Thorlabs Optical Trap

Construction and Application Kit of an Optical Tweezer

Ludwig Eichner
Thorlabs, Inc.
435 Rout 206, Newton NJ
www.thorlabs.om
leichner@thorlabs.com

Education Systems from Thorlabs, Inc.
Providing knowledge for the trade

Kit OTKB

Manual OTKB-MA ver 0.9 (Draft)

THORLABS INC 435 Route 206, Newton, NJ 07860 • Sales (973) 579-7227• Fax (973) 300-3600

Laser safety is the avoidance of laser accidents, especially those involving eye injuries. Since even relatively small amounts of laser light can lead to permanent eye injuries, the sale and usage of lasers is typically subject to government regulations.

Moderate and high-power lasers are potentially hazardous because they can burn the retina of the eye, or even the skin. To control the risk of injury, various specifications, for example ANSI Z136 in the US and IEC 60825 internationally, define "classes" of laser depending on their power and wavelength. These regulations also prescribe required safety measures, such as labeling lasers with specific warnings, and wearing laser safety goggles when operating lasers.

Table of Contents

Thorlabs Optical Tweezer Application Report for AAPT

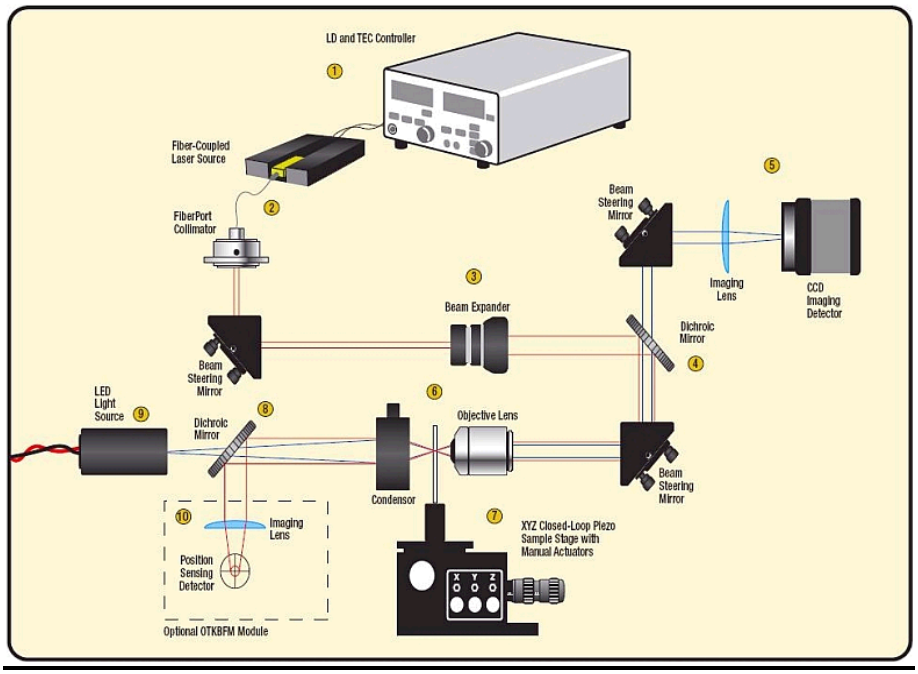
Overview:

Two measure techniques to access the mechanics and elasticity of molecular entities like protein, DNA etc. are atomic force microscopy (AFM) and Optical Tweezers. When these forces are in the sub-Pico Newton, optically tweezing particles or molecules enables their measurement and therefore gives us an understanding of the mechanic and elastic properties. The ThorTweezer is a modular system that enables the measurements of these forces through the creation of an optical trap.

Optical Tweezers, Basic Theory:

A. Ashkin et. al about three decades ago demonstrated that it is possible to use a single beam with a large gradient force to form an optical trap for nano/micro-particles. By measuring the particle's position, we can calculate the dynamic forces on the particle. When you strongly focus a laser beam, a very strong electric field is formed at the focal point and a large electric field gradient is formed in both the axial and radial directions. A sufficiently steep field gradient can create a force on a particle large enough to counter Brownian motion leading to a stable optical trap in all three dimensions. The balance of the gradient and scattering forces in the axial direction causes the potential minimum for the trapped particle to be slightly downstream from the focal point of the objective.

Experimental Setup and Procedure:



The optical tweezers set-up (schematic above) has been used to demonstrate trapping of 1 and 2 um non-

absorbing pure polystyrene beads. The sample in this case was prepared by creating a 3-4mm flow channel on an ordinary microscope slide, filled with polystyrene beads in an appropriate ratio in de-ionized/regular water, with a cover slip placed over. This was mounted on stage and the objective was then raised and adjusted until beads were in focus as seen through CCD camera software live imaging. Then the trapped bead was turned on and stage and objective positions were adjusted until trapped bead was in focus, as shown in fig. 1. A trapped bead can then be moved with respect to the surrounding beads in three dimensions. The microscope stage provides translation in the x-y-z plane.

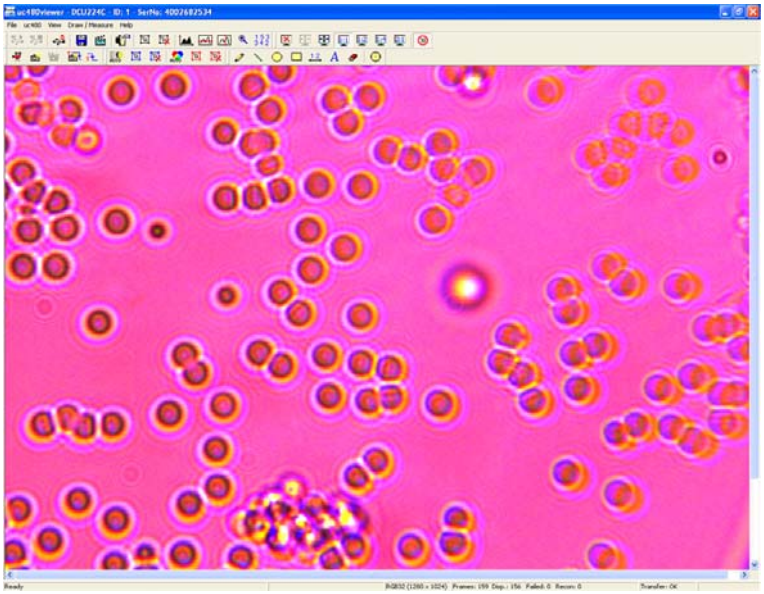


Figure 1: CCD camera application, 1 μm Silica beads. The bright spot near the center of the picture is the trapped bead.

