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Wednesday, December 8, 1999

Modelocked Ti:sapphire laser

Rev 1.7

Our laboratory has now moved (twice) since this document was first distributed.

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Mode-Locked Ti:Sapphire Laser

Rev 1.7
April 4, 1994

Designs and guidelines for constructing a mode-locked ti:sapphire laser.

by

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Basic Laser Design

The basic configuration of the mode-locked ti:sapphire laser is quite simple: 2 end-mirrors (one or both an output coupler), 2 mirrors which focus into the crystal, and a pair of prisms. The following is the configuration which we used to obtain 17 fs pulses:

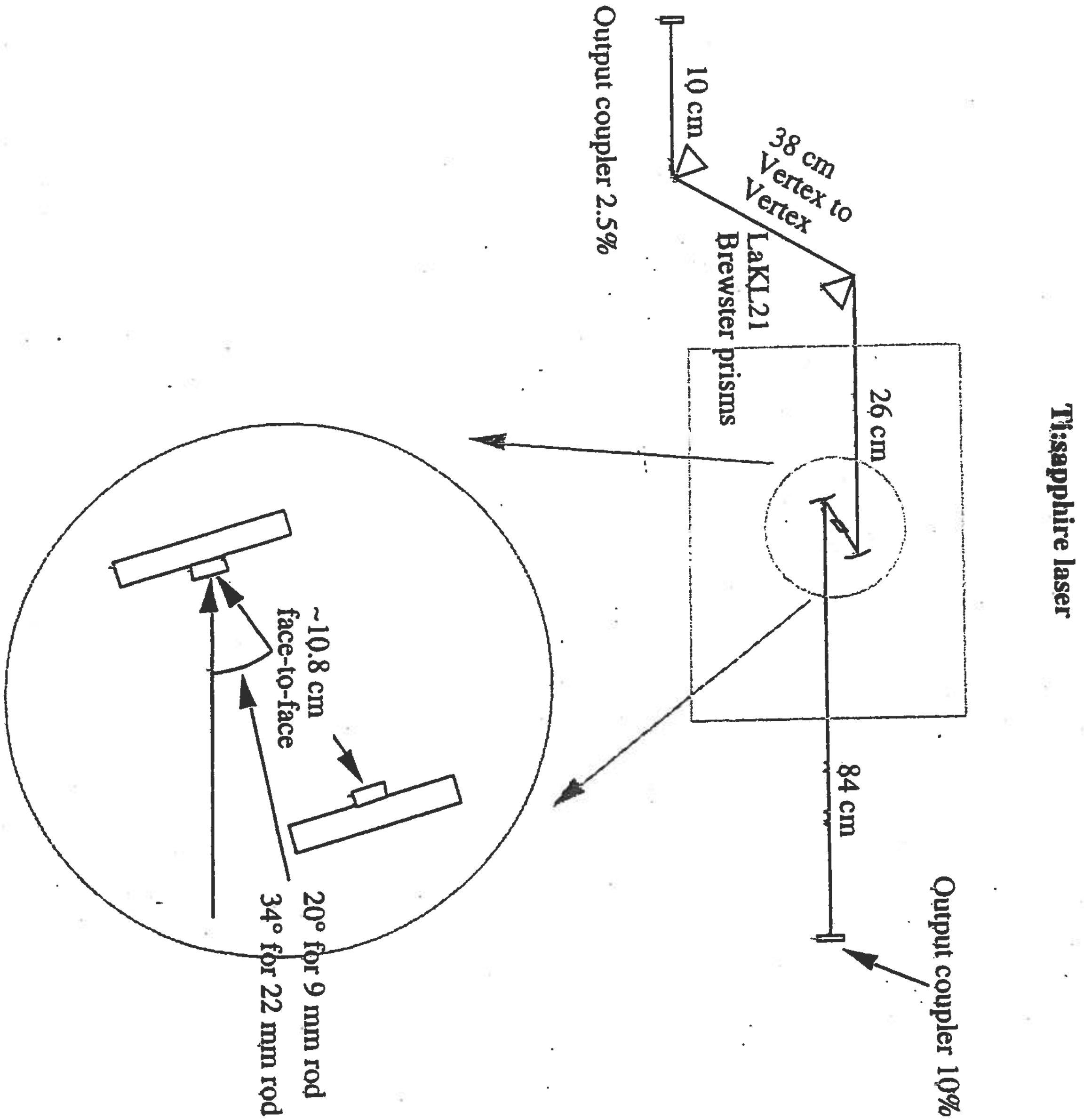

Figure 1: Schematic Diagram of mode-locked ti:sapphire laser.

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Most of the dimensions given here are not critical; i.e. the total cavity length and the length on either "arm" of the laser can vary some amount. The prism separation (for a given ti:sapphire crystal) is somewhat critical to obtain the shortest pulse durations, and the separation between the two 10 cm curved mirrors is very critical, as well as the position of the crystal between these two mirrors. However, these distances are not readily measurable, and the numbers on the diagram are only a starting point. The crystal is positioned very close to (≤1 mm off) the center between the two mirrors.

Figure 1 shows a prism separation of 38 cm, updated from the figure of 51 cm which was included in our paper describing the production of 17 fs pulses. We found that the prisms used in this laser had been manufactured incorrectly to 60.3∞, rather than to the correct Brewster 63∞ angle. A smaller prism separation is required for the 63∞ prisms; we have obtained similar (<20 fs) performance using 63∞ prisms, with somewhat higher output power.

Figure 2 is an illustration of a revised version of this laser which produces shorter pulses (<11 fs and >400 mW). This version uses a crystal with a 4.75 mm path length-- roughly a factor of two shorter than in the previous work. This laser uses fused silica prisms, rather than LaKL21. We have found this laser to be exceptionally easy to work with-- easy to align and easy to start. Apparently pump mode matching is easier for shorter crystals, and thermal effects seem to be smaller as well. We would recommend this configuration unless you need very high power (we have not tested how much pump energy the shorter crystal can sustain long-term). For this laser, the asymmetry in the two laser arms seems to be essential for stable modelocking.

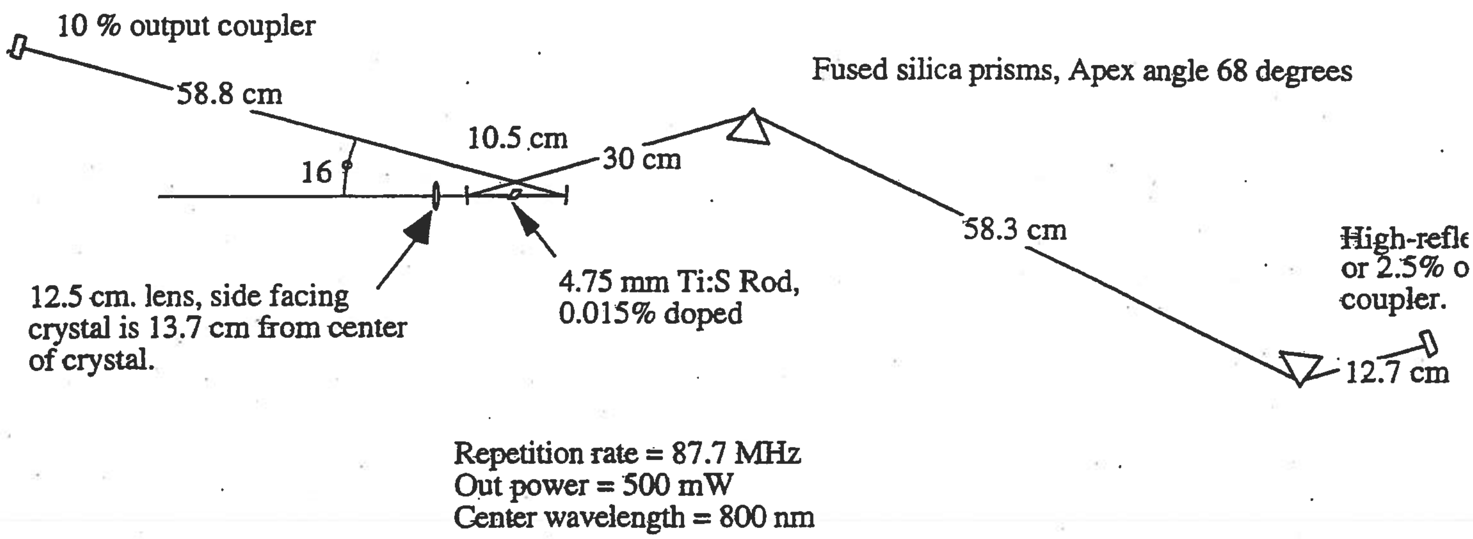

Figure 2: Schematic Diagram of 11 fs mode-locked ti:sapphire laser.

The correct angle of incidence into the curved mirrors controls the beam astigmatism. After the initial setup, this angle can be walked to obtain a round output beam. "Z" or "X" cavity configurations seem to work equivalently. Likewise, the pump beam can be incident to either

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end of the crystal. It is somewhat more convenient to arrange for the residual pump light to exit on the side of the laser away from the output coupler.

