Resonator alignment of a small argon laser with internal mirrors and a wavelength selection prism

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1. Abstract

In the case where resonator mirrors together with a wavelength selection prism are integral parts of the tube and cannot be removed, the alignment procedure tends to be complex. Mirrors are highly reflective at working wavelengths of the laser tube, and the prism needs to be tuned for the chosen one. The wavelength of light used during the alignment procedure needs to be outside of the laser working range, in order to pass through the mirrors. This article analyzes this problem and describes the alignment procedure for a NEC GLG-3023 argon ion laser head using a 632nm red He-Ne laser on an adjustable platform. A similar approach should be usable on other lasers employing a similar configuration.

2. Safety precautions

Argon ion laser is a hazardous device, actions described in this text assume that the you are familiar with all safety precautions while working with lasers and high voltage electronic devices. The author of this text assumes no responsibility on actions carried out by others. Here is a brief summary of the most important safety notices related to this type of laser:

- **High voltages are present inside of the laser head, and the standard power supply is most probably not isolated from the mains outlet. Tube mirrors will be on high potential when the head is powered up. Caution must be exercised while performing adjustments of the tube mirrors using metallic tools. High voltages may remain present inside the head even after the power has been turned off, due to power supply capacitor residual charge.**

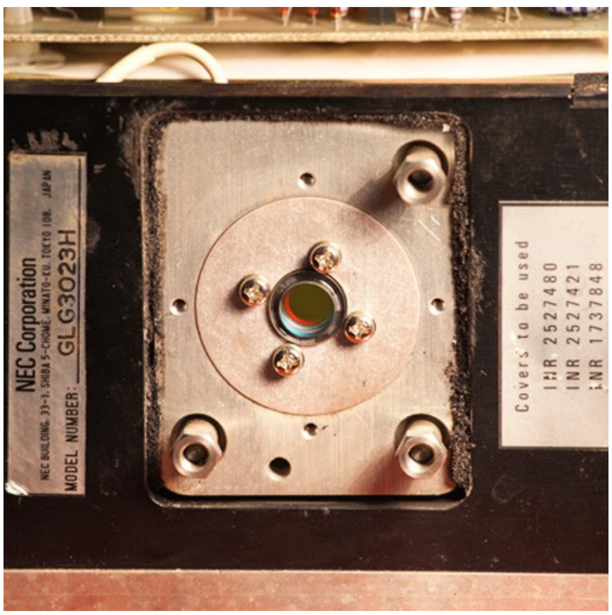
- **Laser radiation is hazardous to the eyes, exposure should be avoided according to the rules defined for a specific laser class. Most argon ion lasers are at least Class IIIb devices, protection should be based according to the rules of the class to which the specific laser model belongs.**

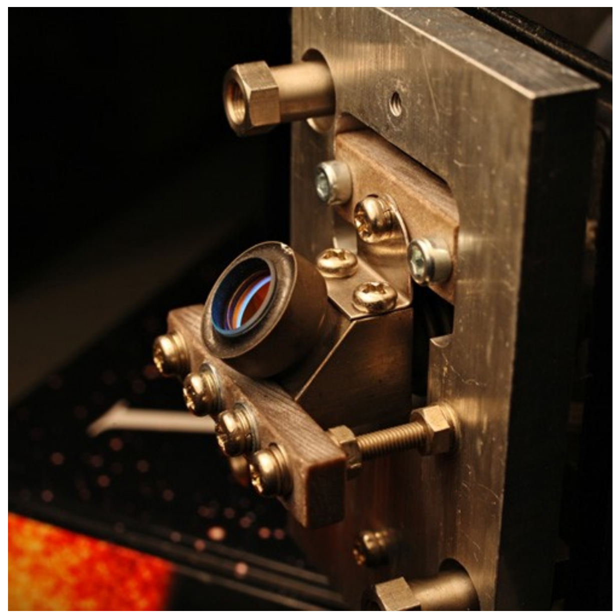
- **The glass surfaces and the anode heatsink will get very hot when the tube is powered up. Caution and adequate cooling is necessary to avoid injury and damage to the tube. The original cover and the fan are designed to provide an adequate air flow, the tube should not be operated with the cover taken off.**