Potential Investigations:

Molecular studies and DNA interaction studies like stretching.

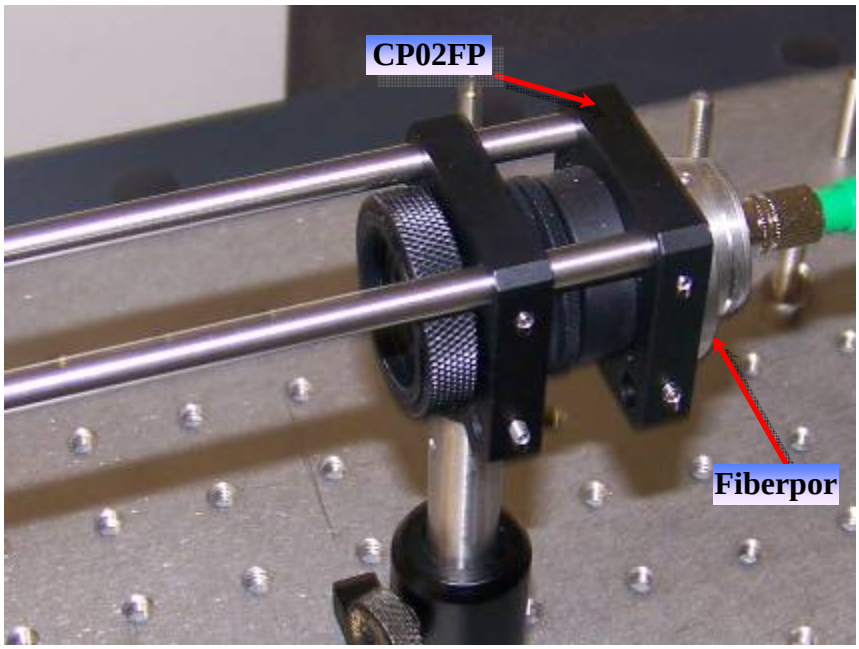
Microviscoelasticity of polymer gels.

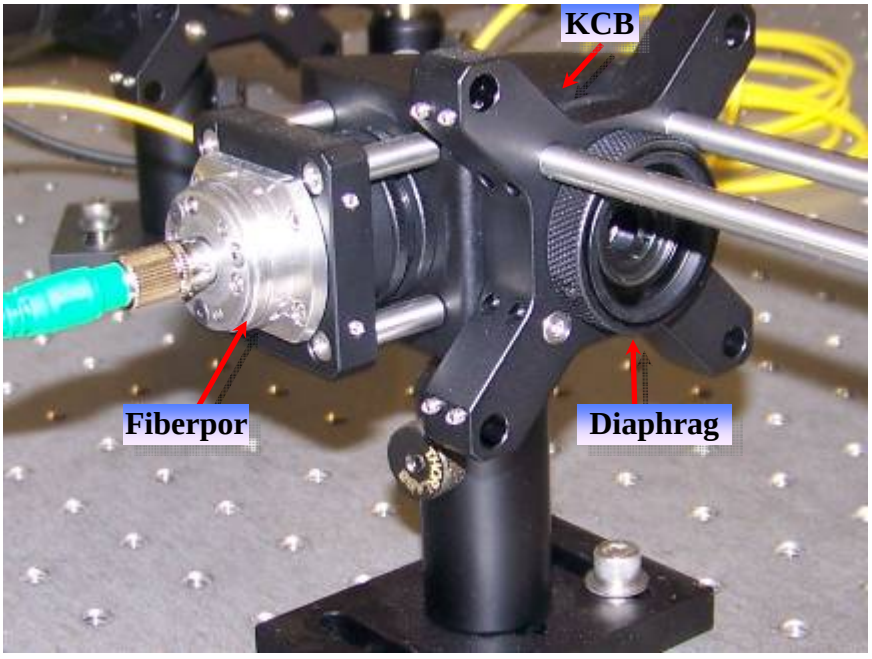
Colloidal forces between two particles/molecules.

THORLABS OPTICAL TWEEZER ASSEMBLY GUIDE

1. Collimating Trap beam from Fibeport

Aim beam to a wall about 5m away and adjust flat head screws on Fiberport until spot size is smallest. You need two people to do this. One with the IR card about 5m away, while the other adjusts fiber port. Then ensure that beam is parallel by using alignment plates on ER6 as on the picture to the right. Use iris, min aperture, and make sure beam intensity is same through both alignment plates.

