UV fiber patch cord recipe

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Rev. 2.1
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These notes describe the method as of the date above for making a simple (unpolished) UV fiber patch cord and curing it.

Disclaimer: Commercial equipment, instruments, and materials are identified in these instructions in order to specify the experimental procedure accurately and to allow duplication by other groups. Such identification does not imply recommendation or endorsement by the National Institute of Standards and Technology, nor is it intended to imply that the materials or equipment identified are necessarily the best available for the purpose.

A) Supplies

- Fiber
  - Desired length of NKT Photonics LMA-10-UV fiber (cut bare fiber about 5-10 cm longer than desired finished length)
- Hydrogen loading
  - O/E Land has performed H2 loading for us: http://www.o-eland.com/FiberOpticProducts/HydrogenLoading.htm . Turnaround times are typically a couple of weeks. Fibers will be shipped in dry ice to reduce out-diffusion of the hydrogen. The shipments are often delayed for ~ 1 week in US customs, so be sure that the fibers are packed with enough dry ice that they arrive cold. Uncollapsed fibers lose the hydrogen loaded in the core in a few hours at room temperature.
  - This company also advertises H2 loading: http://www.ixblue.com/products/optical-components-0
- Fiber splicer, cleaver, microscope:
  - Ericsson FSU 995 FA arc fusion splicer, equipped with the appropriate V-grooves. We use the blue, metallic V-grooves (Fiber Optics For Sale ref. SRPS-ERIC-Vgroove-BL). These are designed for Ø125 µm cladding, Ø250 µm buffer fibers, but work ok for our larger diameter fiber
  - Fujikura CT-100 ultrasonic fiber cleaver with Fujikura FH-100-400 fiber clamps
  - Fiber viewer with FC adapter (NIST uses a Fluke FT140)
  - Micro-Strip fiber stripper with 0.012" blade and 0.018" guide (Thorlabs part number T12S18). It helps to use the rubber "bare fiber gripper" pad that comes with this stripper
- Fiber connector parts
  - 2x zirconia ferrule FC/PC connectors with Ø230 µm bore (Thorlabs part number 30230C) - rubber boot and metal sleeve can be discarded, only connector is required
  - 2x 20 gauge stainless steel syringe needles, ~1" long, luer-lock (Jensen Global part number JG20-1.0X)
  - 2x 1.5" pieces of 24 gauge polyimide tubing, 0.001" wall (Amazon part number B000PHDL2M)
- Adhesives + UV curing source
  - Norland 65 UV curable adhesive (Thorlabs part number NOA65)
  - Epotek OG198-55 UV/heat curable adhesive (optional)
  - UV curing source (between 350 nm and 380 nm). See Norland 65 specifications for cure times vs power. NIST uses a Lumen Dynamics OmniCure LX400 UV source (LX400 controller, 365 nm LED MAX head, 3 mm focusing lens, foot switch)
  - near-UV protection glasses recommended for curing (e.g. the dark ones that come with the LX400, or orange UVEX S1933X)
  - 5-minute epoxy
  - Mixing dishes
  - Epoxy applicators (fine-point q-tips, toothpicks, or 20-24 gauge needles are good for this)
- Misc supplies:
  - Work mat: black silicone makes a good, soft surface with good visual contrast (since you will inevitably drop small fiber bits here or there). NIST uses 2x black 12"x16" silicone baking sheets from Silicone Solutions (Amazon - no longer available) on a 24"x36" black silicone mat (Amazon ASIN B0059JA4Z8)
  - Butane torch (e.g. Amazon B007A9YSPW) or other small flame source (cigarette lighter) to remove needles from plastic Luer-Lok connectors
  - Tweezers with carbon tips (e.g. Techni-Tool 2A ESD, part number 758TW0304)
  - Scissors
  - Razor blade or scalpel
  - Vinyl electrical tape (for holding fibers gently in place)
  - Lint free wipes (Thorlabs part number LFW90 - get lots)
  - Canner air (e.g. Thorlabs part number CA3). Always spray horizontally, never vertically.
  - acetone, isopropanol, methanol (see note below re: bottles)
  - polycarbonate safety glasses (e.g. 3M ref. 11326-00000-100, Amazon, impact rated, T = 0.35 % at 365 nm)
  - powder-free gloves (nitrile or latex)
  - 10x hand held loupe (e.g. Edmund Optics #35-359) -- you may also want higher or lower magnifications as well, depending on your taste
  - Ruler/tape measure
  - fiber optic scrap disposal unit (make your own -- Jensen Global bottles with lid are good for this -- or Fiber Instrument Sales ref. F18326 or F18327)
- Helpful but not essential:
  - Jensen Global bottles (part number JG1.0B) and luer-lok needles (e.g. JG21-1.0 or JG22-0.5T). This makes handy little solvent bottles (acetone, isopropanol, methanol) for dispensing small, controlled amounts of solvent -- see picture. Much easier than regular solvent bottles for this fiber work. Also good for fiber sharps containers (see picture).

Fiber sharps disposal

Jensen Global solvent bottles

- lint roller (for cleaning work surface)
- Milty Zerostat 3 antistatic gun (SPI Supplies ref. 07008-AB). Used to discharge the fiber and the silicone mat when the air is dry

B) Work space setup notes

Please read and understand the material in this section before moving on to the recipe.