Most of the critical adjustments in the laser have to do with the pump beam, the two curved mirrors, and the crystal position. Thus, we have designed a setup where these elements are all mounted on a rail and can be moved collinear to the beam path:

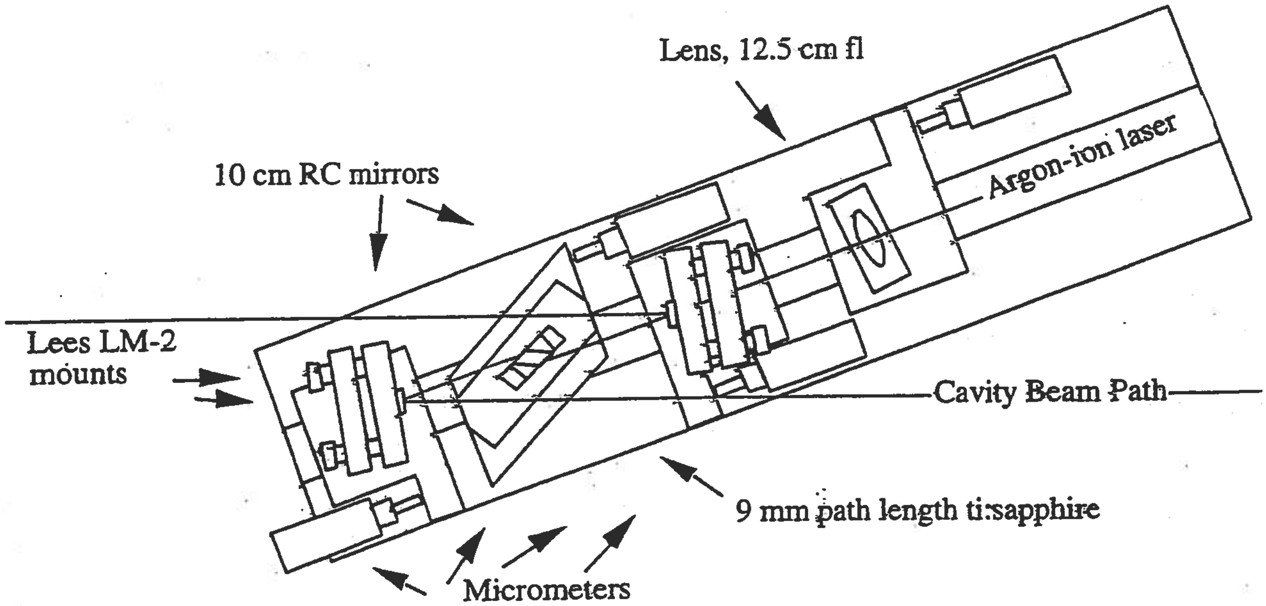

Figure 3: Top view of layout of ti:sapphire crystal and focusing optics.

Figure 3 sows a "Z" configuration. An "X" configuration works equally well, and can be more compact. The laser can be built directly onto an optical table. The beam height is at 4 inches, which is convenient for most argon-ion pump lasers. For most Ar+ lasers, the polarization must be rotated, either with a pair of mirrors, or with a half-wave plate.

The remaining mounts, two end mirrors and two prism mounts, are quite straightforward. Mounts from Lees Optical Instrument Co. are highly recommended, although Klinger mounts with differential micrometer will also work if you already have some.

A warning about the following diagrams-- the parts may be in some cases drawn somewhat out of shape, so refer to the written dimensions. Someday, we may redo these drawings to "machine-shop" standards.

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Translator base plate

The 4-carriage translator rail will bolt to this base plate-- make sure the bottom does not have even a hint of wobble when flat on the table. For flexibility, we drill holes for the micrometer mounts all along the rail-- for the laser using a 9 mm rod, referring to figure 3, the holes starting at the bottom left which are used are: 1, 2, 30, and 31, and from the top left 23, 24, 43, 44. You can restrict your drilling to holes in this vicinity; alternately, you could drill all the holes, but tap only as needed.

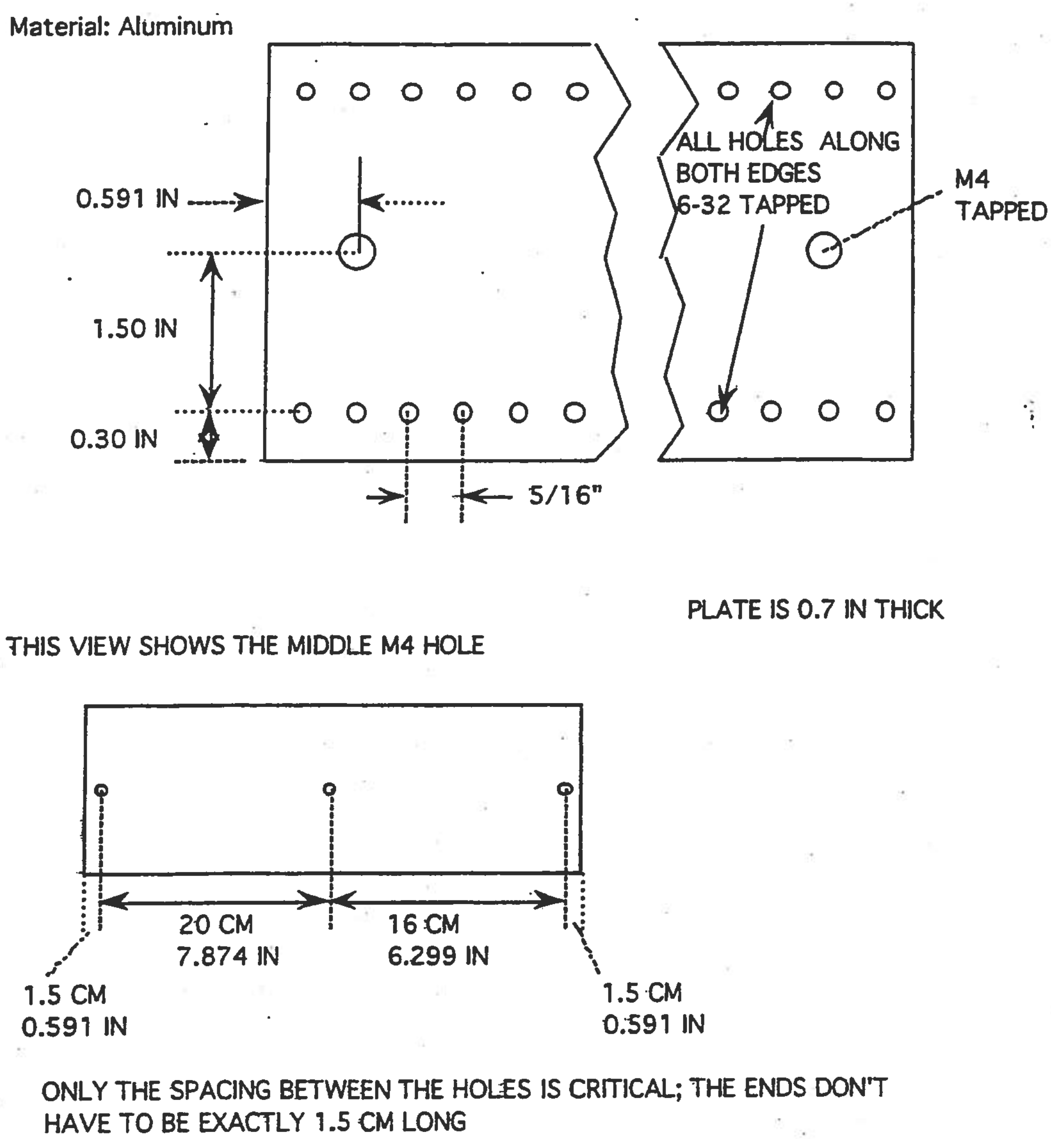

Figure 4: Base plate for laser sub-assembly.

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Mirror Holder Plates

Two of each of these plates is needed, one each for the two mounts holding the 10 cm mirrors. The bottom "L" shaped plate bolts to the translator carriage (note the 6-32 tapped hole in the side of the "L"-- this is for the spring attachment). It is helpful to countersink on both sides of this plate for the M3 screws-- this way, the micrometer can mount on either side of the carriage for flexibility. The LM-2 mount bolts to the top plate with a standard 1/4-20 SHCS, and this plate attaches to the bottom plate. One of the 6-32 screw holes may not be accessible when the LM-2 is properly positioned.

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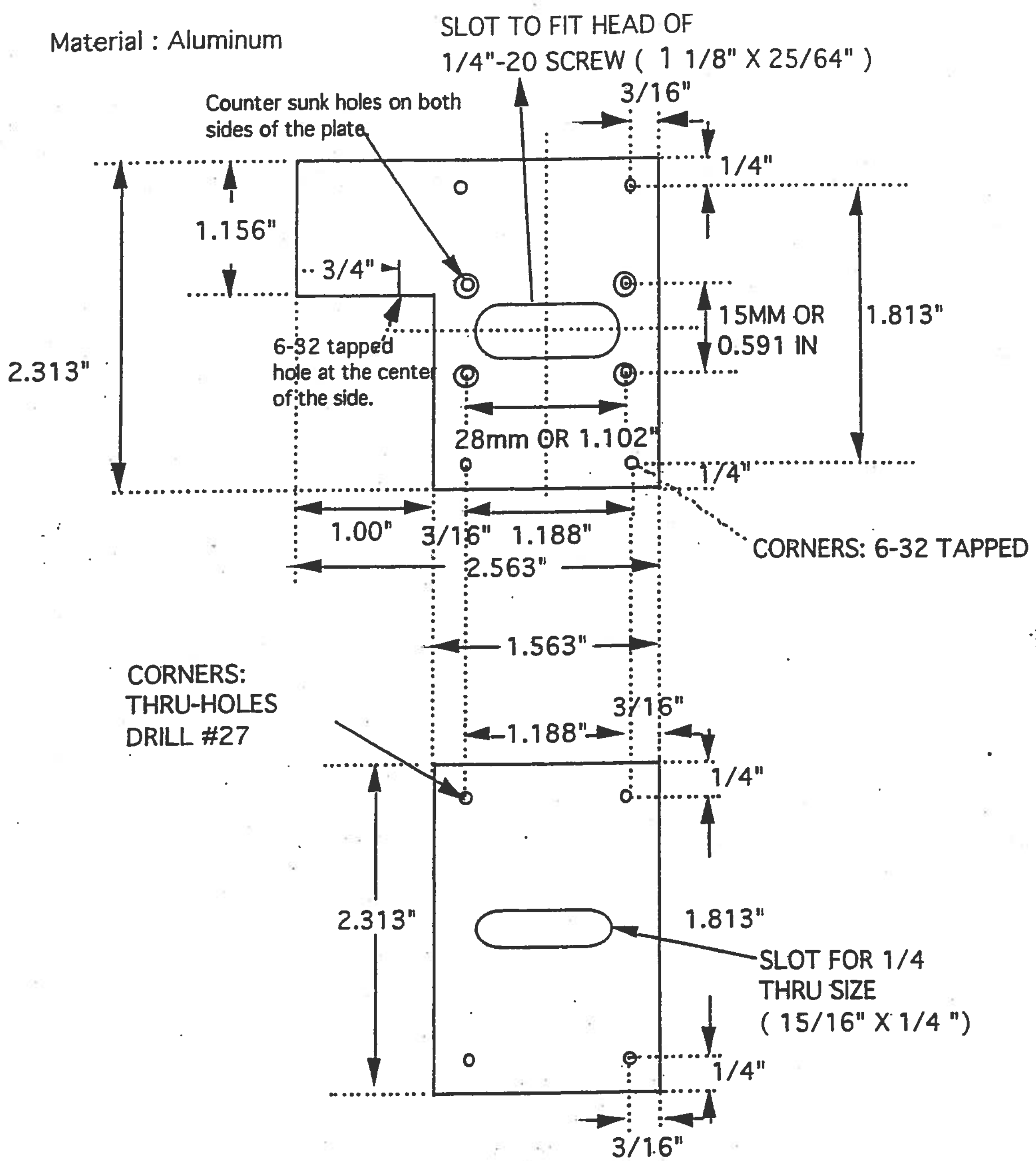

Figure 5 Mirror holder plates (two of each piece are needed).