- **Argon ion laser tube employ beryllium oxide ceramics (beryllia), which is extremely hazardous if inhaled in the powdered state. Any mechanical damage to the tube bore assembly must be dealt with according to the strict rules of beryllia disposal and recycling.**

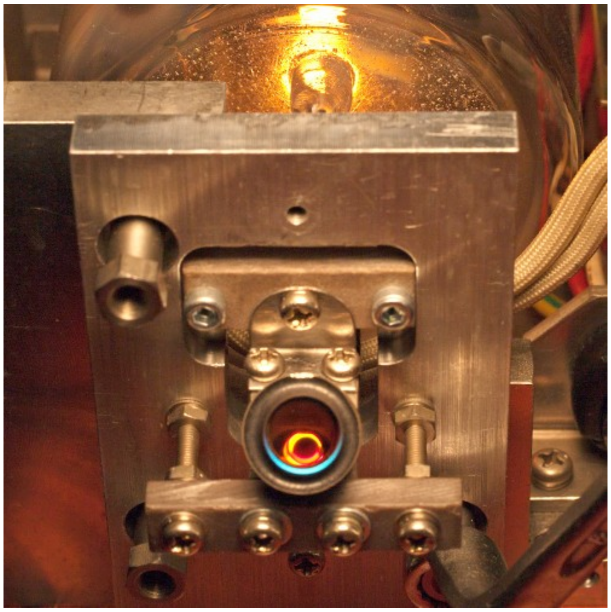
3. Introduction

The NEC GLG-3023 head (a variant of the better known GLS-3030 family) employs an argon tube with a standard OC mirror on the anode side, and an integral prism + mirror system on the cathode side. If the adjustments are carried out correctly, it can be tuned for most of the argon lines. With less than 6A of anode current I was able to obtain the 514.5nm, 496.5nm, 488.0nm and 476.5nm lines easily. The intensity of the 488nm line was the strongest, so it appears that the system (mirror type + gas pressure) was optimized for that.
The following photographs depict the OC mirror and the prism assembly fastened to their respective adjustment plates:





The prism seems to be a double-pass with an HR mirror set at an approx. 45 degree angle. The optical axis is offset from the center of the HR mirror, on the following photograph an image of the filament and the bore can be seen, refracted by the prism:



This offset will be taken into account when setting up the He-Ne laser, as will be described later. The adjustment screw in the top left corner of the mounting plate sets the prism pitch angle, and has the most effect on prism tuning for specific wavelengths.

The procedure assumes that both mirrors are out of alignment. If carried out correctly, the final alignment of the OC mirror will be wavelength independent, while the prism will require additional adjustment for a desired wavelength. The red light needs to be used as the mirrors are highly reflective at shorter wavelengths. Apart from standard tools, the following special equipment is required to carry out the procedure:

- A red He-Ne laser head (or a similar red laser with good quality beam, cheap pocket pointers are not recommended)

- An adjustable platform for the He-Ne laser that can precisely set the position of the beam. It needs to have at least two degrees of freedom in translation, and additional two degrees of freedom in rotation. (e.g. a lab jack that can set the beam height and can be moved on the table, plus a tip/tilt adjustable platform that can set the beam altitude/azimuth angles)

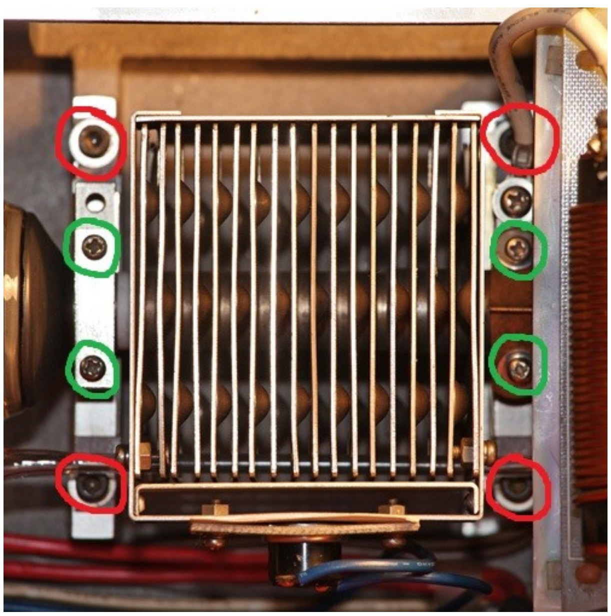
- A stable surface where everything can be mounted stiff (e.g. an optical bench)