Work area. Fiber work requires a clean work area. Black silicone mats are very convenient: they make the fibers more easily visible, and are a good surface to pick the fibers off with tweezers. These mats are resistant to organic solvents (acetone, isopropanol), and easy to clean, for example with a lint roller. They tend to build up electrostatic charge after rubbing, which can be removed with the Zerostat gun as needed.

Protective equipment and fiber hazards. When working with bare fibers (fibers stripped from their polymer coating) it is essential to wear safety glasses and powder-free gloves. Fiber bits and shards are sharp and can penetrate into the skin or eyes. They are thin and transparent, and can be difficult to locate and remove. Dispose of cleaved (or broken) fiber bits immediately, either into a dedicated fiber sharps container with a small opening, or to the trash after embedding them into folded Scotch tape. *Do not leave them in the cleaver or on the work bench!* There is a good chance they will be forgotten, and once they are knocked on the floor or fly up in the air (static charging can cause this), they will be very difficult to find. A black work mat helps when trying to find a small piece of fiber that has dropped.

Small fiber pieces should be handled with tweezers (preferably soft-tipped tweezers such as carbon tweezers).

Adhesives. Eye protection and gloves must be worn when working with the Norland 65 adhesive. Excess adhesive left over after gluing operations can be cured with UV light and disposed of in the trash.

Working with LMA-10-UV. LMA-10-UV fiber has a larger diameter than standard single-mode fiber and is considerably stiffer as a result. Be careful not to bend the fiber too sharply or you may cause microcracking or even a full break in the fiber. A bend radius of 5 cm is about as tight as should be typically employed. When collapsing, cleaving, etc, make sure that the fiber is not sharply bent near the clamps. Because of its stiffness, the LMA-10-UV fiber is rather springy and difficult to wrangle in long pieces. When making fibers longer than ~ 1 meter, it is helpful to coil the midsection of the fiber (~20-30 cm radius) and tape the coil to hold it together, leaving ~30 cm lengths sticking out at each end for collapse/cleave/connectorizing. Tape with good mechanical strength/tear resistance and a relatively gentle adhesive, such as vinyl electrical tape, is recommended for ease of removing the tape without damaging the fibers.

C) Recipe

The recipe below details the entire workflow for creating a cured fiber from raw materials and tools. It is strongly recommended that you read through the ENTIRE recipe and understand all the steps before beginning. As with any new task, practice is key to success, and it will probably take several tries before things work smoothly. Practicing the connectorization recipe with scrap pieces of non-hydrogen-loaded fiber is a good way to build skills before

Step 1 should be performed first. Steps 2-4 should be performed in sequence to connectorize one end of the fiber completely, and then repeated for the other end of the fiber. The fiber tips are much less susceptible to damage once the connectorization process is complete. Step 5, the curing phase, should ideally be carried out as soon as the connectorization process is complete, before the hydrogen has much chance to leak out of the fibers. However, based on diffusion calculations it may be possible to leave a fiber which has been collapsed at both ends at room temperature for up to several weeks before performing the curing. This idea has not been tested experimentally, so do so at your own risk.

Inexperienced users who may take a long time with cleaving and connectorization may benefit from collapsing both fiber ends first (to slow the out-diffusion of hydrogen), protecting the collapsed regions with polyimide tubing, and then carrying out steps 3 and 4 (cleave and connectorize) together for each end of the fiber in turn.

Once the hydrogen has diffused out of the fiber, any repairs where a new collapse region is made will be susceptible to UV solarization in that region and so the fiber will need to be hydrogen loaded again before being exposed to UV light.

1) Make connector assemblies

   a. Remove the Luer-Lok connectors from two JG20-1.0X needles. To do so, clamp the plastic end in a vise, grip the needle gently with pliers, and apply a flame to the joint between the plastic and the needle while pulling on the needle (see photo below). The plastic should soften and melt and the needle will pull free of the plastic. If the plastic catches fire, just blow it out. Any remaining plastic residue on the needle should be cleaned off -- this is easiest to do by wiping with an isopropanol wipe immediately after pulling the needle out, while it is still warm. If needed, the needle can be cleaned with Scotchbrite or fine-grit sandpaper. Wiping with acetone also helps remove residues.

   b. Mix some 5-minute epoxy in a small dish and let it sit ~2-3 minutes, until it is starting to thicken a bit.
   c. Put the plastic cap on the ferrule of the FC/PC connector and stand the connector upright on this cap. Insert the bare JG20 needle into the inner metal tube at back of the connector. Using a toothpick or similar object, apply 5-minute epoxy to bond the needle to the connector tube in which it sits (see photo of completed connector in section 4). Be careful not to apply too much epoxy, or to use epoxy which is too runny, or else the epoxy may flow down past the JG20 needle and block the connector.
   d. Allow epoxy to dry.
   e. Cut two ~30-50 mm sections of 24-gauge, .001" wall polyimide tubing with sharp scissors. Spray isopropanol through the tubing and wipe it on the outside, then blow canned air through the tubing to dry.
   f. Clean the connector by spraying isopropanol into the small hole in the zirconia ferrule until isopropanol comes out the other end of the JG20 needle. Using canned air or clean dry nitrogen, blow into the zirconia ferrule to remove remaining isopropanol.
   g. Insert a piece of cleaned, stripped test fiber (use a ~10-15 cm scrap of LMA-10-UV for this, and keep it in a safe place for future use as well -- see steps 2b, 2c for instructions on stripping fiber) into the JG20 needle and ensure that the fiber can slide freely through the connector and out the ferrule (making sure there is no epoxy or debris blockage).
   h. Set the connector assemblies and polyimide tubing aside on a clean lint free wipe.