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Micrometer holders

Four of these parts are needed, although you may want to make more since these have two different possible orientations. The design of figure 3 uses three as shown, and one of the mirror image. A spring anchor screws into the 6-32 threaded hole, a the spring stretches between this and the anchor in the mirror, lens, of crystal mount.

Micrometer Holder

Quantity : 3 plus
1 mirror image

Material : Aluminum

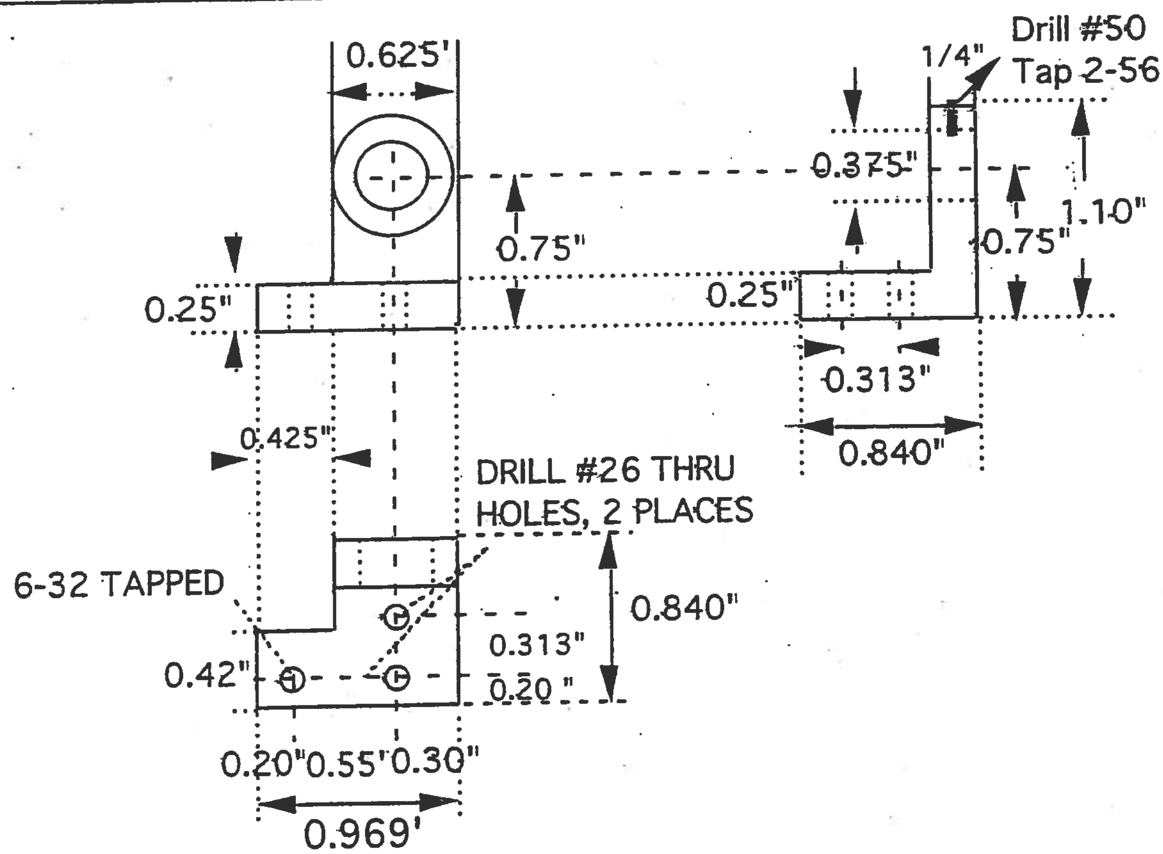

Figure 6: Micrometer holders. Three of this orientation, and one of the mirror image are needed.

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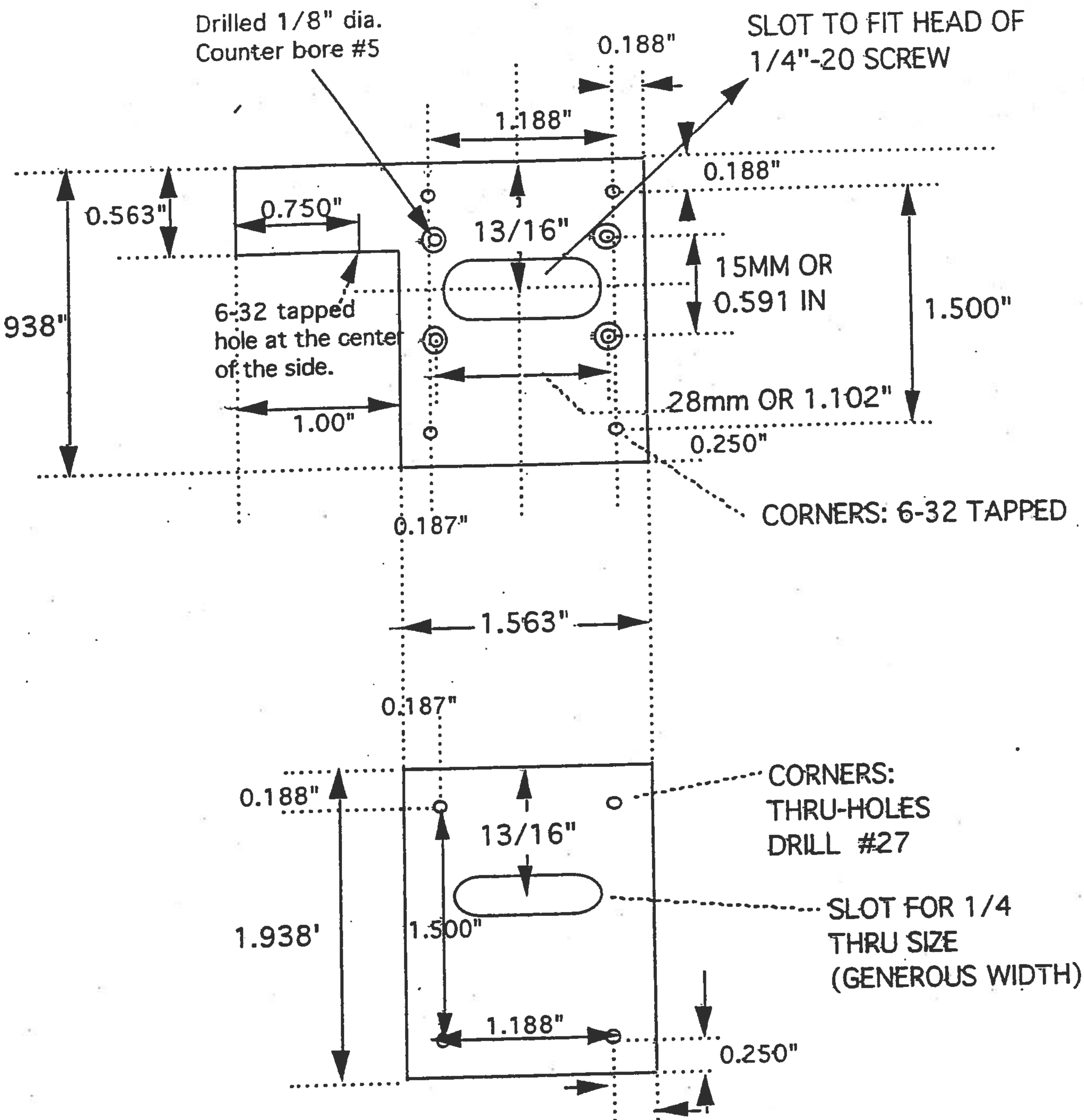
Lens mount

This is virtually identical to the mirror mounts, but is a bit shorter to allow the lens to move closer to the mirror mount. Onto this plate is assembled an LMR-1, a PH-1, and a TR-1.



ach plate is 3/8" thick

Figure 7 Lens holder plates (one of each piece are needed).

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Ti:sapphire crystal holder

The crystal holder is the most complex piece, consisting of seven major parts. Starting from the bottom, there is a slotted plate which bolts onto the translator. Into this slot is a "carriage" which can slide parallel to the crystal face, to adjust where the beams pass through. (We believe that near the edge of the crystal may be better for heat conduction) Onto this plate is a plate which swivels (pivoting on a small dowel pin), to adjust for Brewster. Onto this plate bolts a "stand" which brings the crystal to the proper height. This piece has a top piece which clamps a copper crystal-holding disk. The disk itself is two pieces-- the crystal sandwiches snugly into this copper disk (you can use a small dab of heat-sink grease (Radio Shack) to improve thermal contact) , which also has a lever on top to rotate the crystal normal to the face.

The rod is water-cooled. Small fittings screw into the holes below the crystal; use 1/4" tygon to connect to water (teed-off from the input to the argon laser). We have not yet determined the necessity of water cooling of the crystal. The orientation of the crystal, however, is critical for good modelocked operation.

The copper disk illustrated is for a 9 mm long crystal. For shorter crystals and different shapes, you can modify the disk. It is helpful to inset the faces so that they can be cleaned; i.e. for a 5mm crystal, taper the thickness of the disk so that it is ~4.5 mm thick in the center. Our 4.75 mm crystal was 5 mm x 8 mm square, and did fit inside the same size disk.