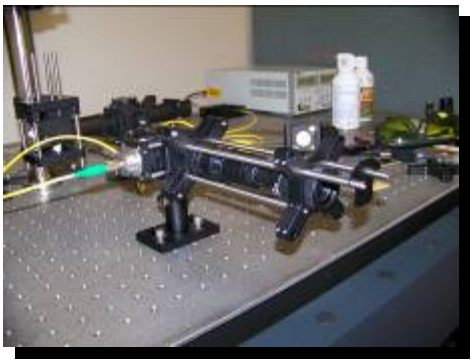


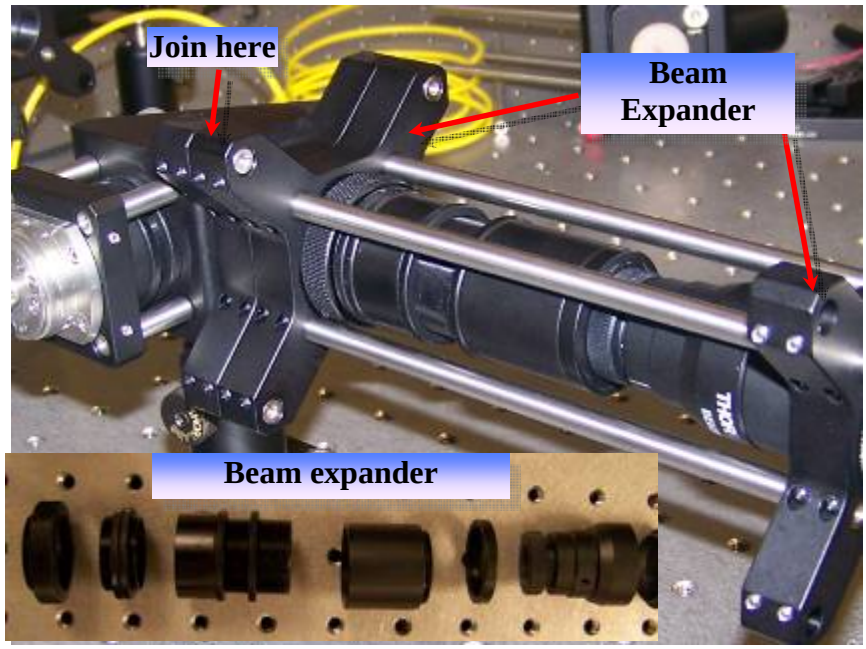


Attach the fiberport section to KCB1. Mount these as in picture and ensure that beam is aligned through diaphragm and alignment plate by steering with knobs on KCB1. Then build the beam expander section as in next picture.

2. Beam Expander section

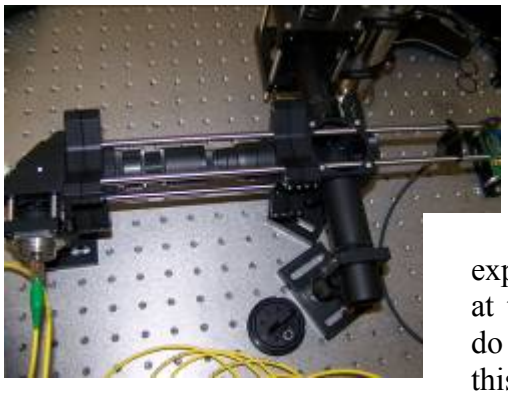
Build the beam expander section, with the following items: SM1D12D, SM1T2, SM1V10, SM1L10, SM1A1, BE02M-B (pictures below), 2 LCP02, 4 ER4 rods. Attach this to LCP02 on KCB1 with ER1 rods as shown. Adjust BE02M-B until beam is well collimated about 5m away Then ensure that beam is aligned as in picture below.

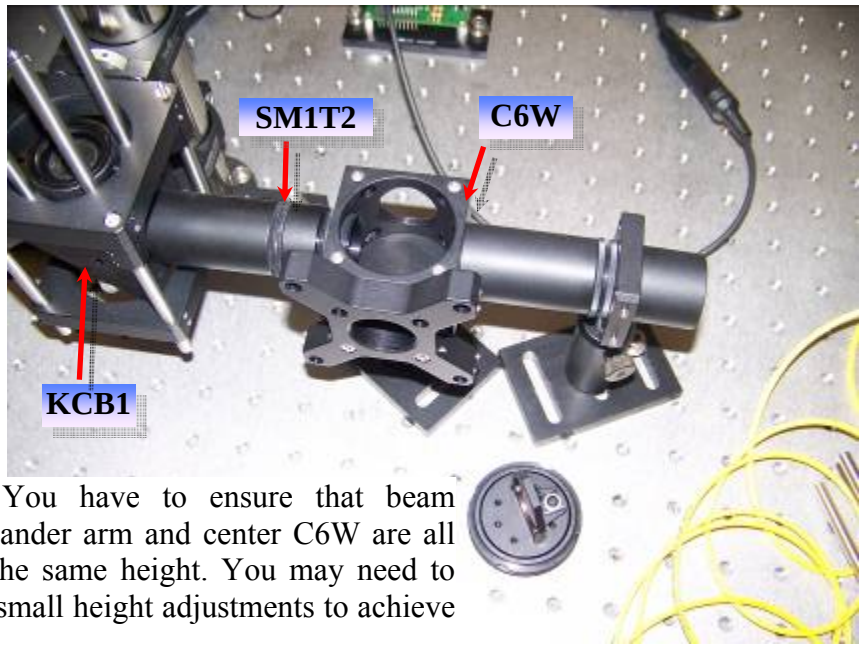




3. C6W and beam expander section

Mount the C6W on post through base and attach an LCP02, SM1V05, lens tubes as shown to the right. Then use alignment plate and ER rods to ensure beam is parallel to breadboard, when beam expander arm is connected as shown below.