4. Setup of the laser head under adjustment

If you are sure already that both mirrors require adjustment (e.g. when replacing an old tube), the head needs to prepped before starting the adjustment. The internal mirror tubes usually employ elastic metal bellows on which the mirrors are mounted, these can be tilted slightly, just enough to provide for the required adjustment range. The flexure of the bellows is used not only for the resonator alignment, but also for adjusting the beam axis position along the bore. From the mechanical side, this flexing has a limited number of degrees of freedom, and also mechanically stresses the fragile glass tube envelope and seals. On power-up and power-down the tube undergoes a thermal cycle with a significant range, so external mechanical stresses such as this should be minimized. The following procedure explains an approach that should minimize the stress on the tube while mounting it and carrying out the alignment:

A1. When installing a new tube, straighten out the bellows gently, if necessary. Manufacturing tolerances should warrant that the beam axis will be passing closely along the center of the bore when the bellows are not bent. Set the tube in place inside the frame and tighten the mounting screws very loosely, just enough so that the tube does not rattle. Mount the mirror adjustment plates and fasten the mirrors (do not forget to orient the elastic washers correctly, there should be two pairs of them for each screw, in each pair the washers should face each other).

A2. In case of an already installed tube, it is recommended that nothing is touched unless the head has been abused previously. However, if for any reason you do not trust the initial placement, you should do it from scratch. Remove the 4 screws holding the OC mirror flange, the 4 screws holding the prism body, and carry out the steps described under A1.



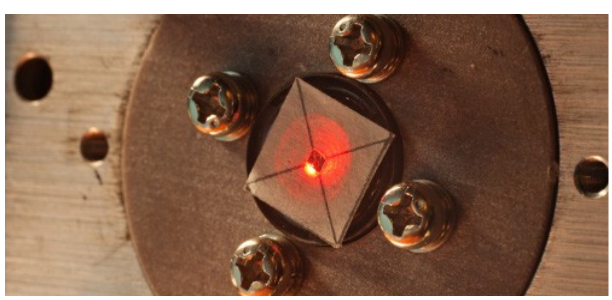
A3. The tube is fastened to the insulating mounting stands that have some free positioning range available with respect to the frame (see photo). Loosen all of the tube mounting screws just enough so that the tube can move freely when you gently push it with your fingers. Do not loosen them too much, it must not be allowed to rattle. The screws marked green on the image permit the axial movement, and the screws marked red allow for the movement sideways.

A4. The bellows of the tube should not be bent sideways too much. In the ideal case the bellows should only stretch a little when the mirrors are fastened to the adjustment plates (note that the OC mirror insulating flange is not permanently fixed to its adjustment plate, it can freely rotate and is held in position only by the stretching force of the bellows). Fasten the OC mirror flange and the prism on their respective sides, the mounting screws loosened in step A3 should now allow the tube to be positioned within the frame so that bellows flexure and stress is minimal.

A5. While fastening the prism on its respective mount, attention should be paid to the rotation of the tube. It is desirable that the edges of the prism casing are as parallel as possible to the adjustment plate edges. If you are lucky to set this properly, the adjustment of the working wavelength will later be much easier (by turning the prism pitch angle adjustment screw with only a minimal correction using the azimuth angle screw). The alignment will be carried out using the red light, and it is very desirable that the correction required to reach the working argon wavelengths could be achieved by using a single screw (although the fine tuning will most certainly require that you touch the azimuth angle screw as well).