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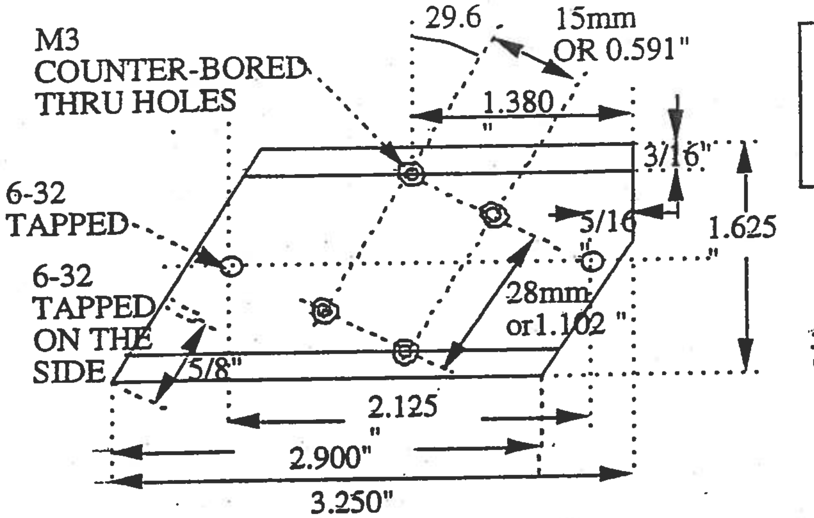
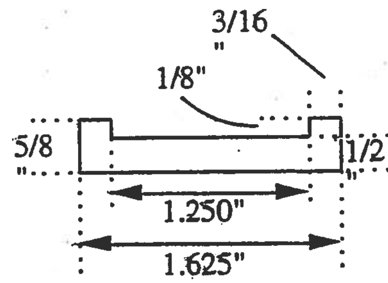
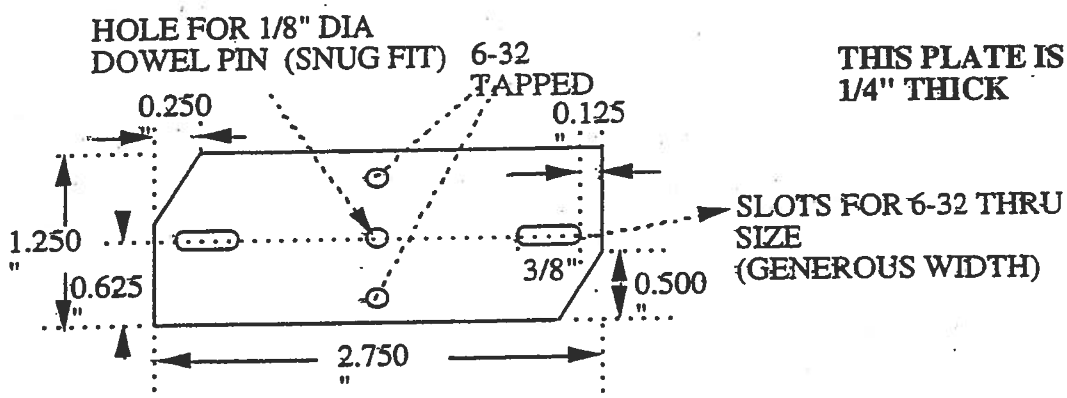
Plates for crystal holder

Material : Aluminum

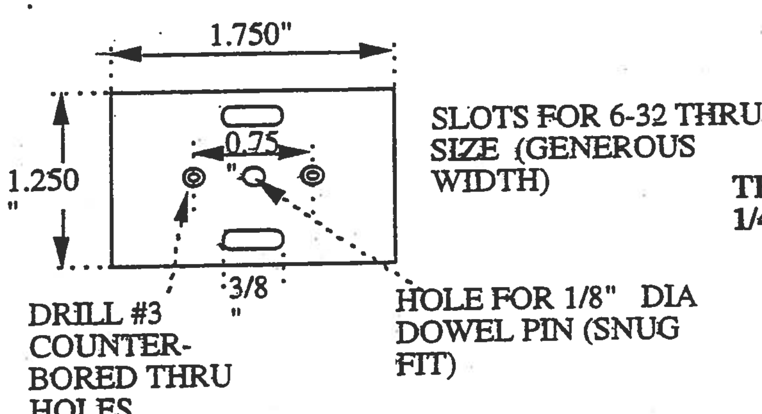




NOTE : ALL ANGLES OTHER THAN 90 DEGREES ARE 29.6 DEGREES FROM THE VERTICAL



THIS PLATE IS 1/4" THICK



THIS PLATE IS 1/4" THICK

Figure 8: Ti:sapphire crystal slide-and-pivot base plates. One of each piece is necessary.

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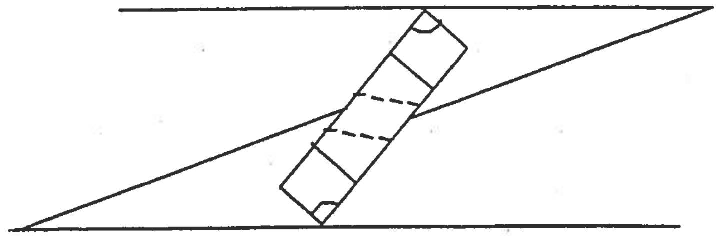
Crystal Holder
Material : Copper
Crystal stand
Material : Aluminum



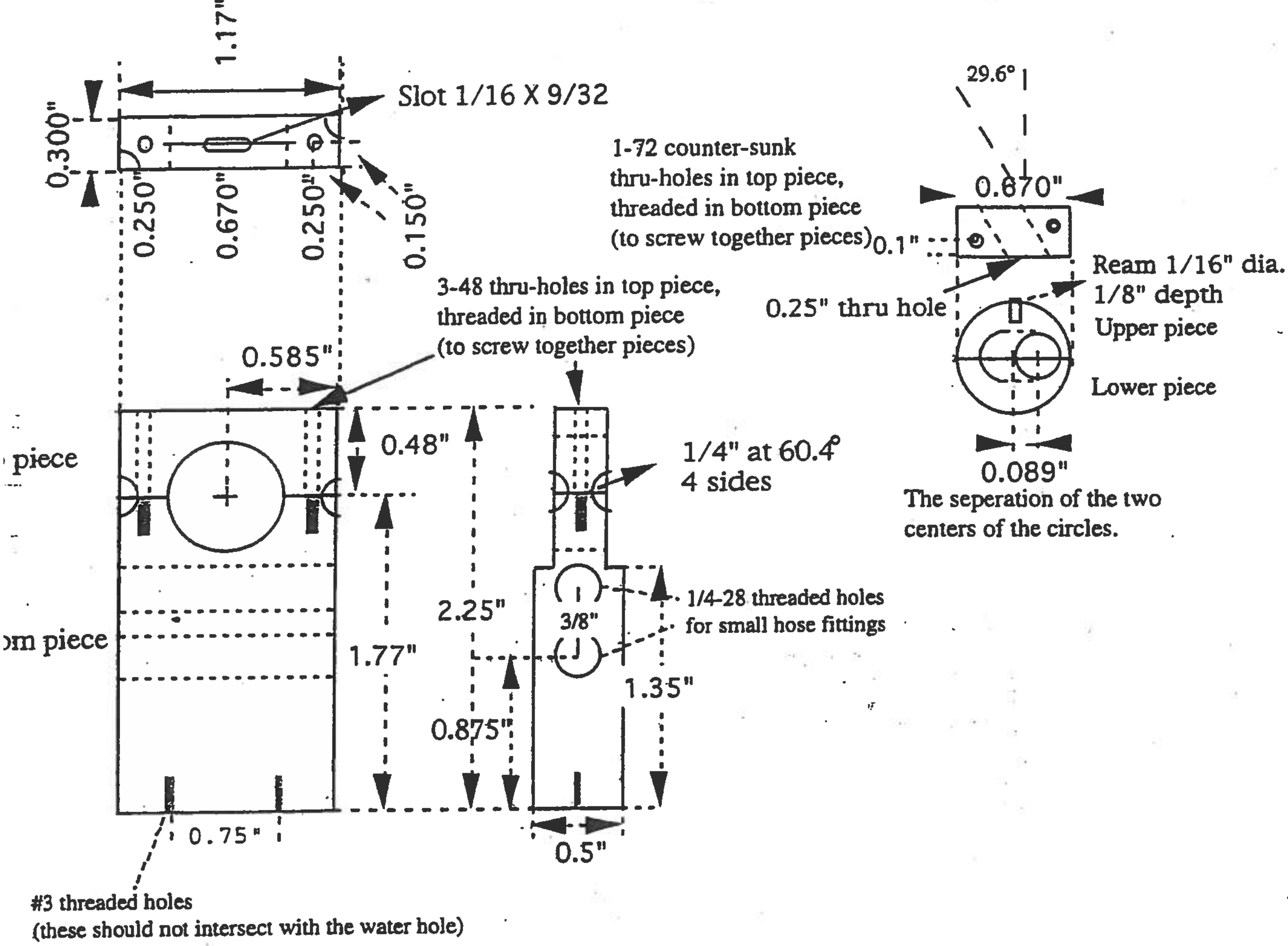


Figure 9A: Ti:sapphire crystal holder and stand. Holder is a small copper disk (this design is for a 1/4" diameter rod), while stand is made of aluminum. Each consists of a top and bottom piece.

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Name	Crystal holder
Material	Copper
Date	Feb. 3, 1993