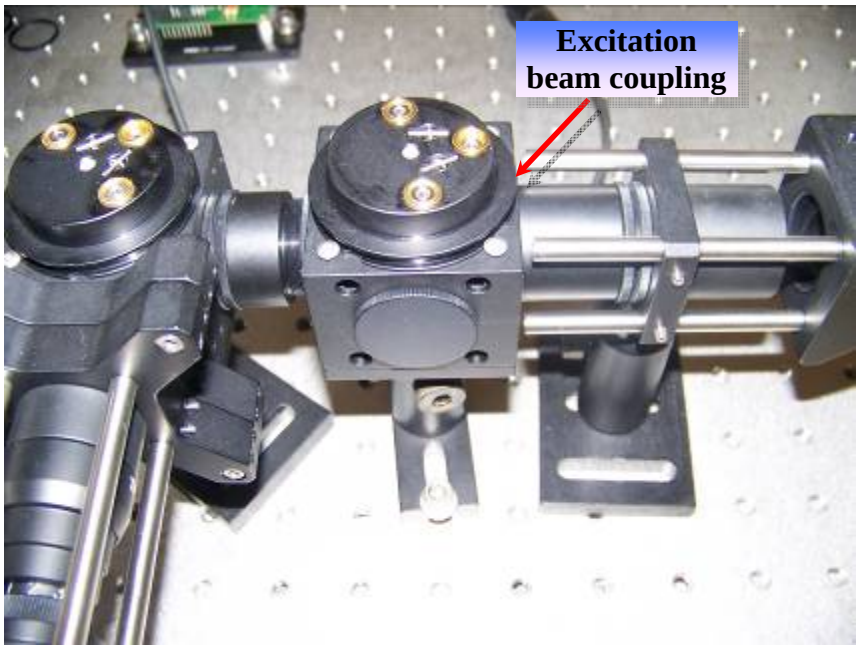




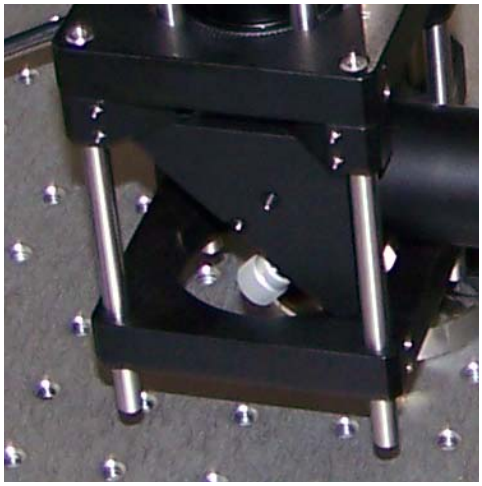
You have to ensure that beam expander arm and center C6W are all at the same height. You may need to do small height adjustments to achieve this.

If excitation beam is needed

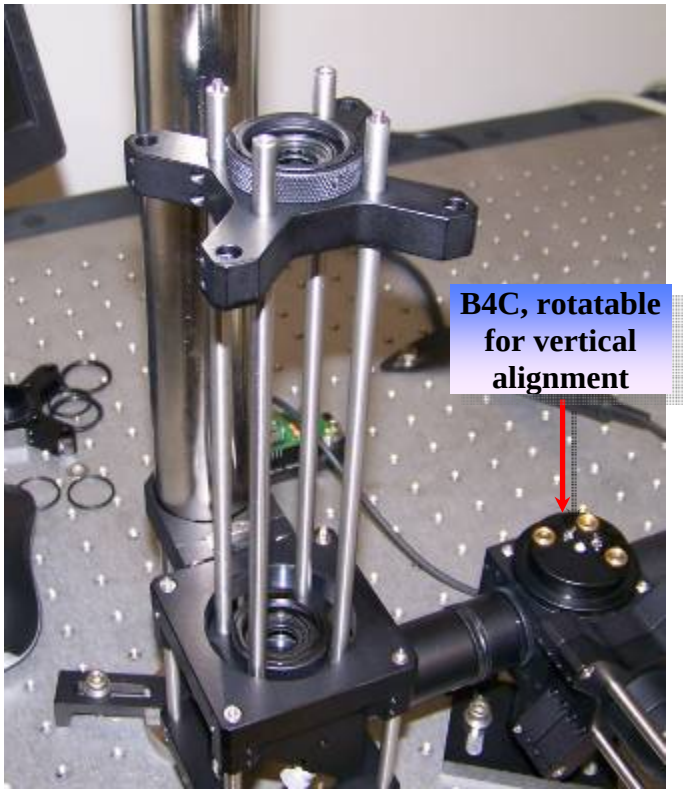
In some applications, you may need to couple in an excitation beam. Then the central section will look like this



