percentage of reflection is produced. In contrast, when a coating is for a specific wavelength, the reflections are minimized. The table below shows the effective broad band anti-reflection coatings available:

Optical region	Range	Basic reflectivity within specified range
ULTRAVIOLET	193nm – 248nm	~ 0.25%
ULTRAVIOLET	255nm – 308nm	~ 0.40%
ULTRAVIOLET	248nm – 355nm	~ 0.10%
VISIBLE	355nm – 532nm	~ 0.10%
VISIBLE	425nm – 675nm	~ 0.10%
VISIBLE	500nm – 800nm	~ 0.10%
NEAR INFRARED	633nm – 1064nm	~ 0.20%
NEAR INFRARED	860nm – 1320nm	~ 0.15%
NEAR INFRARED	1050nm – 1600nm	~ 0.10%
The above represent standard BBAR (broadband anti-reflection) coatings.		

BBAR COATING TABLE

Spectral range is the wavelengths that a material passes. For example, a material such as KD*P used in a modulator has a spectral response of 300nm to 1100nm. This represents the material spectral response of KD*P. Other materials could have different spectral responses. For example, the crystal material ADP, as in Quantum Technology's modulator model 28, has a spectral response of 300nm to 800nm. On to these materials coatings reduce reflections or losses from the surfaces at particular wavelengths. This increases the over-all efficiency of the system.

Another way of reducing internal device losses is using an index matching fluid (FC or Decalin) between the crystal and the outer windows. The window surfaces that face a crystal where fluid is used are uncoated. The outside window is coated to reduce losses.

If a crystal material is uncoated, there will be approximately 4% per surface. Many modulators have multiple crystal; therefore, this 4% loss in encountered at each crystal surface. If there are four crystals in a modulator, then there are eight surfaces with 4% loss each. The spectral response of the material would determine the optical bandwidth to a point in the sense that the optical characteristics are not solely losses due to reflections, but concern losses due to absorption within the material. Absorption causes heat rise within the crystal material that can distort the light ray's characteristics, as well as, damage the crystal.

Quantum Technology, Inc. uses the following methods found in the table below to reduce crystal interface reflections.

INDEX MATCHING FLUID or COATING TYPE	WAVELENGTH RANGE nanometers (nm)	% REFLECTION ON KDP	% REFLECTION ON BBO	% REFLECTION ON LN/LT
FC 43 (fluid)	**400-1300**	**1.0**	**NA**	**NA**
FC 104 (fluid)	**250-2000**	**1.0**	**NA**	**NA**
POLYCOAT (coating)	**250-2000**	**0.5**	**0.1**	**NA** (NOTE 1)
MgFl (coating)	**250-2000**	**1.0**	**0.25**	**0.25**

NOTE 1: *Polycoat may be used on Lithium Niobate or Lithium Tantalate in special cases. These materials have inherently lower damage thresholds. Polycoat has a high damage threshold.*

There are three basic methods crystals are mounted in cells. In the cases shown only single crystals are shown. The first is using windows and an index matching fluid (see DIAGRAM #1), the second is using windows and dry nitrogen and no fluid (see DIAGRAM #2), and third using no windows only a coating on the crystal (see DIAGRAM #3).