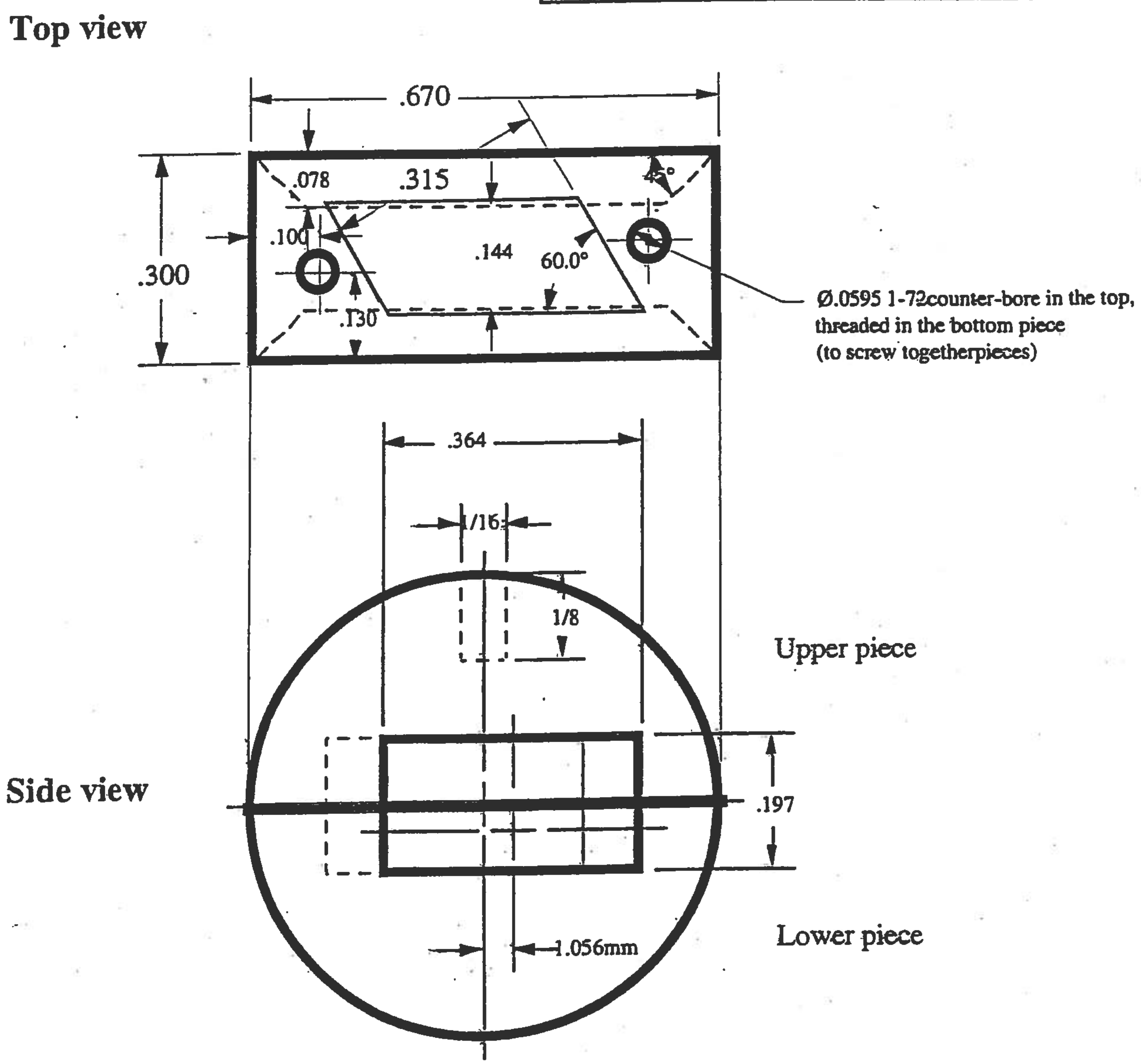

Figure 9B: Ti:sapphire crystal holder . Holder is a small copper disk (this design is for a 4.5 mm rectangular rod). The copper holder has a thickness of 0.3" at the outside edge, which then tapers down to a thickness of 0.144" in the center (see dotted lines on diagram).

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Prism Mounts

We have used a number of different prism mounts. Translation of the prisms in and out of the beam is essential. Rotation to find minimum deviation is essential as well. Adjustment of the tilt of the prisms while the laser is mode-locking is very difficult; for this reason we prefer to set the prism orientation outside the cavity, and leave it. If the prism is cut well, it should be square enough to mount directly onto the translator. Otherwise, shims can be used, and the prism can be glued in place once the proper orientation is found.

A rotation stage for the prisms is preferable, and easier to optimize. The following rod can connect between a Newport 481 stage and a Daedal translator:

Item name : Spacer
Quantity : 2
Material : Stainless steel
Date : 2/10/1992

By : Chung-Po Huang
335-1457

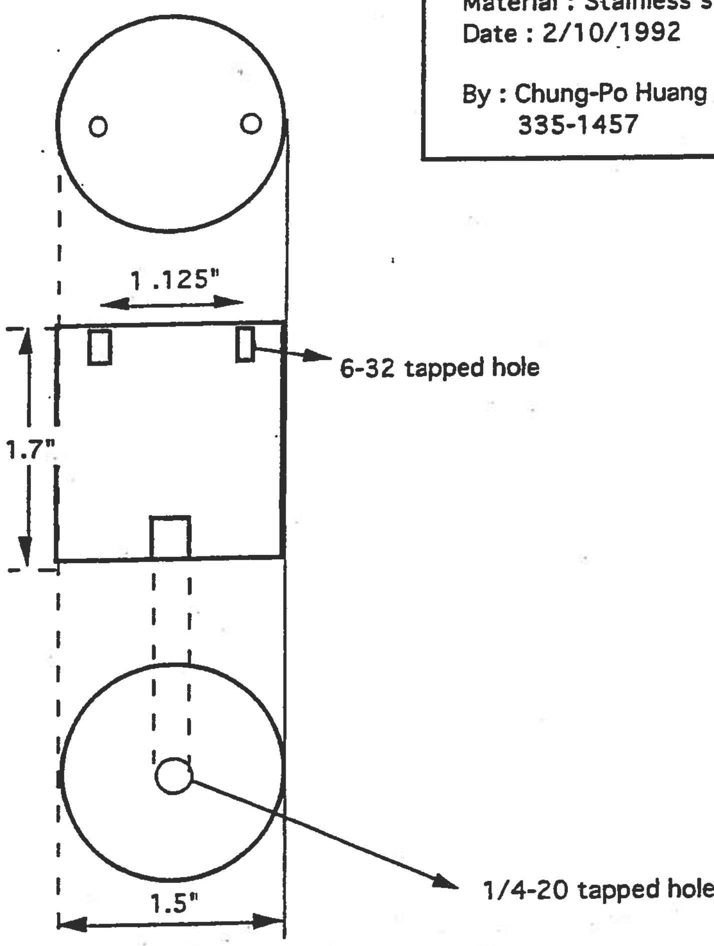

Figure 10: prism mount adapter post.

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Alternatively, one can mount the post directly onto a Thorlabs PB1, and use a ring around the base to keep it in place while rotating:

3/8" thick aluminum

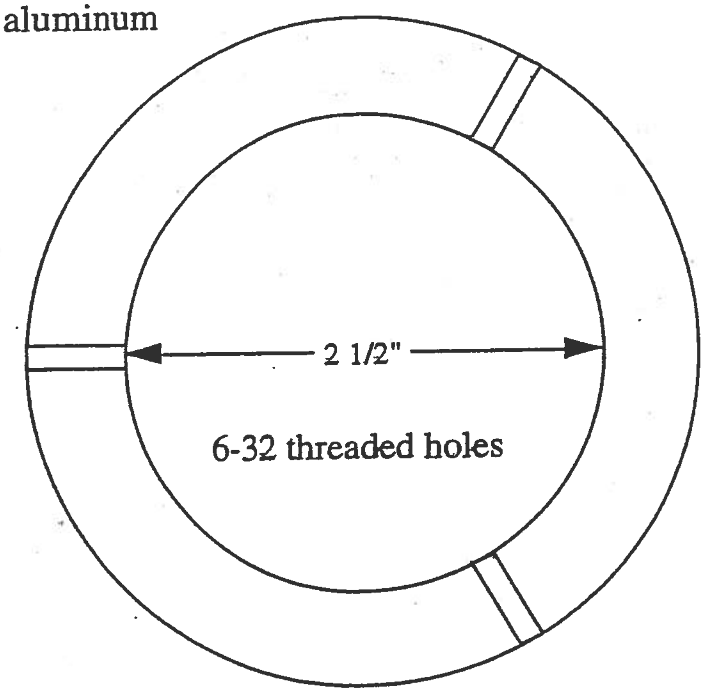

Figure 11: prism rotation ring.

In this case, the post must be 7/8" longer than in figure 10. This arrangement seems to be sufficient for adjusting the prisms; however, we have used it in only one laser so far.

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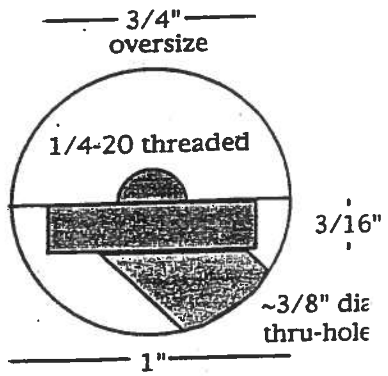
Polarization Rotation

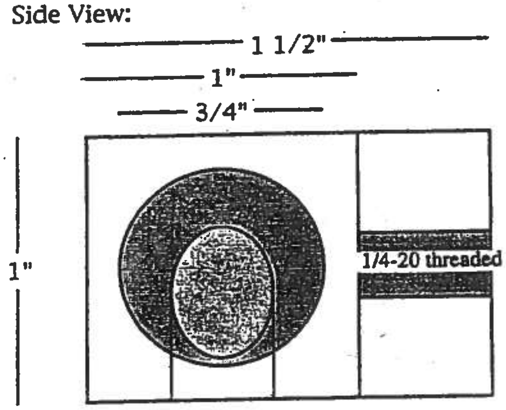
The following pieces can be used with two 0.75" dia. Ar+ mirrors to flip the polarization of the beam. The pieces are mounted onto a Thorlabs Model PSC post mounting clamp. Take off the face plate, and countersink a hole and a slot for 1/4-20 in the backside. It may take several tries to assemble the unit in the correct orientation. This asssembly is the replacement for a mount which we threw together and which had a stability problem-- solid mounts for the pump beam are a must. The holes in the back are there so that residual leak-through light does not heat the mount.