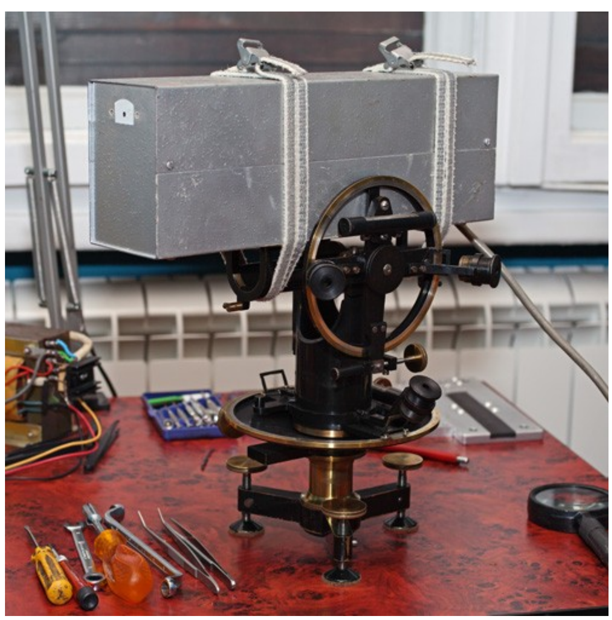
A6. The cast aluminum frame is built fairly precisely, you can use it to get a decent starting position for the alignment and avoid running out of the adjustment range. Use a Vernier caliper equipped with a depth probe to set the adjustment plates parallel to the frame and the adjustment screws at the midpoint of their travel range. If possible, put additional elastic washers under the adjustment screw controlling the pitch angle of the prism, this one will require the greatest travel range. Everything related to the adjustment plates and the mirrors mounted to them should be tightened now.

A7. Make a tool to help you identify the center of the OC mirror precisely; it will help during centering of the He-Ne exit beam. An easy way to make it would be to use a white sticky paper, cut out in such a way that you can position it precisely concentric to the OC. Before applying it to the OC, a square or round hole approx. 1mm in size should be punched in its center. In the following example we can see that the He-Ne beam is missing the central hole:



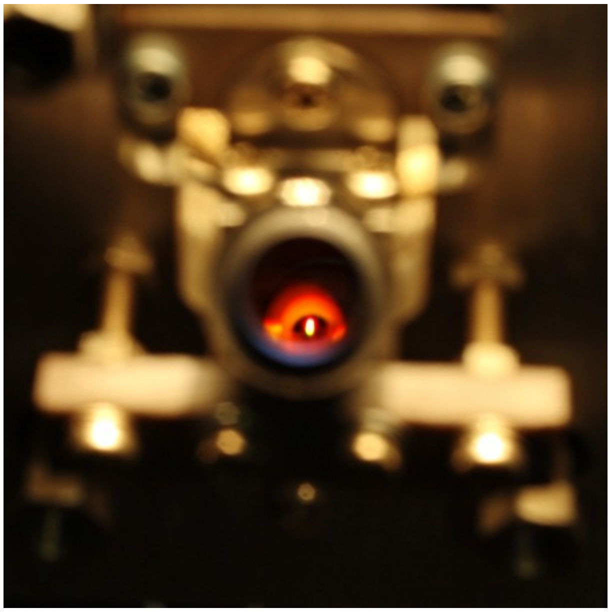
5. Setup of the red He-Ne laser

The He-Ne laser beam should be passing through a small screen on which the reflections will be monitored during adjustment. An easy way to make it would be to use some white sticky paper approx. 2cm x 2cm in size, and apply it on the front of the He-Ne head, with its center covering the beam exit hole. With the head switched on, the spot where the beam is hitting the paper should be clearly visible. By using an awl or a similar sharp tool, a small hole should be punched through the paper (approx. 1mm in diameter), so the beam can pass unobstructed. Next, using a black permanent marker, a thin circular outline should be made on the edge of the hole; it will help during centering of the reflections.
After the He-Ne head is mounted on its adjustment platform, it should be pointed to the HR mirror window (this will be roughly at 45 degrees to the bore axis, the easiest setup would be to turn the argon head on its side). The distance between the argon head and the He-Ne should be between 0.5m-1m. The light will refract through the prism, reflect back from the OC, and head back to the He-Ne. The HR side sequence is done on purpose, as in this case the procedure will yield a more precise adjustment of the OC. Note that the final OC adjustment will be wavelength independent due to the prism double pass action, so it is in our interest to set the OC more precisely. The prism alignment achieved using the He-Ne 632nm red light will not be good for the argon lines, but if everything is carried out precisely, we will be able to tune it properly later.
On the photograph is my old NEC He-Ne laser mounted on the precision adjustable platform of an old theodolite, which served the purpose perfectly:



6. The alignment of the argon head resonator

The first step is to roughly align the He-Ne beam along the bore axis, step A6 of the head preparation procedure should have left you with a good starting point. Position the two lasers so that the red beam is hitting the HR mirror near the edge (this offset is specific to the NEC GLG-3023 head, as already mentioned), perpendicular to the glass window. On the following photograph a shiny spot is showing roughly where the bore axis extension is located (ignore the obvious offset to the right; the camera was tilted when the shot was taken):

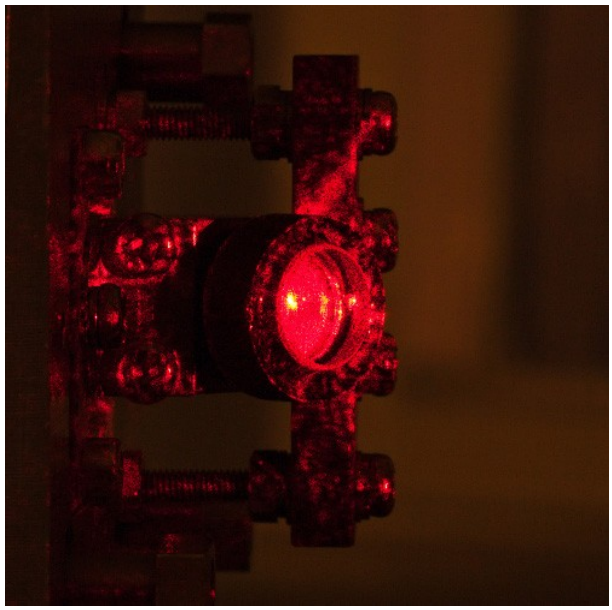


Using the He-Ne platform adjustments, try to get the beam to pass through the bore. Put a white screen on the axis of the OC mirror, darken the room in which you are working and observe the red light that is coming out. The goal is to make the beam exit on the OC side; this can be tricky as you need to adjust all four degrees of freedom that the He-Ne platform provides. With a little luck you should be able to nail it by observing the movement of the red shadows on the white screen.

Once you get the beam through the OC, the rough part of the alignment is over. Since there are a lot of variables in the system affecting each other, fine tuning is an iterative process that slowly converges to a solution. This is one of the possible algorithms that can be followed:

B1. Adjust the He-Ne to pass through the center of the OC, with the help of the white sticker created previously. It is recommended to use the platform altitude/azimuth angle adjustments for this.

B2. Observe the actual entry point of the beam at the HR outer glass window. If you can't see the entry point clearly, touch the window and leave a fingerprint on the surface, it will help you see it better. Note the deviation from the desired entry point (see the previous photograph). Adjust the He-Ne position to reduce this deviation, it is recommended to use the height/depth adjustments of the platform for this. In this example photograph the entry point was the smaller dot, close to the right edge of the window. It was obviously shifted a bit upwards, so the He-Ne head height had to be reduced:



Note: The goal of this step is to ensure that the red beam can pass through the tube by being as far away as possible from any obstructions (as close to the bore axis as possible), and the entry point on the HR mirror should be chosen to satisfy this condition. The most likely objects to cause obstructions are the bore ceramic and the filament, and this can be probed. To assess how far the beam is from these obstructions, the adjustments of the He-Ne platform should be used.

B3. Repeat steps B1-B2 in a loop until satisfied with the result (usually 2-3 iterations are enough). The precision of the entry point placement is not that critical, you should be able to set it within 1mm with a naked eye, and it can be improved later. The most important is that the beam is not obstructed by anything inside the tube.

C1. At this point there should be two reflections visible on the He-Ne laser white screen. Their distance from the central hole will depend on how well the setup step A6 has been carried out, for example:

These reflections are from the OC and the HR, and should be made to converge with the central hole of the screen. The OC reflection may even be missing if the OC alignment is too far off. Adjust the OC first, and then the HR (prism), as precise as you can. The adjustment screws of the mirror platforms form a right angled triangle, avoid touching the screw at the vertex of the right angle, the other two should be used instead.

C2. Verify the position of the prism adjustment screw that is responsible for the prism pitch angle, with respect to its travel range. This whole alignment is carried out using the red light, to be able to reach the tuning positions for the shorter argon working wavelengths later, the prism will need to be tilted inwards, meaning that for red color the adjustment screw now needs to be at the outer extreme edge of its travel range. Tuning for shorter wavelengths is accomplished by tightening this screw; the range can be set by adjusting the support nut located under the adjustment plate, on which the elastic washers reside.

