TM_1 mode crossover in the region $t_3 = 1.5$-2.0 μm (Fig. 3). Because of the small difference in slope between the two attenuation curves in this region, the attenuation of the TM_0 and TM_1 modes are equal for a relatively large change in t_3. It is also worth noting that the attenuation of the TE_0, TM_0, and TM_1 modes are nearly equal at $t_3 = 1$ μm. A filter 50 μm long at this guide thickness would have the following attenuations: $TE_0 = 1.7$ dB, $TM_0 = 2.5$ dB, and $TM_1 = 1.6$ dB. Thus, this guide can be used to select the first three propagation modes with only slight differences in attenuation. At a waveguide thickness of 1.4 μm, the first four modes passed through a 50 μm long filter will be separated by 1.35 dB attenuation. The TM_0 (1.9 dB), TM_1 (1.65 dB), and TE_1 (1.8 dB) are within 0.25 dB, which may prove useful in some filter applications.

The predicted attenuation and mode index curves for GaAs clad waveguides show that it can be used as a mode filter to select one or several modes while exhibiting attenuations as small as those reported for silver. These properties are currently being experimentally verified, and applications are being investigated.

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A Convenient Cell for Angle Tuned Nonlinear Optical Crystals

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Abstract—**The performance of a convenient cell for angle tuning of nonlinear optical crystals, in which the crystal is rotated inside an index matching fluid, is described. Using a new fluid, the cell greatly reduces beam deviation, astigmatism, and transmission loss.**

NONLINEAR optical crystals are extensively used for harmonic generation and for frequency mixing to obtain radiation at wavelengths not directly accessible by laser sources. Many of these crystals are fragile and hygroscopic and have to be protected against environmental conditions. This is usually done by sealing the crystals in cells filled with index matching fluid, which also serves as a good heat conductor and minimizes the reflection losses at the crystal surfaces. Phase matching by angle tuning is required if tunable radiation, scannable over a wide range of wavelengths, is to be obtained. This is usually accomplished by tilting the entire cell, which results in a cumbersome rotational mount for the cell, geometrical limitation of the angle tuning range, and displacement and deviation of the output beam while tuning.

We report on the performance of a new and convenient type of cell for nonlinear crystals. The cell is filled with an index matching fluid and the crystal is directly rotated while being immersed in the fluid [1]. This arrangement proves to be much more convenient than commercially available sealed cells. The advantages of the new cell are as follows. 1) The maximum angle tuning range of a crystal resulting from its physical dimensions is easily realized. 2) The displacement of the beam (when there is no recollimation after the crystal) or the deviation of the beam (with a recollimation lens) caused by the tilted cell are greatly reduced. 3) The astigmatism introduced by the tilted cell on the optical beam is reduced. 4)

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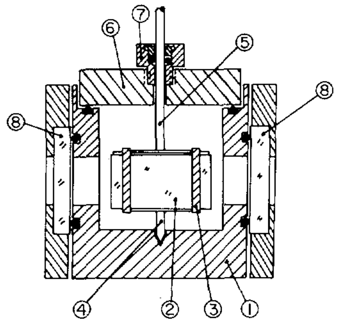

Fig. 1. Cross section of the cell. 1: Body. 2: Crystal. 3: Cage. 4: Pivot rod. 5: Rotating rod. 6: Cover. 7: Retainer. 8: Windows.

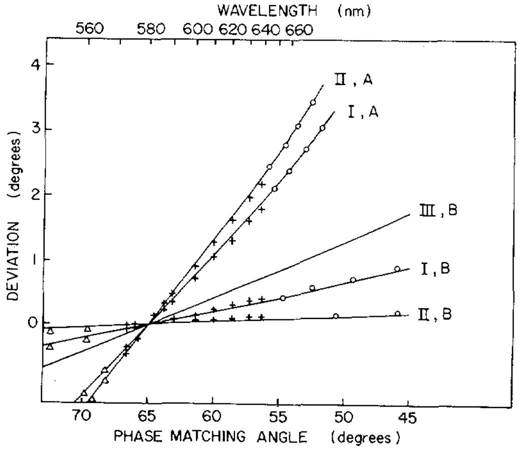

Fig. 2. Beam deviation after recollimation lens. —: Calculated. +: Measured with UV. ○: Measured with visible at 630 nm. △: Measured with visible at 575 nm. I: Cell filled with FC-104. II: Cell filled with decalin. III: Cell filled with air. A: Cell rotation. B: Crystal rotation.

There is no need for a separate cell for each crystal since the crystals can be easily replaced inside the cell.

The cross section of the cell is shown in Fig. 1. The body (1) is made of aluminum. The nonlinear crystal (2) is attached to a cage (3) made of thin stainless steel strips attached to stainless steel rods (4) and (5) by spot welding. Rod (4) serves as a pivot while rotation of the cage and the crystal is performed using rod (5) which is attached to a small rotational mount. The cell is sealed with a cover (6), and a retainer (7), and two AR coated quartz windows (8), using Viton "O" rings throughout. Different crystals may be mounted in separate holders complete with rods. When not in use, the crystals are kept in a "storage box" of a design similar to the optical cell filled with the same index matching fluid. Thus, changing of crystals is a very short and easy task.

The performance of the cell was checked by frequency doubling the output of a rhodamine 6 G CW dye laser in an ammonium dihydrogen phosphate (ADP) crystal. The crystal dimensions were 14 X 14 X 25 mm, with a 65° *z*-cut. The focusing and recollimation lenses had focal lengths of 7.5 and 10 cm, respectively. Two index matching fluids were tried. One was a fluorocarbon commonly used in commercial cells [2]. The second fluid was decalin [3], which thus far has not been used with nonlinear crystals [4]. The index of refraction of decalin ($n = 1.4745$) matches the index of the crystal ($n \sim 1.52$) much better than the index of the fluorocarbon ($n = 1.27$). Hence index matching with decalin reduces the reflection losses at the crystal and window surfaces (~0.02 and 0.8 percent loss per surface for decalin and FC-104, respectively). The UV beam deviation was measured and compared for each of the two fluids as a function of the phase matching angle of the crystal with both cell rotation and with crystal rotation. Outside the tuning range of Rh 6 G, the deviation of the visible fundamental beam was measured instead. The results are given in Fig. 2, together with the calculated deviations. It is seen that the beam deviation is greatly reduced when the crystal is rotated in a stationary cell filled with the proper index matching fluid. However, this arrangement is not able to fully compensate for the lateral position of the UV beam because of the walk-off angle in ADP which changes by 0.35°, which is converted by the recollimation lens to a displacement of 0.7 mm, comparable to the beamwidth.

In summary, we have demonstrated a new cell and index matching fluid that has very low losses and which eliminates the output beam deviation associated with continuous angle tuning in a tunable source. Since this arrangement also eliminates astigmatism of the fundamental, it may be particularly useful in intracavity doubling. In addition, it may also be useful in mixing schemes since the refraction, and hence the deviation, of the different wavelength input beams inside the crystal is negligible, thus making the alignment and tuning of the mixing schemes much easier.

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