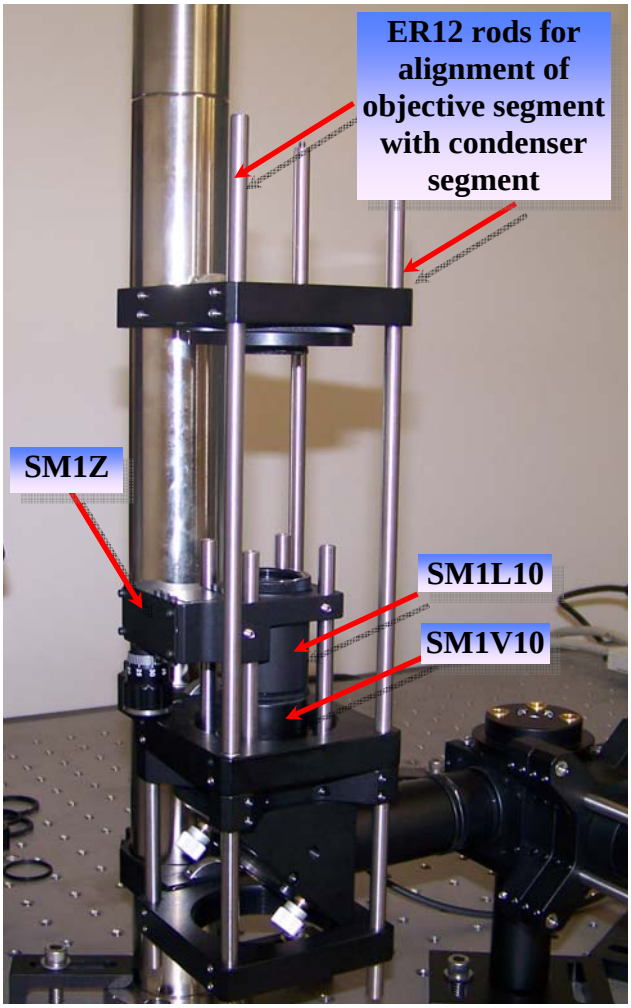
4. Vertical alignment of Trap Beam



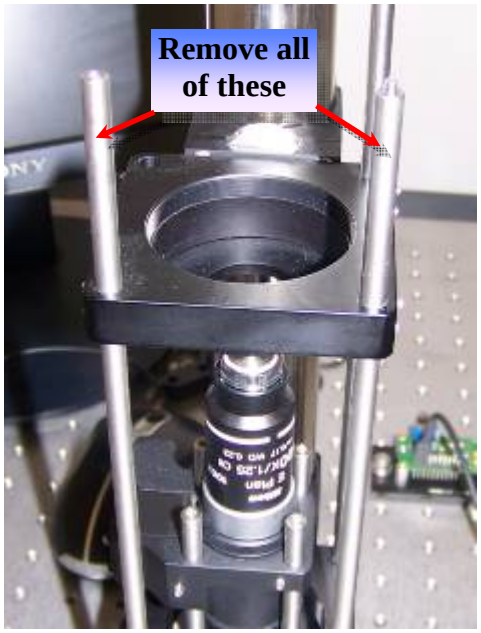
After attaching the vertical steering mirror on KCB1 as shown above, use 4 ER rods, LCP02, and two diaphragms to achieve a bull's eye vertical alignment as shown to the right. This is done by slowly rotating the B4C and watching alignment through both diaphragms with an IR card for instance, if your trap beam is IR.

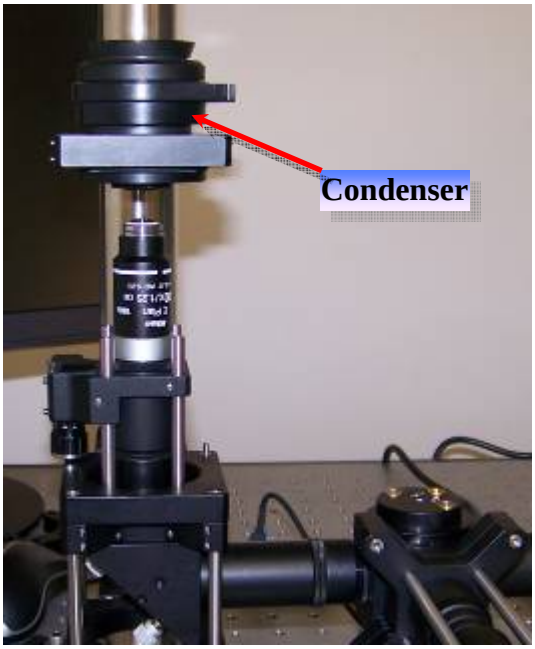


5. Objective and Condenser segments' alignment

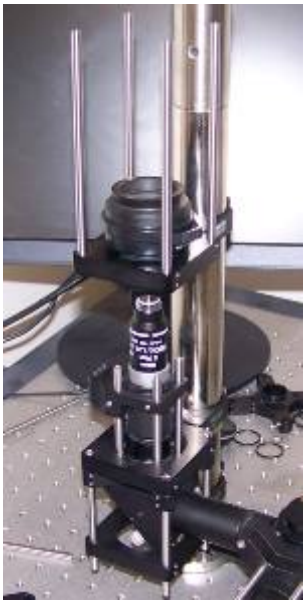


Use the ER10 rods or longer to align objective and condenser segments. Then mount objective as below. Once the Condenser plate is mounted and held firmly on the central post, the ER rods used for the alignment can then be removed.



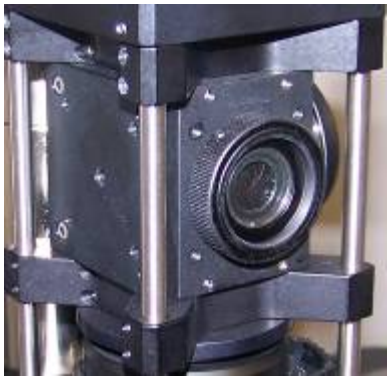


Mount condenser and nudge it couple of times until it is aligned with objective. Distance between objective top and condenser should be around 4 - 6 mm. Then mount ER rods to hold the rest of condenser segment. Make sure condenser shutter control is between ER rods such that it

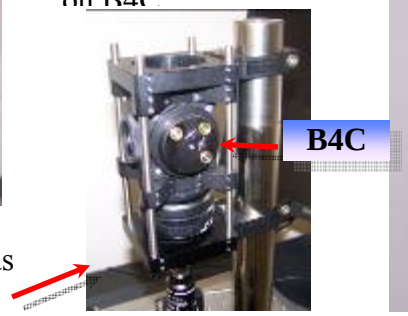


6. Quadrant Detector Segment

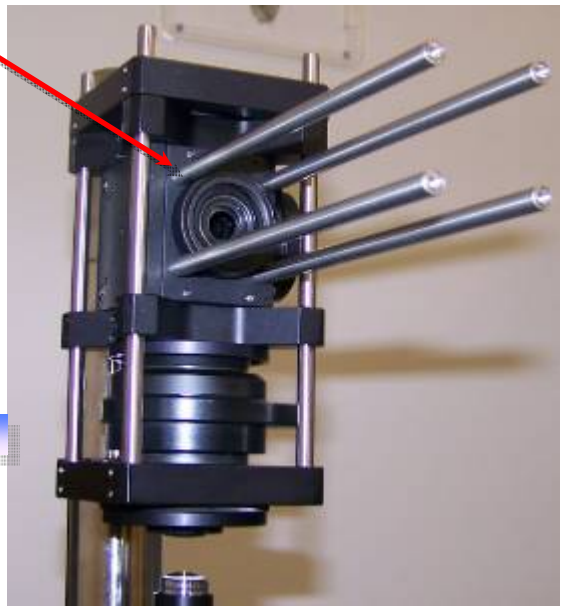
Connect the C6W section that should go on-top the condenser as shown below.



Then attach this to the rods as shown below.