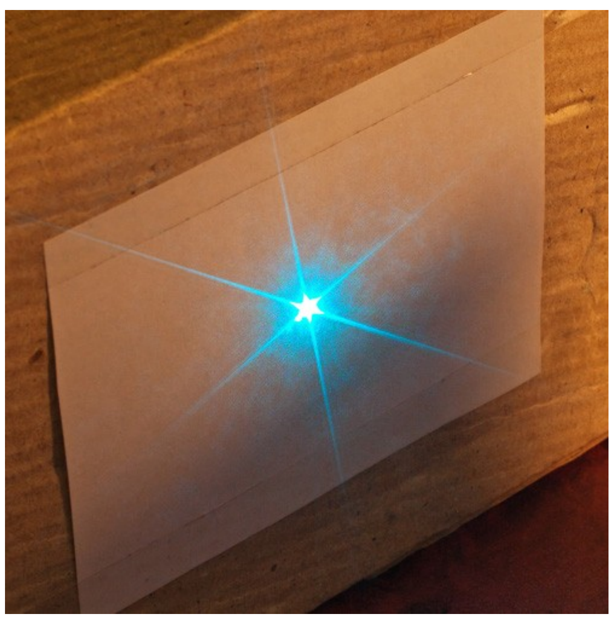
C3. The change in prism angle from the step C1 has now changed the refraction angle of the beam, meaning that it most likely needs to be readjusted to hit the OC center again. In this case proceed to step B1 and repeat the whole procedure. However, if the beam is hitting the OC center precisely, is passing the system unobstructed and both reflections are precisely centered at the He-Ne screen central hole, then this alignment phase is over.

C4. Tighten the flexible anode contact on the tube; this must be done to prevent sparks and arcing when the tube is powered up. All other mounting screws should be left as described under step A3. Ensure that there is no change in the alignment achieved at the previous step.

The process described is convergent, and it usually takes around 3-5 iterations to get it right. At this point the head is adjusted for the red light, and must be tuned for argon lines. Before you decide to move it and cancel the fine alignment achieved with the He-Ne, make sure that the travel range of the wavelength tuning screw is adjusted as described in the step C2.

The next alignment is carried out with the tube powered up (**do not forget the cooling and safety precautions!**). The OC should not be touched at this step; all adjustments are carried out on the prism. It is recommended to have two wrenches ready, one for the wavelength tuning screw, and another for the screw across the adjustment plate diagonal. The anode current should be set to the highest value permitted by the system/cooling (although I successfully nailed the alignment easily using a current of less than 6A). A white screen should be placed nearby facing the OC. The following steps should be carried out:

D1. Try to remember roughly the starting position of the screw across of the wavelength tuning screw (the easiest way is to use a box-end wrench and not take it off of the screw during the alignment).
D2. With the tube powered up, begin by tightening the wavelength tuning screw slowly. The setup from the C2 step warrants that the full travel range is ahead of you. There is a significant chance that you will get a laser light flash right away at some point. If not, do not let your spirit go down and go all the way through the travel range of this screw.
D3. Pick one direction and rotate the other screw approx. 1/20 of a full turn in that direction. This should be just a tiny nudge, be careful not to overdo it. Repeat the steps D2-D3 a few times. If no luck, go to step D4.
D4. Try the same approach as in D3, but in the opposite direction. Start close from the position you remembered in D1.



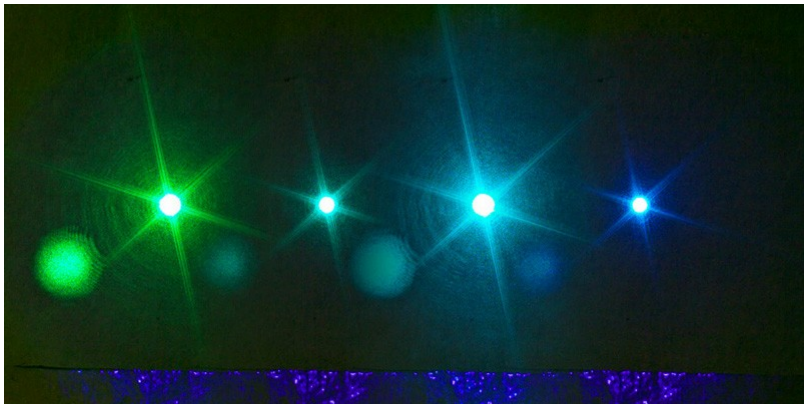
At this point you should have gotten the tube lasing on at least 514.5nm or 488.0nm. If you don't get the laser light flash, you may try some of the following:

- Increase the travel range of the wavelength tuning screw. This can be accomplished by adding extra elastic washers under the adjustment plate. Just be careful not to bend the bellows too much, for the NEC head the travel range of this screw should be below 3mm.