2) Collapse the fiber ends

We use an Ericsson FSU 995 FA arc fusion splicer to collapse the fiber (please READ THE SPLICER MANUAL for instructions). The splicer has to be equipped with the blue, metallic V-grooves as described in the supplies list. ***Be sure that the "altitude" parameter of the splicer is set properly!*** The fusion splicer current depends strongly on altitude, so incorrect setting of this parameter may result in inability to collapse the fiber, or overheating and deformation of the fiber.

The default view of the fiber is a side view, and the fiber is displayed at the top half of the screen (fiber is dark, background is bright). A top view can be shown after the shield is closed ('View' button), displayed in the lower half of the screen. By rotating the fiber, one can see the photonic crystal holes at specific rotation angles as a series of thin bright horizontal lines (see photos below).

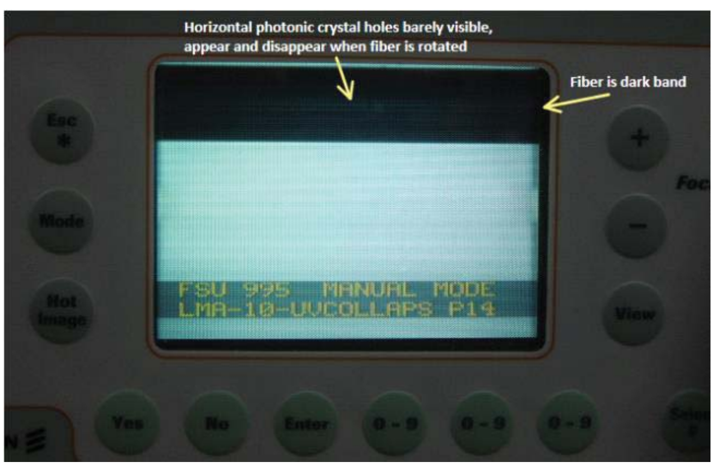
The collapsing method requires that at least one end of the photonic crystal be open to air. It is typically impossible to form a collapsed region in a fiber in between two other collapsed regions. If one is making a new collapse in a previously collapsed fiber, it is essential to snip off the undesired old collapse before proceeding with any of the steps below.

   a. Cut fiber to desired length. When removing fiber from cold storage, try to minimize the amount of condensation on or in the fiber by keeping it in a sealed bag while it warms up. Condensation inside the photonic crystal holes appears to make it difficult to collapse the fiber. It often helps to snip off a ~10 cm section from each end after the fiber has warmed up.
   b. Strip ~41 mm of the plastic coating with the Micro-Strip stripping tool (Thorlabs T12S18). The coating is tough and usually does not strip very cleanly. It helps to grip the fiber with a rubber pad (such as the "bare fiber gripper" that comes with the stripping tool, Thorlabs BFG1) while pulling the stripping tool. Because the stripping tends to generate particles of the plastic coating, it's best not to do it right over the work surface. When done, clean coating debris out of the stripping tool with canned air. Debris on the work surface is most easily cleaned up with a lint roller. You may need to "de-static" the work surface afterwards using the Zerostat gun.

c. Clean any remaining coating residue off the stripped fiber end with a lint free wipe impregnated with acetone. It is importa nt not to let acetone wick into the holes of the photonic crystal at the fiber tip, or else the collapsing may not work, so don't linger on the tip regi on. Fold over a wipe, put acetone on it, and run it smoothly along the length of the stripped region to remove the large chunks of coating which remain , being careful to move very quickly when nearing the fiber tip (to prevent acetone from leaking in). Repeat this with a fresh fold and new acetone (so that the chunks of coating are not redeposited on the fiber by the second wipe). Then wipe once or twice more with a fresh wipe, again folding over to get a fresh area each time. Both the collapse and the cleave are very sensitive to any remaining coating particles or residue, so be sure the fiber is thoroughly clean before proceeding.
d. Turn on the Ericsson FSU 995 FA fusion splicer. If needed, clean the electrodes by pushing the 'Select/#' button and followin g on-screen instructions (see step 2m). Splicer must be in "auto" mode to clean electrodes.
e. Switch to manual splice mode ('Mode" button).
f. Select program 14 ('Enter' button), named **'LMA-10-UV COLLAPS'**. The parameters of program 14 are in the table below, in case it has not already been programmed into the fusion splicer. Parameters noted "dummy" have arbitrary values that do not actually affect the recipe (no te that the splicer needs some of these values to be non-zero to execute the program). For a normal splicing, the Fusion 1 pulse is applied to pre-heat the two fiber tips just before they are brought in contact by the splicer; Here we skip this step by setting its duration to 0.