Part #1:

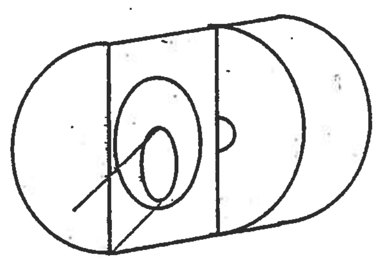
End view:



Side View:

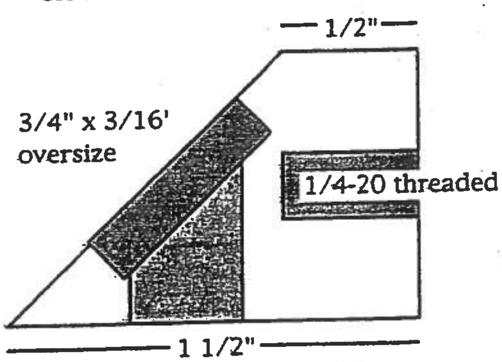


Perspective:

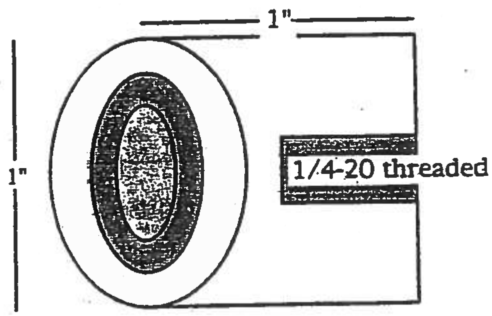


Part #2:

Side view:



Side view (rotated)



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Parts List

Qty	Description	Price ea	Price total	Source
1	Ti:sapphire crystal Brewster cut, 9 mm length 0.10% doping for ~90% absorption of 488 nm light or Ti:Sapphire 4.75 mm path length, 0.15% doping, 5 mm height x 8 mm width.	1500 or 1865	1500 or 1865	Union Carbide Crystal Products 750 S. 32nd Street Washougal, WA 98671 (206) 835-2001 (206) 835-9848 FAX Attn: George Venikouas
4	Prisms, LaKL21 glass, Brewster cut (63∞ apex angle), approximate size 15 mm. For 4.75 mm crystal: fused silica prisms, apex angle 69.06±0.25 deg. (2 prisms in cavity, 2 prisms for extracavity compression.)	~200 ~125	800	R. Matthews Optical Works 26280 Olhava Way, Suite A Poulsbo, WA 98370 (206) 697-6160
4	Mitutoyo Micrometer Head #148-804	35	140	Bixby Machine Tool 1218 N. Fancher Spokane WA 99212 or other Mitutoyo dist.
1	Linear motion slide, 4 carriages on a 390 mm long rail. Stainless steel, pre-loaded with end seals. Part # 4RSR12WMUUC1+390LM	282	282	THK America 3745 Wilshire Lane Eugene, OR 97405 PHONE (503) 484-0408 FAX (503) 484-4703
4	Sapphire endstone, .31" diameter .060 thick, Part #E7.87	6	24	Swiss Jewel Co. Lafayette Building Philadelphia, PA 19106 (215) 925-2867 FAX 922-3055
1	Lens Mount Part # LMR1	18	18	Thorlabs, Inc. P.O. Box 366 Newton, NJ 07860 (201) 579-7227 FAX (201) 383-8406
4	Adapter for 15mm optic Part # AD15MM (for S-P mirrors)	12	48	"
4	Adapter for 1/2" optics (for CVI curved mirrors) Part # AD1	12	48	"
1	Post Holder PH1	10	10	"

1	Post TR1	4.75	4.75	"
4	Prism Mounting Hardware #PMH	7	28	"
4	Iris diaphragm #ID12 (for defining beam path)	33	132	"
2	Base #PB1 (Optional-for prisms)	19	38	"
4	LM-2 Optic Mount with sapphire vee and flat, 1" optic, stepped hole, left "L" shape, delrin pins 2-ti:sapphire cavity 2- argon ion laser mirrors	160	640	Lees Optical Instrument Company P.O. Box 530 Niwot, CO 80544 (303)530-5287
2	LM-3 Optic Mount with sapphire vee and flat, 1" optic, stepped hole, left "L" shape, delrin pins	205	410	"
4	LM-2B Riser base for 4" beam height 2-end mirror 2-argon ion beam mirror	60	240	"
1	Plano-Convex lens, 12.5 cm fl Part # KPX097-AR.14	40	40	Newport Corp. P.O. Box 8020 Fountain Valley, CA 92728-8020 (714) 963-9811 FAX (714) 963-2015
2	Rotation Stage Part # 481-S (optional-for prisms)	360	720	"
2	Translation Stage, 1.75 " square table, side-mounted drive with positive position lock Model 4052	184	368	Parker Daedal Pacific Motion Group 35912 SE 46th Street Fall City, WA 98024 Ph. (800) 522 - 7387 FAX: 206) 222 - 7873
1	Single-Stack high reflector for 800 nm center wavelength. NRC # 05B20UF.20 CVI #TLM2-800-0∞-1037 Spectra-Physics # G0324-002	235	235	Newport Corporation P.O. Box 19607 Irvine, CA 92713-9607 Phone: (800) 222-6440 CVI West, Alex Jacobson 361 Lindberg Avenue Livermore, CA 94550 Phone: (510) 449-1064 Spectra-Physics Inc. 1250 W. Middlefield Rd. P.O. Box 7013 Mountain View, CA 94039-7013 Phone: (800) 456-2552

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1	Single-Stack output coupler for 800 nm. Transmission ~10-12%. NRC # 10B20OC20 CVI #PR2-800-90-1F-1012-UV	290	290	" "
2	10 cm radius of curvature mirrors, high reflector at 800 nm, high transmission at 488-514 nm. NRC # 05BV10UF.20 Spectra-Physics #G0079-012 CVI # SWP2-0∞-R800-T(488-515)-SMCC-0537-0.100-UV	260	520	" "
8	Spring Anchor, #9634K11	1.87	15	McMaster Carr P.O. Box 54960 Los Angeles, CA 90054-0960
4	Spring, #9651K11	.49	2	"
1 pkg	M3 x 10 SHCS, # 91290A115	5.50	5.50	"
4	Hose-Barb Fitting, #S40-1	.18	.72	Value Plastics Inc. 3350 Estbrook Dr. Ft. Collins, CO 80525 USA (303) 223-8306 FAX 223-0953

Specifications

The LaKL21 prisms must be custom-made. We ordered the glass directly from Schott, and sent the glass to the prism fabricator, R. Matthews Optical.

The glass specifications are:

LaKL21 prism glass:
1) 0.9" x 0.9" x 5" block
2) Precision quality, grade AA
3) Stress birefringence ≤ 6 nm / cm
4) Homogeneity better than ± 5 x 10^{-6}

Supplier:

Schott Glass Technologies Inc.
Attn: Robert Chamberlain
1400 North Harbor Blvd.
Suite 225
Fullerton, CA 92635
Ph. (714) 871 - 0800 FAX: (714) 870 - 0162

The instructions for the fabricator are:

Prisms to be manufactured from user-supplied material.

Material: Precision quality, grade AA LaKL21 Schott Glass, with stress birefringence ≤ 6 nm / cm and homogeneity better than ± 5 x 10-6. Wavelength: 840 nm

Prisms specifications -
1) 2 surfaces to be polished to a surface figure of l/10 in transmitted wavefront, with beam near minimum deviation. Surface quality to be 20-10 laser grade.

2) Apex Angle : 63.00 ± 0.25 deg.
All 4 prisms must have same apex angle, within 10 seconds

3) Prism dimensions ≈ 15 mm on a side, and ≈ 15 mm high. 2 surfaces polished. Top and bottom of prism must be square to sides and parallel within 1/2 degree.

Fabricator:

R. Matthews Optical
26280 Olhava Way, Suite A
Poulsbo, WA 98370
(Phone 206) 697 - 6160 FAX (206) 697 - 7417

Another prism fabricator who comes highly recommended by Brett Bouma at the University of Illinois at Chicago is Planar Optical, (716) 671-0100. A fellow named Horst is the manager who is familiar with prism fabrication.

For quartz prisms, the proper apex angle is 69.06 degrees. R. Matthews can also supply these at a very reasonable cost.

Mirrors

We have used a number of different output coupler and flat high-reflector mirrors in this laser. Any single-stack dielectric mirror with a broad reflectivity bandwidth will do fine -- we use Newport and CVI mirrors. For the high-reflector, a protected-silver mirror even works, although the protective overlayer can introduce phase problems sometimes. We are in the process of determining which mirrors are ok to use. We have found ~10% - 12% transmission to be a reasonable coupling for 5W pumping power. The modelocked output power from the laser in this case is 400 - 500mW. Using 9W pump with a 30% output coupler, we obtained 0.8 - 0.8W modelocked output. The high power setting is more difficult to align however. If too low an output coupling for a given pump power is used, it is harder to keep the laser from running without some CW output as well as the pulses, and also harder to keep the laser from double-pulsing.

The two 10-cm radius of curvature mirrors are a bit more problematic. The mirrors from Newport or the Spectra-Physics 3900 laser work well. However, it may be difficult to obtain the S-P mirrors if you do not already own a 3900 laser. CVI laser can also make these mirrors, but their version reflects somewhat more of the pump light.

Pump laser

We have used several argon-ion lasers successfully (in all-lines 488 nm) with these lasers, including a Spectra-Physics 2040 and 2060 with Beamlok, a S-P 2017, a Coherent 310 with Powertrack, and a Coherent Innova-20, manufactured in 1983. Pointing-stability is a concern-- pumping with an I-20 laser gives marginal long-term stability for mode-locking. However, even using this pump laser, the ti:sapphire can mode-lock uninterrupted for up to 2 hours after the pump laser warms up. The other lasers that we have used all give decent stability. The 2017 is a bit underpowered for starting the laser modelocking, although we were not very experienced at proper alignment when we were using the 2017. A minimum of 5 watts in a TEM00 mode is desirable for initial alignment.

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Construction and Alignment Procedure

Following is a basic alignment procedure for these lasers. It is best to try very hard to get beams level with the table and square with the table when appropriate. We are not yet certain which adjustments are most critical, so it is better to be careful from the start than to be frustrated later.

1. Bolt THK rail to base plate. Place base plate on table at the correct angle with respect to the table holes (20∞ for a 9 mm crystal).

2. Align the argon-ion pump beam along the center of the rail at 4 " beam height. Assemble mount for the 10 cm mirror closest to the lens. Adjust the position of the mount until it is at a ~10∞ angle with respect to normal, for 9mm crystal, (16° for 4.75mm crystal) and with the pump beam passing through the center of the mirror. Check transmitted beam to make sure that the mirror does not deflect it. You can do this by making a spot on a far wall where the beam hits, then inserting the mirror and getting the spot centered. Since the height of the mirror is not adjustable, you may have to change the height of the pump beam by a small amount. (Keep the beam level with the table!) We consistently have more success optimizing this laser when we take care that translation of the components does not misalign anything. Once the micrometer is in place with the spring attached, glue a sapphire endstone to the mount so that the micrometer seats on a hard surface.

3. Assemble the lens mount , and insert the lens so that it does not deviate the pump beam when translated. A small (~5∞) rotation of the lens with respect to normal will slightly improve the overlap of the pump beam with the cavity mode. Translate the lens along rail to make sure it remains undeviated. You may have to spend a little time iterating the alignment of the mirror and lens.

