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CRYSTAL FOR DOUBLING 1064nm

There are six most useful crystals for second harmonic generation – SHG of 1064nm. The choice depends upon the peak power density and other laser parameters. These five crystals are:

1) KD*P
2) CD*A
3) Lithium Iodate
4) KTP
5) BBO
6) LBO

The application of each of these crystals depends on the crystal symmetry and the phase-matching angle. The most suitable cut for efficient SHG in **KD*P** and **KTP** is **Type II**, where the input plane of polarization is along the diagonal of the front face, and the optic axis makes the appropriate angle. These angles are:

a) KD*P > 53.5^0
b) KTP > 24.0^0

All other crystals for efficient SHG are **Type I**, with the following angles:

a) Lithium Iodate > 29.4^0
b) CD*A > 82.0^0
c) BBO > 22.0^0
d) LBO > 11.8^0

For these Type I crystal the input plane of polarization is parallel to the edge face of the crystal, and perpendicular to the plane containing the optic axis.

Out of the four Type 1 crystals listed above, two of them, CD*A and LBO can be temperature phase matched. The temperature matching points are:

1) CD*A - 110^0C
2) LBO - 149°C

When these crystals are heated to their respective temperatures, the CD*A crystal becomes 90^0 from the 82^0 degrees at room temperature ~20^0 C, and the LBO crystal goes from 11.8^0 C to 0^0 C at this high temperature. When these crystals are temperature phase-matched, the input beam and the output beam are collinear, making the walk-off zero. The efficiency of the crystals are maximized, and is approximate 50%~55% depending on the peak power density of the laser, and also, the crystal's length. Even higher efficiencies can be obtained by tight focusing, since at higher temperatures the acceptance angle increases. But, the MTBF – mean time between failures – increases because of severe crystal damage that may occur. However, CD*A Type I crystal is usually operated at 60^0 C at an angle of 84^0, and LBO Type I crystal is also operated at 60^0 C at an angle of 9.8^0. Please note that the angle is dependent upon the temperature. Lowering the crystal temperature increases its longevity without degrading much of its performance, loosing of only a few percent.

Lithium Iodate ($LiIO_3$) and BBO are only Type I, and use angle tuning. Temperature tuning is not possible with these two crystals.

A broad comparison is shown in Table 1 below.

CRYSTAL	TYPE	EFFECTIVE SHG coefficient with respect to KD*P	DAMAGE THRESHOLD @ 10nsec pulse	ANGULAR ACCEPTANCE cm-milliRAD	WALKOFF ANGLE milliRAD
KD*P	II	1	500MW/cm^2 with 95% deuteration	5.0	18.0
KTP	II	14	400MW/cm^2 Flux Grown method	15.0	1.0
CD*A	I	1 – temp tuned	300MW/cm^2 with 95% deuteration	30.0	1.5
LBO	I	2 – temp tuned	5GW/cm^2	40.0	0.4
LiIO3	I	10	100MW/cm^2	0.5	71.0
BBO	I	4	4GW/cm^2	1.5	51.0

TABLE 1

In the above table it is assumed that the laser beam is operating in TEMoo Gaussian mode. With the exception of KTP, all the crystals are hygroscopic, sensitive to moisture, and require a protective single layer coating or Antireflective (AR) triple layer coating. Only KTP has triple layer ($\geq$0.25% R - Reflection). A single layer coat gives approximately 0.5% R per surface at 1064nm. Usually MgF_2 (Magnesium Fluoride) or Polymer Coating (Quantum Technology high damage exclusive) is monitored during deposition by a photometer.

CRYSTAL SUMMERIZATION

1) KD*P:

This Type II crystal is the most popular commercial crystal with 95% deuteration level. They are cut from cost-effective sizes ranging from apertures of 15mm through 30mm, and a length 30mm. For input powers of 20~30Watts, the beam degrades and becomes unstable.

2) KTP:

This Type II crystal is cost effective for beams between 6~9mm, usually used intracavity. It may also be used with CW lasers in this mode since it has high non-linearity. This crystal is flux grown and is most efficient. Sizes are typically 15 mm^3. This crystal will damage with input powers above 15W. For CW intracavity operation, they damage at about 3W. This crystal can also be grown without flux using the hydrothermal method. However, these are expensive, but their damage threshold is doubled that of the flux-grown material. In this method of growth an efficiency of over 50% is possible. There are three output beams with KTP. Two are 1064nm, and one is the harmonic at 532nm. Since the 1064nm beams are not in phase. they are elliptically polarized.

3) CD*A:

This crystal was used in J-K Laser (now Lumonics) systems. They operate at 75^0 C at an angle of 85^0 with respect to the optic axis. The popular sizes were 12mm x 12mm x 25mm. Efficiencies of about 50% were normal. Larger sizes of 15mm x 15mm x 30mm were used by N.A.S.A.

4) LBO:

This Type I crystal is used in intracavity diode pumped high average power (10KHz) Nd:YAG lasers to generate 50 W of green (532nm) from a 100W 1064nm laser. The crystal is 3mm x 3mm x 18mm, and is operated at 60^0 C. Since used intracavity, the output coupler is 100% R at 1064nm with a maximum transmission at 532nm. There are two output beams from this crystal, 1064nm and 532nm, which are orthogonal. LBO can

generate 20W of green (532nm) without damage. The maximum size is 12mm x 12mm x 18 mm, and it is produce by flux growth at 950^0 C.

5) LiIO3:

Lithium Iodate crystals are Type I, and have a low damage Threshold, about 20% of KD*P (or 100MW/cm^2). These are useful in only low power CW intracavity lasers. In this use, the crystal can damage at 1.5W output at 532nm. This crystal has lost commercial value because of the low damage Threshold as compared to KTP and LBO.

6) BBO:

This is a Type I flux grown crystal with high damage Threshold characteristics, about four (4) times greater than KD*P (4GW/cm^2). This crystal has a very large acceptance angle of 55cm-0^0C, and a 100W average input power that is converted to green (532nm) with ~ 30% efficiency. It is used as an OPO crystal. It is available is 12mm x 12mm x 18mm sizes.