Program		14	
Pre-fuse	t (s)	0.2	cleaning pulse
	I (mA)	11.0	
	Gap (µm)	5.0	dummy
	Overlap (µm)	1.0	dummy
Fusion 1	t (s)	0.0	
	I (mA)	8.0	dummy
Fusion 2	t (s)	2.0	
	I (mA)	11.5	
Fusion 3	t (s)	2.0	
	I (mA)	14.5	
Center (pix)		250	dummy

g. Open the shield. Open the left and right V-groove clamps.
h. Position the fiber on the right side of the splicer, such that the coated section is just outside of the Ø125 µm section of t he right V-groove. The stripped portion of the fiber then extends from before the Ø125 µm section of the right V-groove, to after the Ø125 µm section of the left V-groove. Clamp the fiber with the right V-groove clamp only, leave the left clamp open. If the left clamp is closed, the fiber will be bent during the collapse process .
i. Close the shield.
j. Manually rotate the fiber (grip the fiber to the right of the clamp and spin the fiber between your fingers) to see transmiss ion through the lattice of holes on the fusion splicer screen (this may be fairly faint -- see photo). This will appear as a series of bright horizontal lines within the dark horizontal band of the fiber. As the fiber is rotated, these lines will appear and disappear. You should also check to ensure that no dust or debris is visible on the outside of the fiber. Rotate the fiber through 360 degrees and check that the top and bottom edges of the dark band always r emain smooth. If any debris is present, it will probably cause the collapsing process to fail. Remove the fiber, reclean as in step 2c, then rein sert the fiber as in 2g/2h/2i.



k. Press the 'Fuse' button. This applies the pre-fuse cleaning pulse (0.2 s duration, 11.0 mA, see table above)
l. Press the 'Fuse' button again. This applies fusion pulse (consisting of Fusion 2 and Fusion 3 steps, see table above). With clean, new electrodes, this is typically enough to create a collapsed region. The collapsed region will be visible on the screen as a fairly thick bright h orizontal band in the middle of

the dark horizontal band of the fiber (see photo below). If you rotate the fiber you can see the photonic crystal holes and how they disappear in the collapse region.

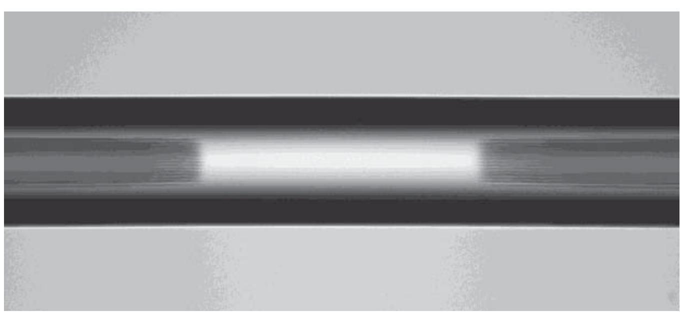
i. Several additional fusion pulses may be necessary to get a collapse of the fiber holes at the center of the field if the electrodes of the splicer are dirty - even 8 or 10 pulses in extreme cases. Cleaning the electrodes (see step 2d) may help in this case. Manual cleaning of the electrodes or electrode replacement are your options if this does not resolve the problem. You can also try increasing the fusion current in the program (see step 2f) to 12.5 mA and 15.5 mA for the two stages, respectively. Consult the fusion splicer manual for instructions on any of these tasks. NEVER SPRAY COMPRESSED AIR INTO THE FUSION SPLICER.

ii. Sometimes the collapse is not perfect and a few photonic crystal holes remain uncollapsed. They are visible as thin dark lines which partially obscure the bright band of the collapsed region, and move across the collapse as the fiber is rotated. If you are unsure of the quality of a collapse, rotate the fiber through 360 degrees and check for the presence of uncollapsed holes.

iii. During the fusion pulse, the camera will show bright areas where the arc is hottest. A typical fusion pulse should show a single, thin, steady horizontal bright band that moves slightly vertically. Large bright areas to the sides, or bright areas which flash on and off, are typically due to remaining contamination on the surface or in the photonic crystal holes and are often (but not always) correlated with a substandard or unsuccessful collapse.

m. Once the fiber is collapsed at the center of the field, the length of the collapsed region can be increased by shifting the f iber to the left (pushing it into the right V-groove) about half a fiber diameter and then repeating step 2l. Repeat as necessary to extend the collapse region.

n. Open the shield, open the right V-groove clamp, and carefully remove the fiber



Collapsed region (bright in center) of fiber, with photonic crystal holes visible to left and right of collapsed region (optical microscope image).

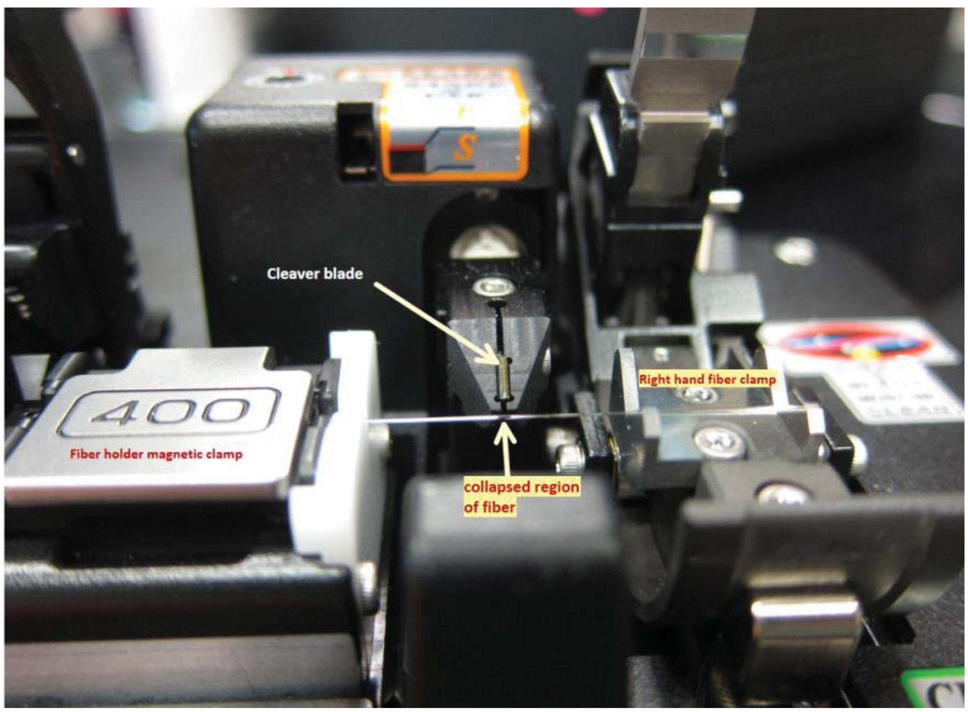
3) <u>Cleave the fiber in the collapsed region</u>