4. Assemble laser crystal mount. Place the crystal in bottom half of copper holder, with copper holder square to table. Rotate the crystal in the holder so that the surface reflection from the crystal is parallel to the table. Clamp the crystal with the top copper half. Recheck the reflection from the crystal. You may need to unscrew and readjust the crystal. Clamp the copper crystal holder in the mount. Use a small length of S.S. bar as a lever to rotate the Ti:sapphire crystal face-normal. Note that there are two possible axes of rotation of the crystal-- along the axis of the crystal, and normal to the face of the crystal. You have now set the axis rotation; the rotation of the copper holder in the aluminum mount will allow face-normal rotation. Then rotate the mount on the base plate to obtain minimum reflection of the pump beam (Brewster angle).

5. Assemble the second 10 cm mirror mount, and position similar to the other 10 cm mirror.

6. Assemble the two end mirror mounts, using the LM-3's and bases.

7. At this point, you can make a CW ti:sapphire laser. Place the end mirrors (on the prism side of the laser, use a temporary mount and mirror) as close as they can get to the 10 cm mirrors. Pump at 5 watts. Align for lasing by overlapping fluorescence spots. Optimize

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power and mode by alternately tweaking horizontal and vertical on both end mirrors, and translating the lens, curved mirrors, and crystal. You should be able to obtain ≈ 1W output.

8. Extend the cavity to the desired total length. Do this by moving the mirrors, one at a time, on the table while maintaining lasing. Stop every few inches and optimize the laser power by moving the curved mirrors and crystal, and by adjusting the end mirror alignment. At ~2 meter cavity length, you should be able to achieve >6-800 mW output, and a round cw mode. We have found that the laser modelocks best when the extension is done asymmetrically, with the arm which contains the prisms much longer than the other arm (see Fig. 3).

9. Assemble the prism mounts. Before using the mounts in the cavity, check for flatness by setting up a He-Ne at constant 4" beam height, and checking that surface reflections from both sides of prisms remain at constant beam height. If not, use shims to adjust the prism orientation. Alternatively, one could mount the prism translator on a blank mirror mount to give adjustable tilt.

10. Insert first prism by grazing a bit of the ti:sapphire laser beam off the apex of the prism. Rotate the prism for minimum deviation of this light.

11. Insert second prism at the proper separation into this picked-off beam, and adjust for minimum deviation.

12. Retroreflect this beam using the end mirror in the LM-3 mount. Once the beam is retracing itself, translate the prism into the beam until the laser is barely lasing. Optimize the power with the prism side end mirror. Translate the prism fully into the beam. Optimize power in this configuration-- you should be able to get > 600 mW. Adjust the end mirrors, the lens and the crystal and 10 cm mirror positions to get a round cw TEMoo mode and MAX power.

13. Adjust the face-normal rotation of the rod. For this procedure and for alignment of the mode-locking, we highly recommend the "poor man's OMA" described elsewhere in this document. This device gives the experimenter information on both the mode shape (in one dimension) and the bandwidth, at a fast (30 hz) update rate. To adjust the rotation, set up a razor blade at beam height on a base, or use a small muffin fan as a chopper. If the blade is moved into the beam at the dispersed end of the cavity (from either side), the laser wavelength will tune. As the rod is rotated, you will see that the wavelength tuning is continuous only for a small range of orientations. With the fan running, the laser will rapidly tune, and will create a smear on the video screen of the OMA. Adjust for the smoothest smear possible (although it will not necessarily be free of brighter lines). Clamp the rod orientation at the center of this range.

Peak up the laser power again. Make sure that the beam is level. The 800 nm beam and the Argon beam should be almost overlapped on the curved mirrors - if not, walk the 800 nm beam using the end mirrors until they are. You can check if the prisms are level by looking at the two beams reflected from their faces - they should be parallel and at the same height.

14. Now you should be ready to modelock the laser. Use the OMA to look at the spectrum from the laser, and let the beam propagate until you can see the mode shape (use a mirror to

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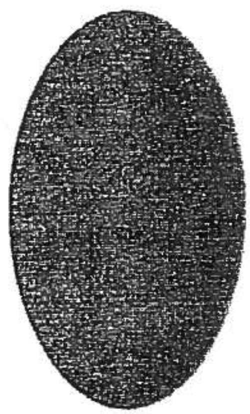
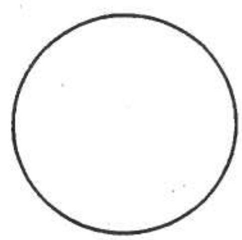
project it on to a card close to where you are working). Using a lens to look at the mode can be misleading. A fast photodiode can also be helpful. The following procedure consistently works for us, to find modelocking within ~10 minutes (using the 4.75mm Ti:S rod configuration). Align the laser for max power cw and for a round near-TEM00 mode. Translate the prisms so that the beam is within 1 - 2 mm from edge. Move the crystal and curved mirrors a small distance until the output beam looks oval (like an egg), as shown below. We achieve this by translating the curved mirror farthest from the lens towards the crystal, until the beam looks slightly elongated vertically. Then move the crystal and lens to fill in the center of the oval mode. At the same time, the spectrum will get "jumpy" when the output coupler mount is tapped. Tapping the 10 cm mirror farthest from lens should then cause the laser to self-modelock. (Don't be afraid to be moderately vigorous-the Lee's mounts are very stable.) You can also try the mode "knocker" described later in this document. Adjusting the prisms (amount of glass the beam passes through; prism separation in ~1-2 cm increments) may also be useful. When aligned properly, the modelocked laser mode is perfectly round and energy efficient, while the cw mode is oval and blurred, with less power than in the modelocked case (up to 50% less). You are getting closer when:

-> The spectrum will get "jumpy" when tapped, or the cw spectrum is broader when not tapped. Also, a spectrum with two or more wavelengths separated by the bandwidth of the mode-locked pulses (~20-80 nm) is a sign that you are close.

-> The photodiode signal will get very noisy when the mirrors are tapped.



cw mode



modelocked mode

In general, we have found that by translating the crystal and the end 10cm mirror (the one far from the lens), we can find the mode-locked mode. This mode is much smaller than the cw mode, and of higher power. Also, the beam should be very close to (possibly slightly clipping) at the apex of the prism near the end mirror. Beyond these pointers, there are no hard and fast rules. However, this laser does have the necessary adjustments. Although it might take you a while at first, after you gain experience in what to look for, you will have no problem aligning for modelocking.

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15. Often, there is some CW light co-lasing with the mode-locked light. The best way to get rid of this is to turn down the pump power. You can suppress this by using an aperture clipping in the horizontal or the vertical direction. Often, if the laser is hard to start, you can temporarily increase the pump power by <0.5W, start it, then turn the power down a bit.

16. When the laser first mode-locks, it may not have its full potential bandwidth. By adjusting the prisms (varying the amount of glass in the beam, small rotations), and also optimizing the crystal and mirror alignment, you should be able to find the short-pulse "mode".

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A Simple OMA for Laser alignment

We find that the following simple spectrometer with a fast update rate is very helpful for getting the laser modelocking. It is simply a Littrow-angle spectrometer with a TV camera readout. The device only allows a qualitative readout of bandwidth, but it also gives some mode information on the screen. If quantitative readout is desired, you can use a frame-grabber card. We have software for use with a Data Translation DT2255 for the Mac II and LABVIEW II. This setup is still not particularly accurate, but gives a reliable relative bandwidth.

We build the spectrometer on a small length of slotted rail. The entrance slit and TV camera are on an endplate, with the slit directly above the camera. Focusing of the device is accomplished by putting the lens at the correct approximate distance (its focal length), and sliding the camera and slit forward and backward. The Lens and grating can be mounted on conventional bases and mirror and lens mounts. Make a cover from heavy cardboard.

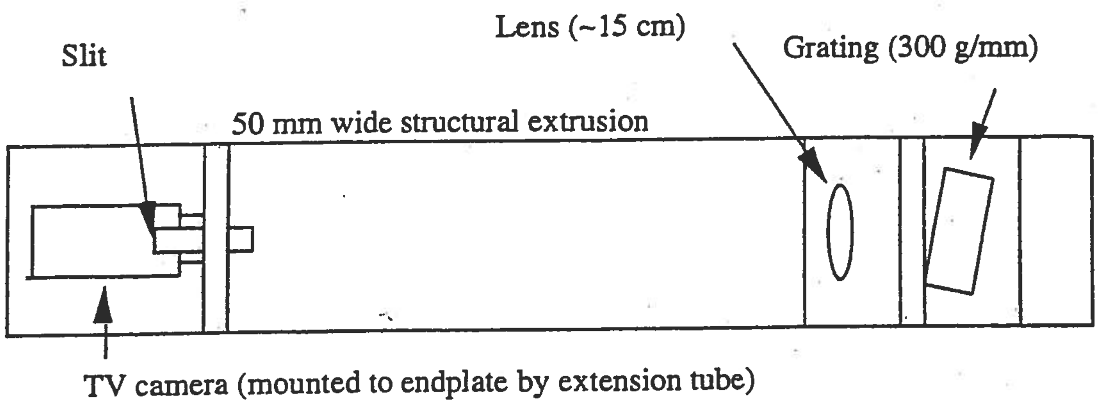
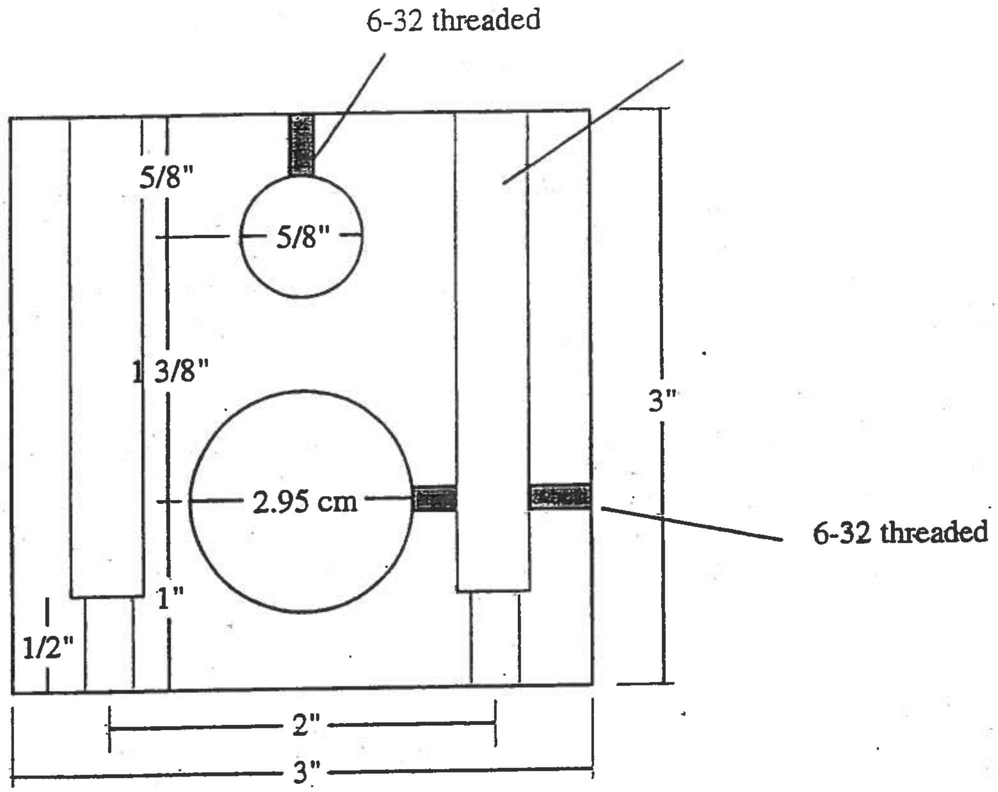


Figure 12: Diagram of simple OMA.