- Repeat the B1-C3 procedure again, with additional attention to hard-to-notice obstructions. Sagged filament can be one of the probable causes. The beam positioning along the bore has its tolerances, you can try to pick a different entry point on the HR mirror window, as long as the beam passes unobstructed at the OC side.

7. Fine tuning of the mirrors after the tube started to lase

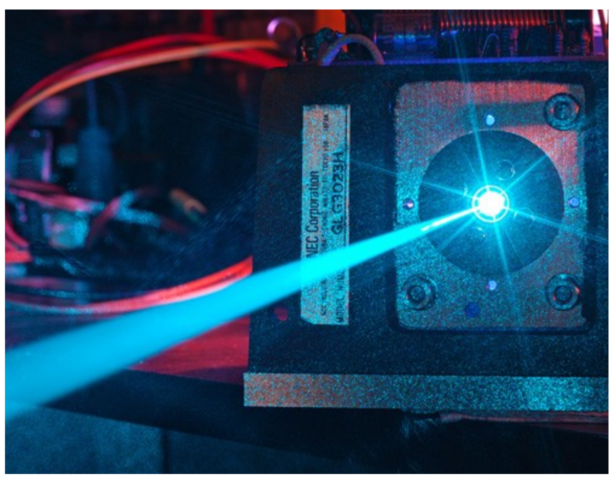
At this point you should be very well relaxed as the worst is behind you. Just be gentle with the adjustments now, and make sure you don't lose the beam. Fine tuning of the mirror alignment should ensure that you can get all of the possible argon lines, and that you can get the most power out of the laser head.
The four major argon lines at 514.5nm, 496.5nm, 488.0nm and 476.5nm should be easily obtainable by using the wavelength tuning screw. If you got the setup step A5 precisely, you may be able to get them all without using the screw across at all. Adjust the support nut under the adjustment plate so that enough range is available to get all the lines. Add some elastic washers if necessary. This is a composite photograph of the four major lines obtained by tuning the prism for each:



Anode current was set to approx. 5.5A. The exposure in each frame was the same, so the intensity is comparable. The 488nm line was stronger than the 514.5nm, most likely because this laser model was optimized for 488nm.

The final adjustment is more-less optional, except the E1 step (see below). The output power of the laser depends on how well the optical axis of the resonator is aligned to the mechanical axis of the bore (the most power should be obtained when the resonator axis is passing along the central, hottest area of the plasma). This power tuning is usually called "walking the mirrors", and requires a power measurement instrument and a lot of patience. It is usually accomplished by following these steps:

E1. Remove the sticker from the OC mirror, and properly clean both the OC and HR mirror windows.
E2. Power up and let the system stabilize thermally for a while (approx. 30min).
E3. Note the present output power of the tube, maxed out by tuning the two prism screws.
E4. Perform a small nudge of one of the two OC adjustment screws. The beam must not be lost with this change.
E5. Max out the output power by adjusting the two prism screws. If the power recorded is greater than the starting one recorded at step E3, continue the E4-E5 loop in the same direction. If not, perform the E4-E5 loop in some other direction of the nudge described in E4.
At the end of the alignment, gently move the tube inside the frame using your hand until it settles in a position with the lowest mechanical strain from the stretched bellows. The tube mounting screws should now be finally tightened. Use a reasonable force on the ones fastening the mounting stands to the frame (be careful as they are brittle), and a very gentle force on the ones tightening the tube itself.



8. References

1. Ar/Kr Ion Laser Testing, Maintenance, Repair (Sam's Laser FAQ):

http://www.repairfaq.org/sam/laseratr.htm

2. Photo story of the NEC GLG-3023 laser:

http://www.nfilipovic.com/electronics/argon-ion-laser