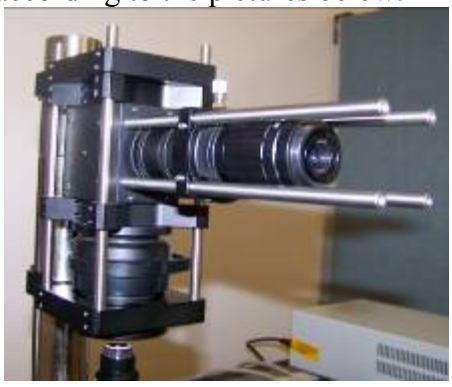


Then using ER rods and alignment plates, ensure that beam is reflected parallel to rods, and going through center, by rotating FM02 mirror on B4C



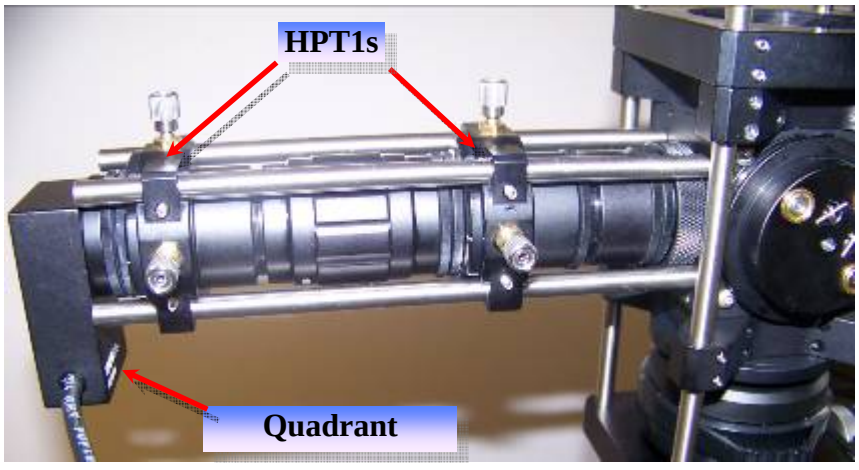
Then complete the quadrant detector arm by mounting components according to the pictures below.

Note that the SM1NR05 contains the QD focussing lens.



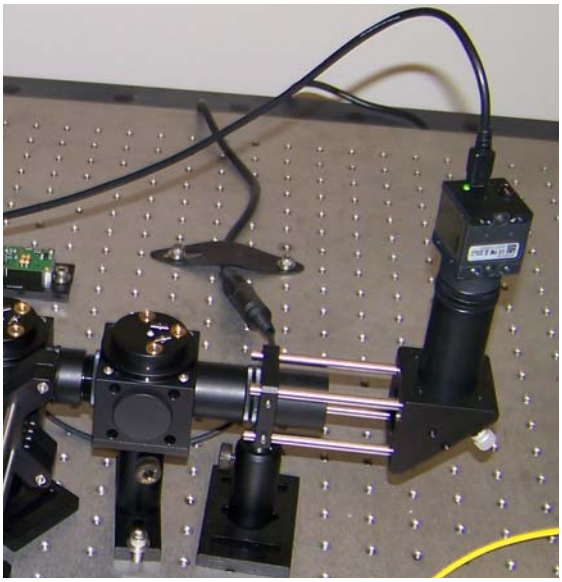
The Quadrant detector Arm once complete will look like this.

Note that in order to align the beam along this section, you have just the hot mirror on the rotatable B4C with its tip and tilt adjusters. To get this right, you may need to manually adjust B5C on B4C, and then use rotation and tip/tilt to get this aligned. The HPT1 are then used to complete the very small adjustments needed to center beam on quadrant detector during viewing.

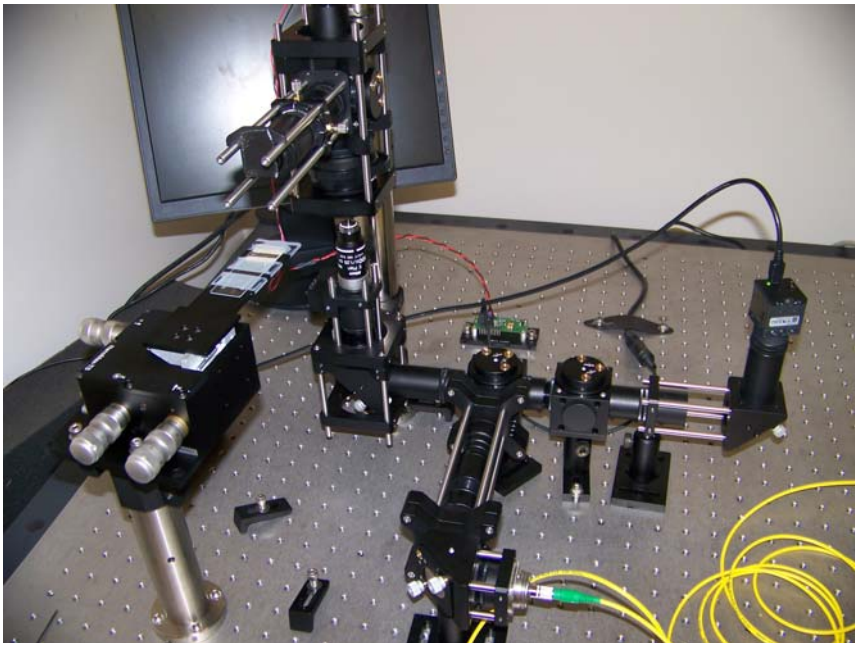


7. CCD Camera

Now that you have everything connected, connect the CCD camera as shown. You may need to use longer ER rods if bead is not being trapped in focus.