1/2" thick aluminum plate.

Slit Holder: Aluminum Rod

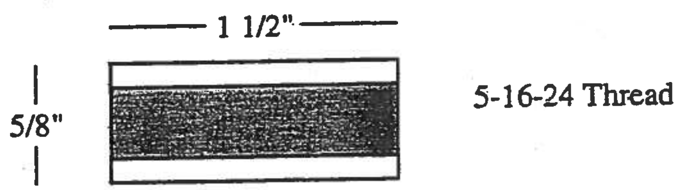


Figure 13: Endplate and slit holder for simple OMA.

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Qty	Description	Price ea	Price total	Source
1	TV camera Video Runner 1020	233	233	Marshall Electronics P.O. Box 2027 Culver City, CA 90230 (213)390-6608
1	Power Adapter PS 12	11	11	"
1	High power precision slit, width = 25 µm, length = 5mm Catalog # HPS 25 ± 2	85	85	National Aperture 27A Roulston Road Windham, NH 03087 Phone: (603) 893 - 7393 FAX : (603) 893 - 7857
1	PA-3Q Pinhole adapter	25	25	"
1	Diffraction grating 300 g/mm (1500 Å coverage for 15 cm lens) or 600 g/mm, 1" square, blaze at 7500 Å.	150	150	Optometrics USA, Inc. Stony Brook Industrial Park PO Box 699 Ayer, MA 01432-0699 Phone: (508) 772-1700 FAX: (508) 772-0017
1	C-mount extension tube kit #EX10	17	17	Audio Video Supply 4575 Ruffner St. San Diego, CA 92111 (800) 284-2288
1	Sony 9" monitor #SSM-920	114	114	"
1	Structural Extrusion, 75 mm x 15 mm x 1 meter #HL4720M1001-1000	31	31	Techno Isel U.S.A. Division 2101 Jericho Tpke., Box 5416 New Hyde Park, NY 11042-5416 Tel: (516) 328-3970 Fax: (516) 326-8827
10	T-slot nut, oval #HL6100M209001	.40	4.00	"
1 pkg	M6 x 16 SHCS	6.15	6.15	McMaster Carr P.O. Box 54960 Los Angeles, CA 90054-0960

Variable Slit

This variable slit design allows aperturing in either the vertical or horizontal direction. Simply glue a pair of razor blades to the movable pieces. Slits are not necessary in the laser, but would help if wavelength tuning is desired.

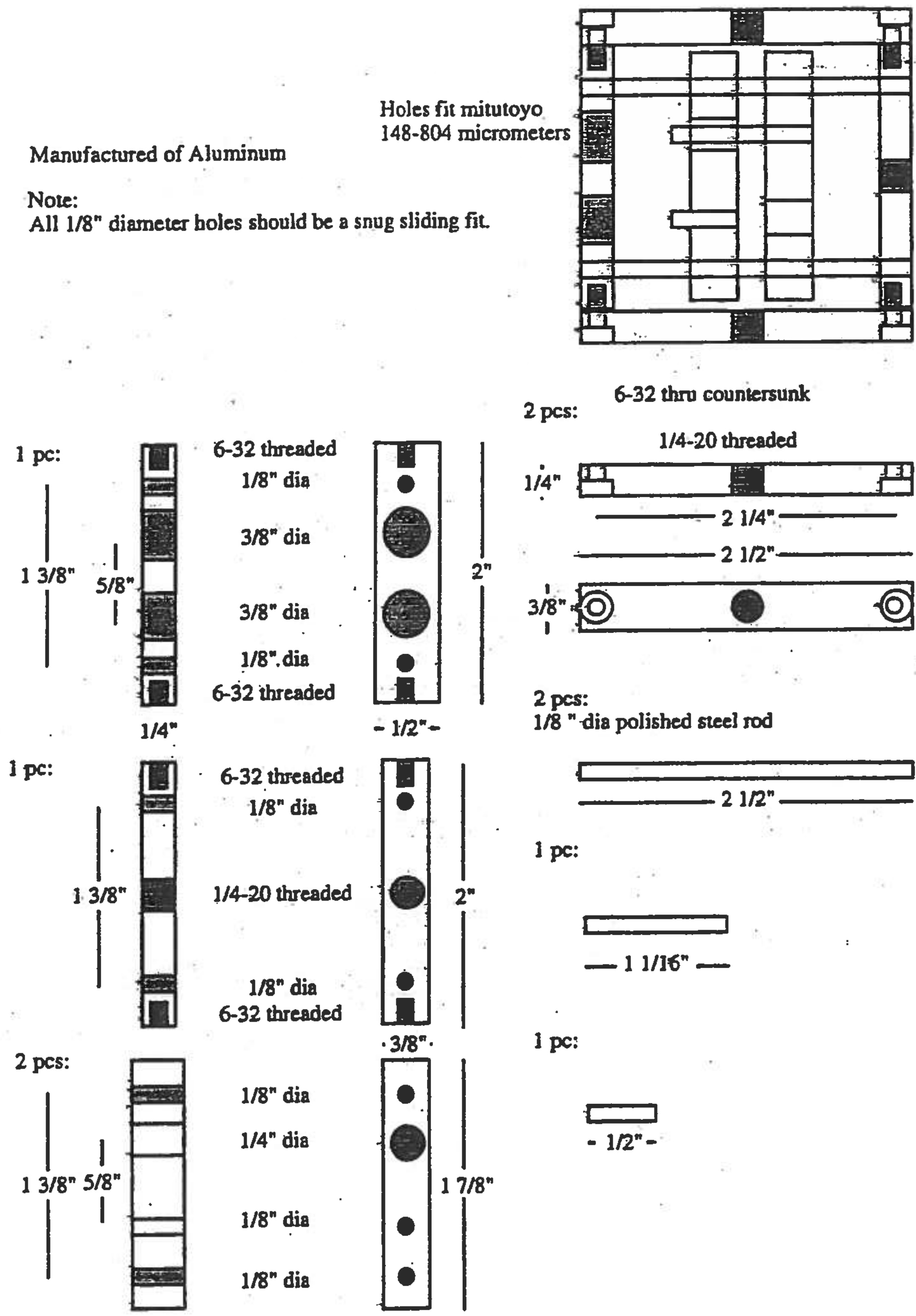

Figure 14: Slit.

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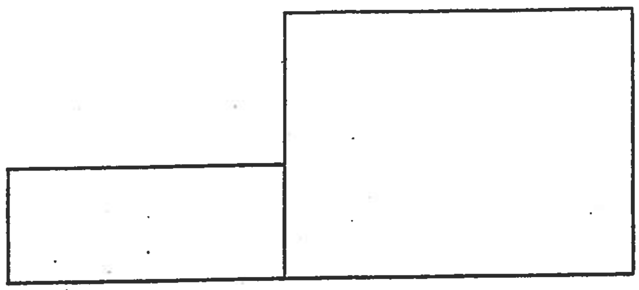
Enclosure

An enclosure is essential to obtain stable mode-locking-- dust drifting past the face of the ti:sapphire crystal seems to be the major cause of loss of modelocking. I have not included a specific plan for the box, but the following parts make a very nice-looking and easy to construct box. We make a box with the following shape, which allows easy access to the output coupler end mirror for starting:



For the 4 mm laser, the configuration is more linear so that a square box can be used. We have found that the best way to do the lid is to cut it to fit the inside of the top of the frame. Then use thin strips of plexiglass which fit the inside slot on the structural extrusion, around the perimeter. The lid sits on this lip.

Qty	Description	Price ea	Price total	Source
3	25 mm x 25 mm Structural Extrusion, 2 meters long #HL4720M0001-2000	30	90	Techno Isel U.S.A. Division 2101 Jericho Tpke., Box 5416 New Hyde Park, NY 11042-5416 Tel: (516) 328-3970 Fax: (516) 326-8827
2	Panel support Inserts, 6 meters #HL6100M209211	21.25	42.50	"
1	Corner Connector, pkg of 10 #HL6100M209103	13.75	13.75	"
4	Right Angle bracket #HL6100M1124	1	4	"
1	Plexiglass, "Amber" (opaque to green light) 1/8" thick for side panels, 1/4" thick for lid.			

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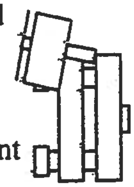
Mode-locking starter

We have very-recently developed a reasonably reliable self-starting mechanism. If a small solenoid is pressed lightly against one of the 10-cm mirror mounts, and is driven by AC current (~60 Hz) seems best, the vibration coupled into the mount can be sufficient to initiate mode-locking.



This information is very preliminary and may work more or less reliably. But the price can't be beat, and it may be worth experimenting with this idea. We drive the solenoid with an inexpensive function generator.

This vibration does add noticeable noise to the laser, so ultimately it would be wise to build a circuit which only vibrates when pulsing lapses. SHG generation is an easy way to tell if the laser is pulsing, and almost any scrap of non-linear crystal (KDP, Lithium Niobate, etc) will generate detectable amounts of light.

Qty	Description	Price ea	Price total	Source
1	Solenoid Cat # F3-LS-3	2	2	Meredith Instruments PO Box 1724 6403 N. 59th Ave. Glendale, AZ 85301 Ph. (602) 934 - 9387 FAX: (602) 939 - 3369
1	Function generator or AC transformer (~3V RMS)			

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