Because LMA-10-UV fiber has a larger diameter (230 um) than the 125 um for standard single mode fibers, we need a fiber cleaver capable of handling large-diameter fibers. A standard cleaver is not able to apply sufficient tension to the fiber to cleave. NIST uses a Fujikura CT-100 ultrasonic cleaver, which is simple and relatively inexpensive. We use Fujikura FH-100-400 fiber holders to hold the fiber in place. For cleaving, we only use the left-hand holder (where the silver magnetic clamp is on the right-hand side of the fiber holder when the numbers are right side up). READ THE CLEAVER MANUAL before starting to cleave. It is simple and will save you lots of time and hassle to read it first.

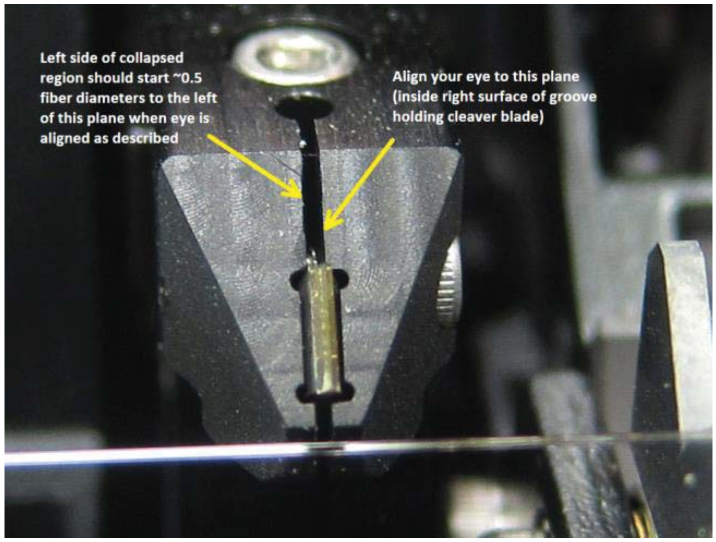
If cleaved surfaces have large rough or striated areas, cleave tension is too high. If the fiber fails to cleave, tension is too low. When the fiber fails to cleave, the diamond cleaver blade can be damaged, so it is important that the tension not be too low. In either case, some small experimentation with the tension (+/- 5 or 10 grams) may resolve the issue. Consult the cleaver manual for further details. If the cleaver blade is damaged, tension adjustments will not fix the issue, and the blade will need to be moved to a new, undamaged position (see cleaver manual).

When setting up a new cleaver or new blade, set the tension a bit higher than anticipated (e.g. 670 grams for LMA-10-UV) and make a series of test cleaves with slowly decreasing tension until good facet quality is achieved.

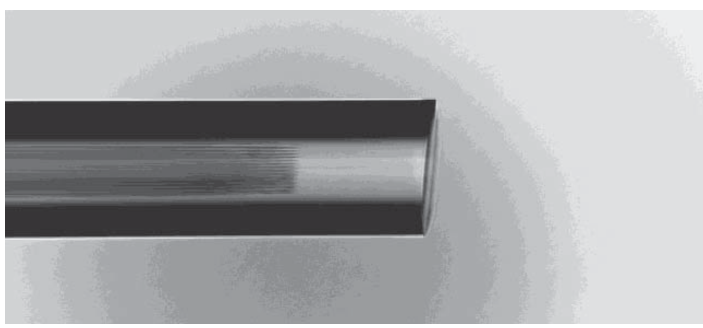
a. Adjust the tension of the cleaver to 645 grams.
b. Close and tip up the right-hand clamp by pulling the handle towards you as far as it will go. Check the angle to which the clamp tips up using the whit e radial angle marks on the side of the clamp (see manual). Each mark indicates 5 degrees of tilt. We use an ~8 degree tilt. Increasing the tilt angle will give an increased facet angle for the cleave, and may require a small decrease in tension to maintain good facet quality. Se e cleaver manual.
c. Inspect the fiber holder and right hand fiber clamp for any fiber debris and clean with isopropanol and qtips or lint -free wipes as necessary. Debris in the clamps will cause the fiber to break and not cleave properly.
d. Place the fiber holder in the receptacle with the magnetic clamp open. Lay the fiber in the fiber holder groove so that the collapsed region is near the cleaver blade and hold the fiber in place with a finger on the left-hand (non-clamp) part of the fiber holder. Slide the fiber left and right to adjust the position as needed. See photo below (note that the magnetic clamp is closed in the photo, but you should still have it open) :