DIAGRAM #1– Also known as a *wet cell.*

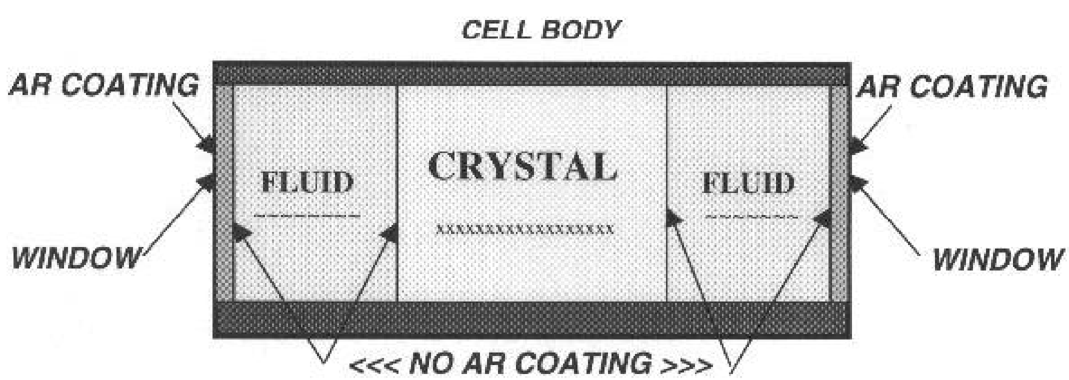


DIAGRAM #2 – Also known as a *dry cell* with windows.

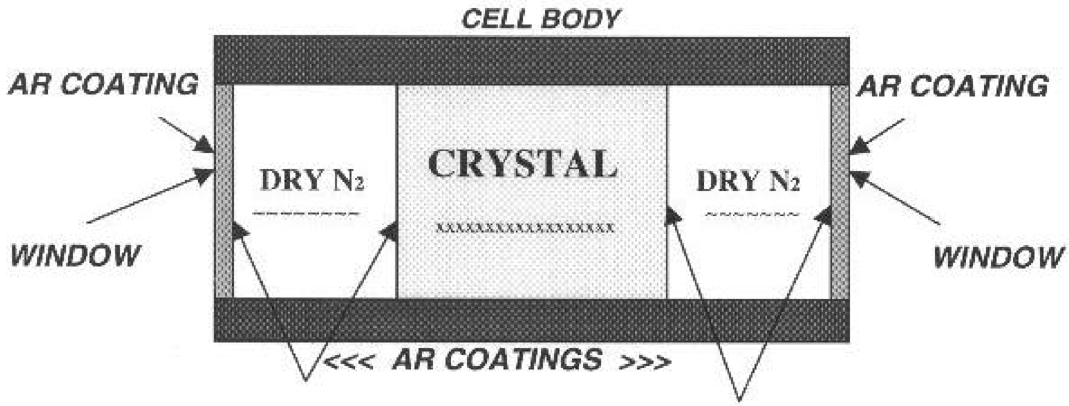
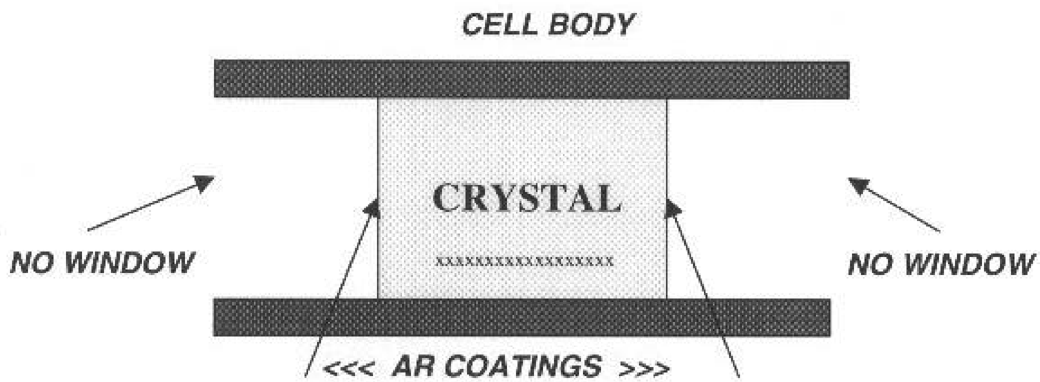


DIAGRAM #3 – Also known as a *dry cell* without windows.



Pockels cells can use any of the three methods as shown in the diagrams 1 through 3. Most Pockels cells are wet cells. When no windows are used, the POLYCOAT is applied to the crystal.