Complete System



Optical Trap
Application Example

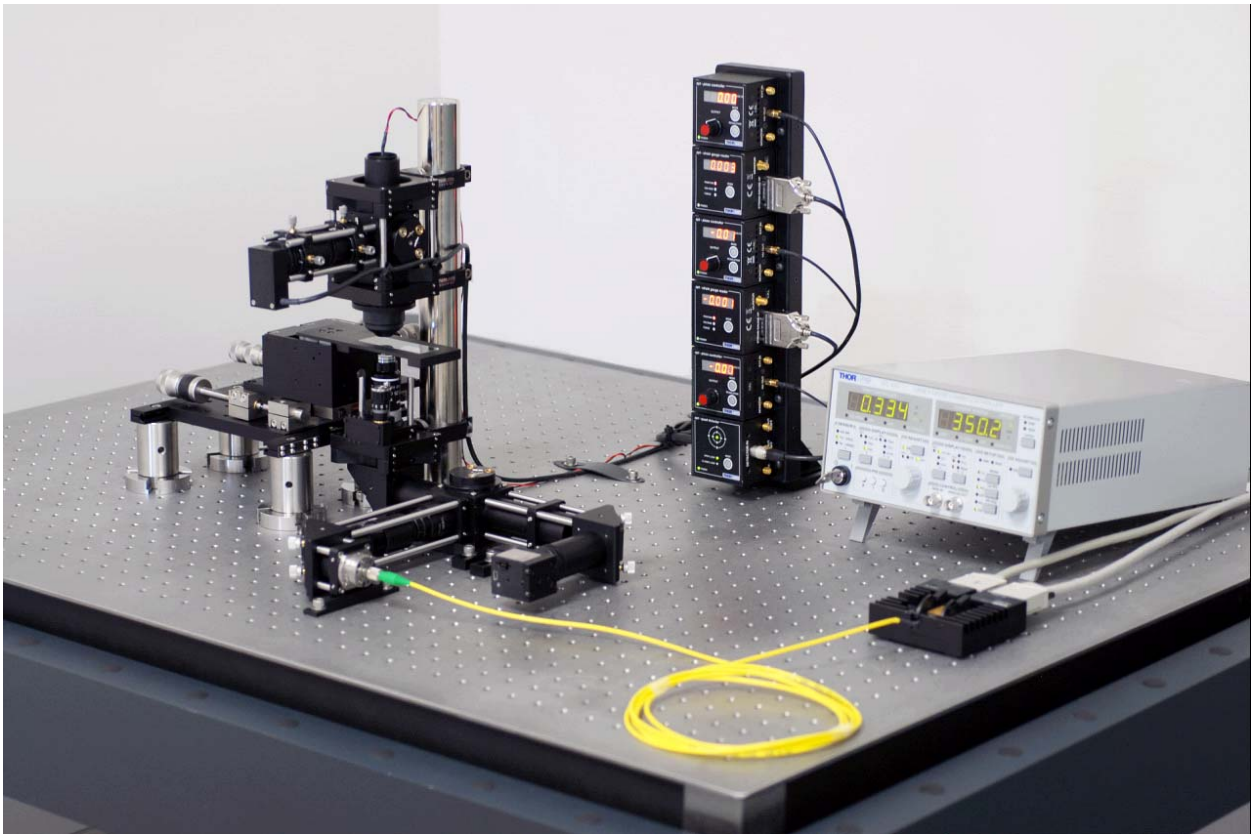


Table of Contents

Introduction

S. Wasserman, D. Appleyard and M. Lang at the Department of Biological Engineering, MIT (Optical Trapping for Undergraduates, Am. J. Phys. 75(1), January 2007) built an optical trapping setup for use in teaching labs. Thorlabs, in collaboration with the aforementioned, has designed a kit that includes all of the components required to build an optical trapping setup with the same capabilities. One of the advantages of building an optical trapping system out of Thorlabs' components is that the user can easily add additional functionalities to the system as their needs evolve over time. For example, if the user wishes to add the ability to steer the optical trap they can add a 1:1 beam expander with an adjustable lens. Another example is if the user wishes to incorporate an excitation light source they can easily add a beamsplitting cube to the beam path.

Thorlabs has bundled all of the components, instructions and software needed to construct a fully functional optical trapping system into a cost effective kit with the part number 'Optical Trap Kit'.

Setup Description

Optical Trapping Kit OTKB (OTKB/M)

Like many optical trapping systems, this one is based on an inverted microscope design. All of the parts discussed in this section are included in the kit. The trapping laser source (part number PL980P330J) is a pigtailed FBG stabilized single mode laser diode in a hermetically sealed 14-pin butterfly package.

The integrated TEC element and thermistor in the butterfly package allows the temperature of the laser to be precisely controlled when mounted in the LM14S2 laser diode mount and controlled using an ITC510 TEC and Laser Diode Current Driver. This laser, mount, and controller combination was chosen to ensure that the output power (330 mW max) of the laser will be extremely stable, which is important to maintaining a constant trapping force.

The laser output is collimated using a compact, ultra-stable FiberPort micropositioner PAF-X-7-B and subsequently expanded with a 2X beam expander (BE02M), which allows for continuous adjustment of the beam's collimation so that optical focus can be easily adjusted with respect to the position of trapped beads. The expanded beam is then reflected by a wide band hot mirror into the vertical path of the microscope. After the adjustable ring iris, a Nikon 100X oil immersion objective (MRP01902) focuses the beam down to form the optical trap. The objective has a 5 mm back aperture which is not overfilled when using the combination of the fiber coupled laser source and 2X beam expander provided in the kit. However, the stiffness of the trap was still excellent. The calculated fundamental limit of the trap diameter imposed by diffraction theory for our test system is 1.1µm. The trap beam then goes through the Nikon Condenser and is reflected by another wide band hot mirror into the detector path. The detector path contains a biconvex BK7 lens (LB1378) with a 40 mm focal length that images the back focal plane of the condenser onto the quadrant detector (PDB80A). To prevent damage to the quadrant detector, an absorptive neutral density filter (NE06D) is also in the detector beam path. The detector is a silicon based segmented quadrant position-sensing detector with a rise time of 40nsec and a bandwidth of 150kHz. The output of the detector is measured with a T-Cube Position Sensing Controller (TQD001).

The structure of the inverted light microscope is constructed using Thorlabs' 60mm cage system, which is supported with a damped ∅1.5″ post (DP14). A white LED source (LEDWE10) is mounted above the optical trap in order to illuminate the sample with light in the visible part of the electromagnetic spectrum.

This allows for the simultaneous acquisition of a real-time image of the sample using a 1280 x 1024 pixel color CCD camera (DCU224C). A plano-convex BK7 lens (LA1509-B) is used to image the sample onto the CCD camera while a shortpass filter (FES0750) blocks any scattered or reflected light from the trapping laser.