e. Using a 10x loupe, inspect the position of the collapsed region relative to the cleaver blade, and adjust the fiber position using your finger which is holding the fiber in the fiber holder. Exact cleave position may vary slightly from cleaver to cleaver. For our cleaver, op timum cleave position is as follows (see photos below):
    i. Look through the loupe at the blade clamp of the cleaver (the slit in the black block which holds the diamond blade). Align your eye position so that you are in the plane of the right hand inner edge of the slit where the blade is clamped.
    ii. Adjust the position of the fiber so that the collapsed region extends very slightly (0.3-0.5 fiber diameters) to the left of the left edge of the slit where the blade is clamped, as viewed from the eye position described in (i).
    iii. Enough fiber should remain to the right of the collapse region to extend at least 90% of the way through the right hand fiber clamp. If not, snip off collapsed region and redo step 2 (collapse), making sure to leave enough fiber past the collapsed region this time.



f. Once the fiber is in the correct position, flick down the magnetic clamp on the fiber holder to hold it in place. Close the large black left-hand holder clamp lever. Inspect the fiber position to make sure it is still as desired from step d. If necessary, reopen clamp and rep osition fiber.
g. Close the right clamp and tip it up toward you to tilt clamp to the preset angle from step 3b.
h. Press "cleave" button, while continuing to hold clamp in tilted position. The right hand clamp will move to the right and te nsion the fiber, then the blade will move in and cleave fiber. Clamp must be tilted during this entire process.
i. After cleaving, open the left hand clamp and remove the fiber holder with the fiber still clamped inside. Place it in a safe spot on the work surface where the cleaved facet will not be damaged.
j. Open the right hand clamp. Clamp will move left to "home" position. Be sure that left -side fiber holder has been removed, otherwise the small piece remaining in the right clamp will crash into the cleaved fiber facet. Remove this small piece of fiber from the right hand c lamp and dispose of it immediately in a fiber sharps container.



Angle-cleaved fiber showing typical size of remaining collapsed region (optical microscope image).

4) Connectorize the fiber

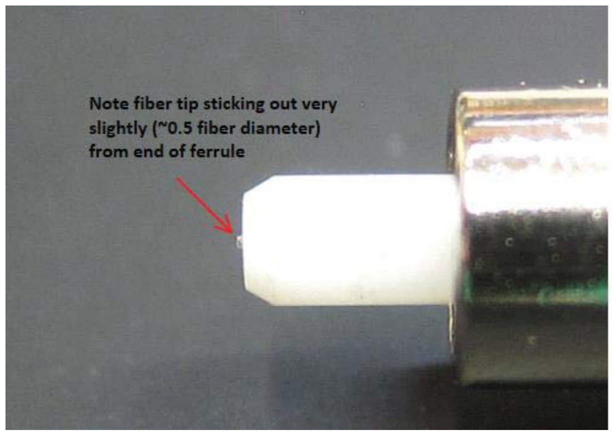
See the annotated photograph below showing a completed connector assembly.

a. Open the magnetic clamp of the fiber holder and remove the fiber. Carefully slide one of the cleaned pieces of 24 gauge poly imide tubing onto the cleaved end to protect the cleaved facet (cleaved facet should be roughly in the middle of the polyimide tube length). If pr eferred, the polyimide tubing can be slid onto the fiber before cleaving, and then slid up to protect the facet after cleaving is complete.
b. Lay one of the connector assemblies on its side on the table, removing the plastic cap from the ferrule.
c. Slide the polyimide tube with fiber inside into the stainless steel JG20 needle glued into the back of the connector. Be car eful to keep the fiber from coming out of the polyimide tube (either too far forward or too far back).
d. Once the polyimide tube has bottomed out in the connector, carefully slide the fiber further into the connector until the tip emerges from the ferrule. You should not encounter resistance to this process (sometimes there is very gentle resistance which can be overcome by rotat ing the fiber as you slide it). If the fiber does not slide easily through and out the end of the ferrule, pull out the fiber and try cleaning and test ing the connector again as in steps 1e and 1f.
e. *Optional*: if you are unsure of the quality of your cleave, hold the fiber/polyimide/tubing assembly together with your fingers or gen tle tape (vinyl electrical tape works well) and inspect the fiber facet in a fiber microscope. With practice, you will learn to distinguish dust/contamination on the facet

from defects in the cleave.

f. Apply Norland 65 adhesive to the joint between the JG20 needle and the polyimide tubing with a needle or toothpick (it is sim ple to put a drop from the bottle in a small mixing tray and then scoop from this). The polyimide tube should extend at least 10 mm past the end of the JG20 needle; pull it out a bit if needed.
    i. For best results, ensure that the adhesive extends at least 3 mm onto the outside of the needle (adhesion is worse on the steel than on the polyimide). Cure with UV light until Norland 65 fluorescence color changes (becomes more green), typically 10-30 seconds with Omnicure LX400 source and 365 nm MAX LED head. Begin the curing with more diffuse UV light and then bring LED head closer to apply more focused light.
    ii. It may be most efficient to do several cycles of NOA65 application and curing. Alternatively, Epotek OG198-55 UV curable adhesive may be used to provide somewhat better bonding to the stainless steel.