Modulators usually use diagrams 2 and 3. If amplitude modulation is used, a polarizer can also placed at the output end of the cell. See Quantum Technology application note: *A comparison of PHASE, AMPLITUDE EOM and EO POLARIZATION ROTATORS.* The input beam must be polarized for either Pockels cells or modulators.

THE PROCESS OF THE POLYMER COATING - *POLYCOAT©*

Quantum Technology developed a Polymer Coating (AR Polycoat) for dry (non-index matching fluid) Pockels Cells that can be used with BBO (QS series), KD*P (QC series), and for dry SHG (Second Harmonic Generator) / THG (Third Harmonic Generator) Crystals made of BBO, LBO, KD*P or CD*A mounted with windows. This proprietary high damage single layer Anti-Reflective (AR) coating bonds directly onto the crystal faces during the coating process. This coating has excellent index matching properties, and serves as a good Protective Coating for these hygroscopic crystals. This single layer AR Polycoat© process is available at any specific wavelength from 360 nm to 1064 nm.

The research and development work for this Polymer Coating was performed as a cooperative effort under a CRADA Project of the Lawrence Livermore National Laboratory and the staff of Quantum Technology, Inc. The Damage Threshold measurements were carried out with a Flash Lamp pumped Nd:YAG laser (1064 nm) at 10 Hz, at CREOL's facility at the University of Central Florida. Used as a complete Pockels cell assembly, standard AR coatings covered both faces of the windows and the Polymer AR coating covered the crystal faces. The cell was filled with dry N_2 (Nitrogen), eliminating the problems of liquids such as Decalin or fluorocarbon fluids such as the FC series. From these series of tests, the total Reflection Loss of the Pockels cell under these conditions is < 1% at 1.064 nm for crystal faces and < 1% for window AR faces for <2%.

This process is ***not*** a SOL-GEL^R coating, but an exclusive process developed and produced by Quantum Technology, in collaboration with LLNL expertise. SOL-GEL^R is a chemical process, whereas, Polycoat© is an evaporative process.

Additional tests of damage measurements on the Polycoat© coating were made with a flash lamp diode pumped Nd:YAG laser. Under these conditions, the damage threshold was greater than 27 GW/cm^2 peak irradiance, and 0.78 J/cm^2 peak fluence, for 16.7 picosecond pulse width.

This new "DRY" design is free from any fluid related problems, such as, fluid leakage and air bubbles. Hermetically sealed and filled with dry nitrogen gas (DRY N_2), the Pockels Cell performance is not affected by its position (vertical or horizontal). Please note that the double-crystal Pockels devices are also useful for extra-cavity switching and at lower wavelength operation down to 2.1 micron (Nd:Holmium) for BBO Pockels Cells (QS series).

These dry Pockels cells are available as QS (BBO) or QC (KD*P) series. For dry SHG or THG crystals such as BBO, LBO, KD*P or CD*A, the total reflection loss is <2 %.

The Polycoat© process is monitored during the evaporative process by actually measuring the reflectivity of the surface crystal to which the coating is applied. The Polycoat© is used for high damage operation in which a level of 1GW/cm^2 could be obtained.

For lower levels of energy, Magnesium Fluoride is used. Magnesium Fluoride is usually used with levels of approximately 250MW/cm^2. It is a very good general wideband AR coating.

Both coatings, $MgFl_2$ (Magnesium Fluoride) and Polycoat®, have an over all AR (Antireflective) property of <1.5%. This is dependent on wavelength and crystal material, for example, KD*P has an AR level of 0.5% and BBO an AR level of 1.5% at 1064nm.

There are AR coatings with levels of < 0.25%. Three layer coatings form this group. Under this type of coating the deposited material on the crystal surface is controlled as to produce either a) a very low AR level, or 2) produce a low AR level at more than one wavelength, such as 1064nm and 532nm. Each having an AR level in the order of < 0.5%.

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