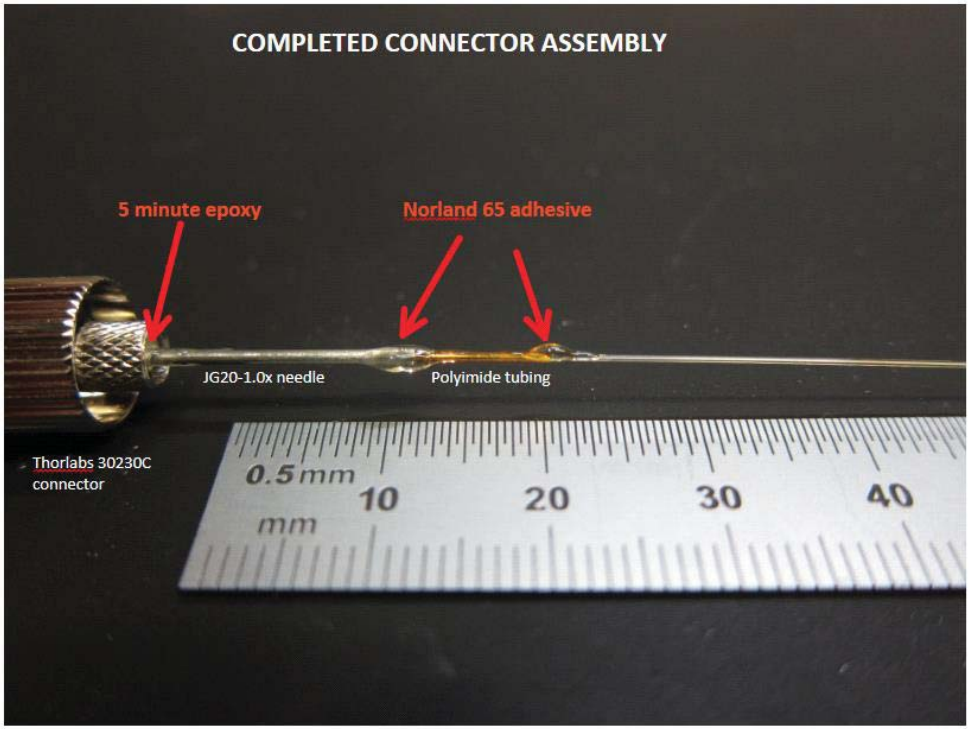
g. Adjust the position of the fiber so that the cleaved facet is roughly half a fiber diameter past the surface of the ferrule (see detail photo below). Use the 10x loupe to monitor the position of the fiber tip as you adjust it. If the facet does not extend past the surface of the fe rrule, it will not be possible to clean it and debris will collect on the facet.



h. Apply Norland 65 adhesive to the fiber/polyimide tubing joint and spread it to cover at least 2 -3 mm on either side. Double check the position of the fiber tip with respect to the ferrule using the 10x loupe and readjust if needed.

i. Being very careful not to disturb the fiber position, cure the Norland 65 adhesive at the fiber/polyimide joint using UV ligh t as before.

j. Insert the connector into the fiber microscope and inspect the facet. If all looks good (debris on the fiber facet is accept able since it will be cleaned off subsequently), cap the connector with its protective plastic cap.



5) Cleaning and curing the fiber

The most difficult part of the fiber curing process is the initial task of finding the single mode and optimizing transmissio n through it, since the LMA-10-UV fiber has a much smaller NA/acceptance angle than typical single-mode fibers. It is recommended that a permanent fiber curing setup (mirrors and in-coupling lens) be built, since this will make finding the mode to cure subsequent fibers much simpler.

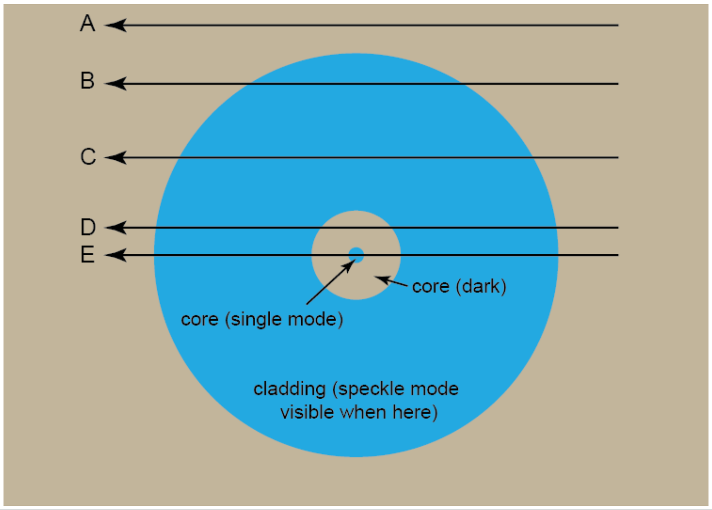
a. INITIAL ALIGNMENT OF CURING SETUP: This step needs to be performed before the first fiber is cured in a setup, however once t he in-coupling is reasonably well aligned it does not need to be repeated before subsequent curing operations as long as nothing in the optical setup has been moved.
   i. Select an appropriate focal length lens to match the fiber mode to the input beam. Typical focal lengths at NIST are 20-30 mm.
   ii. Build a suitable fiber-coupling rig with lens, mirrors, and FC/PC connector holder. The lens-fiber distance should be variable with a micrometer or similar fine-threaded stage. Putting the lens on a 3-axis micrometer stage, with fixed fiber mounting, is a nice if less compact solution.
   iii. Using a ruler to measure, adjust the lens position so the fiber tip will be at the focus of the input beam (to the best of your ability).
   iv. Place a card behind the FC/PC connector holder where the fiber will be mounted. Steer the laser light using mirrors and/or lens until the beam appears to be centered in the hole of the FC/PC connector holder, as judged by the beam shape and position on the card.
   v. Insert an empty fiber connector into the FC/PC connector holder and repeat, this time optimizing to steer the beam focus to the center of the connector ferrule.
b. Clean the fiber facets before inserting the connectors into the curing setup. Since the cleaved fiber facet extends past the tip of the ferrule, standard fiber connector cleaners can catch on the fiber corners and cause chips on the facet. The recommended method for tip cleanin g is as follows:
   i. Take a single, unfolded piece of lens cleaning tissue and wet a patch of it with methanol.
   ii. Hold the fiber connector so it points horizontally, with the fiber facet in the vertical plane.
   iii. Dangling the lens tissue vertically, bring the fiber tip into contact with the methanol-wetted portion of the lens tissue.
   iv. Gently move the fiber vertically through the methanol-wet region of the lens tissue, applying as little horizontal force as possible (just enough to keep the fiber in contact with the lens tissue). You may feel the fiber catch a little on the lens tissue periodically. Move through the methanol region and onto a dry region of the lens tissue. When no more methanol is visible on the ferrule tip, pull the fiber back from the lens wipe.
   v. Inspect the facet in the fiber microscope and repeat as necessary until the facet is suitably clean.
c. Insert the fiber into the curing setup. Provision should be made for a card and/or power meter at the fiber output during al ignment. For best results, make sure the fiber has a 90-180 degree bend of ~6-10 cm radius at some point. This will suppress the propagation of higher order modes and make it easier to find the single mode and optimize coupling to it.
d. Turn on the curing laser at low power (200-400 uW) for initial alignment.
e. With the lights off, check to see if any light is visible on a card at the fiber output. Two types of modes can propagate in the fiber, a "speckle" mode and the single mode. The speckle mode looks very speckled, and is associated with the beam propagating through the cladding and not the core. Photos are below:

	
Speckle mode - note larger diameter/beam spread and speckled quality. Very sensitive to fiber jiggling.	Single mode - looks Gaussian (sometimes hexagonal pattern of spots is visible around the central mode), smaller in size, smooth and not speckled. Not sensitive to fiber being jiggled.

f. If you have performed the alignment steps in step 5a well enough, you should probably see some light coming out of the fiber already. If you don't see any light coming out, play with the position of the beam spot on the fiber facet (the final mirror before the lens, or the tr ansverse lens position) until you see light coming out.
    i. If you still don't see light coming out of the fiber, you may see some fluorescence in the fiber where it emerges from the back of the input connector. Play with the input coupling to maximize this fluorescence, and you should be able to see some light at the fiber output. Turning off the lights can help with this process.
    ii. If all else fails, go back and repeat step 5a to try to get a better rough alignment.

g. If you are lucky, you will see some of the single mode at the fiber output, and you can walk the input coupling (position, an gle, and focal length all require adjustment) to maximize the output power.

h. Usually, though, you will see some of the speckle mode at the output, and not the single mode. If so, use the final mirror (or lens x-y) to shift the position of the beam across the fiber facet back and forth. As you sweep the beam from side to side, the speckle mode will a ppear and then disappear. Then shift the beam position a bit up or down. The diagram below illustrates five sideways beam sweeps across the facet (A -E) at different vertical positions:
    i. In sweep A, no light is seen at the output of the fiber. Shift the beam vertically until some light becomes visible during the horizontal sweep, e.g. in sweep B.
    ii. Keep moving the beam vertically by small amounts so that the speckle mode is visible for larger and larger ranges of the sideways sweep (e.g. for sweep C, the speckle mode is visible for a larger horizontal range of beam positions than for sweep B).
    iii. Eventually, you will reach a region (sweep D) where the output shows speckle mode, then a brief dimming/extinction, and then more speckle mode again over the course of a single horizontal sweep. This indicates that your beam sweep is going over a portion of the center core, where the speckle mode is not excited.
    iv. Using small vertical adjustments, you should be able to shift until you reach a trajectory like sweep E, where over the course of a single horizontal sweep you will see speckle -> dark -> single mode -> dark -> speckle. Depending on various factors, it may not be quite this clean-cut, and you may still see some speckle mode superimposed on the single mode (this is particularly likely if the lens-fiber distance is not correct). Temporarily putting a sharp bend in the fiber (~4 cm radius or even sharper - be careful not to damage the fiber) can help suppress transmission of the speckle mode and make the single mode easier to see.



Finding the single mode. Image shows the fiber facet, five different sweep positions for an input beam, and regions of the facet where different modes are excited. If the facet is not at the focus of the lens, the input beam will have a large area and may excite both the single mode and the speckle mode at the same time, making it more difficult to see the single mode.

i. Once you have found the single mode, walk the input beam in x, y, and z (focal length) until you have maximized transmission through the single mode. You should see at least 65% to 75% transmission for a 1-3 m fiber if you are reasonably well mode-matched, depending somewhat on wavelength. Badly misshapen input beams will typically give lower efficiency.
j. Beam curing parameters (time and power) have NOT been exhaustively studied. However, we have found that a cure of ~24 -48 hours is generally sufficient. We generally cure at the highest available power in the curing setup, but it appears that this may not be necessary and curing w ith lower power can work fine. Individual users are welcome to test curing parameters for themselves.