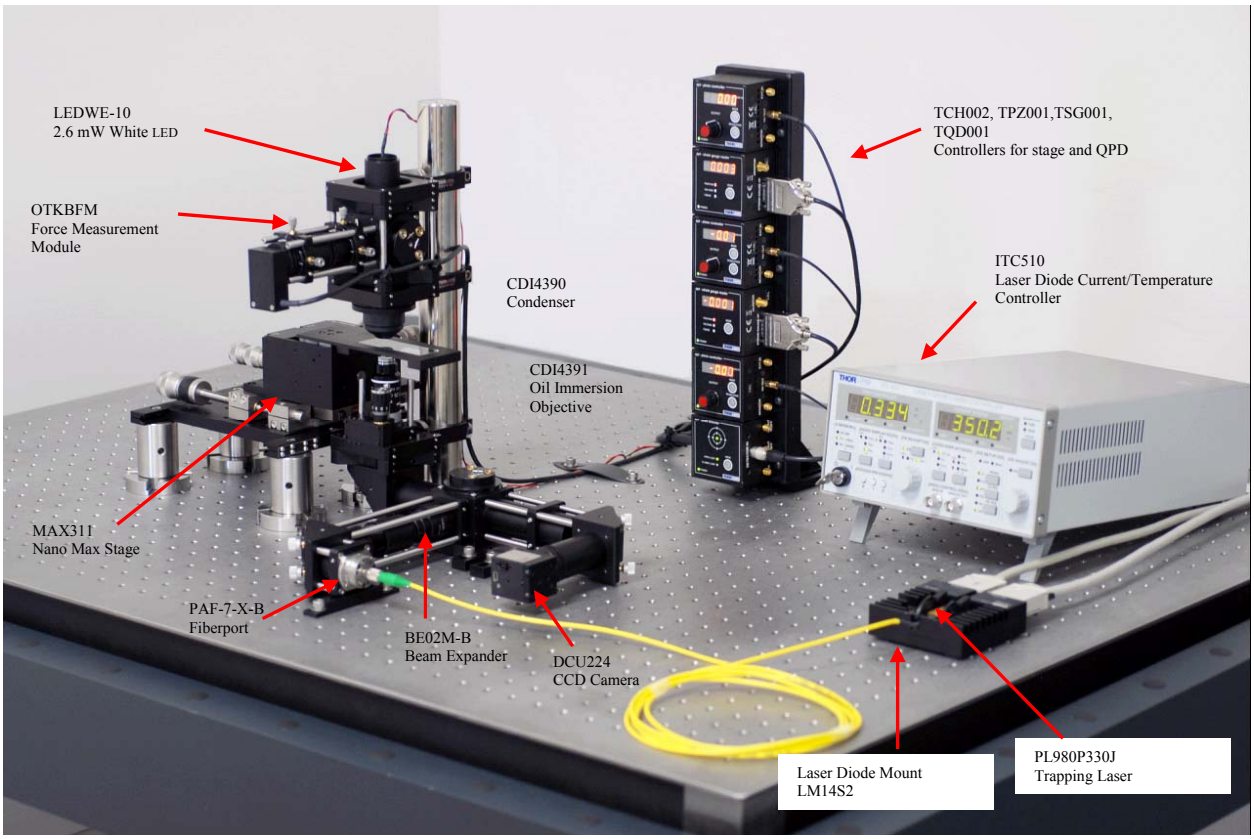


Figure 2.1 Setup with main components

The sample stage consists of a 3-axis piezo stage (MAX301) with strain gauge feedback, which has an overall travel range of 4 mm via micrometer adjusters (DRV002) and 20 um translation via the internal piezo actuators. The piezo actuators allow the sample to be positioned with a resolution of 20nm, 5 nm if the strain gauge feedback signal is used (the TGS001 controllers for two axis are included with the OTKBFM force measurement module). The MAX stage is mounted on top of an LNR50D stage which allows adjustments of up to 50mm perpendicular to the axis along which the sample is loaded. For greater flexibility and ease of use when loading a new sample the sample stage is mounted on a translating breadboard TBB0606 (TBB0606/M)

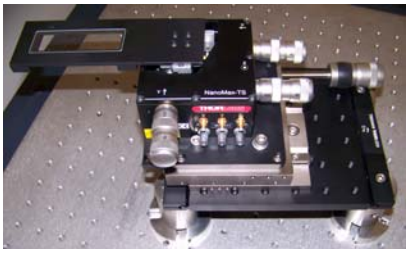


Figure 2.2 Sample Positioning Unit

Optical Force Measurement Module OTKBFM

The OTKBFM module contains the hardware needed to calibrate the trap using positional detection of the back-focal plane of the condenser. By placing the Quadrant Position Detector (QPD) in a plane conjugate to the back focal plane of the condenser the signal generated by the QPD is sensitive to the relative displacement of the trapped particle from the laser beam axis. As a result the output of the detector can be used to calibrate the position, stiffness, and force of the optical trap. The detector is connected to the cage cube above the condenser (see picture). A TQD001 T-Cube Quadrant Detector Reader and two T-Cube Strain Gauge Readers are the main components included in this module. For high bandwidth measurements the QPD signal can be read out from the controller cube directly via a DAQ card (not included).

Figure 3.1 Force Measurement Module OTKBFM consisting of two TGS001, TQD001, PDQ80A and the cage assembly for connecting the detector and optics to the base kit. The shaded controllers and the USB hub TCH002 are included with the base kit OTKB (OTKB/M)

Initial Setup and Alignment

Unless otherwise noted, all of the parts mentioned in this section are included. Please observe proper laser safety procedures. IR laser beams are particularly dangerous because they can not be seen. Always wear the appropriate type of laser glasses (not included) when working with laser beams.

Mount fiber coupled laser into LM14S2 and connect to the ITC510 controller. Make sure the correct pin style is set on the controller and mount. Adjust the temperature controller and set the current limit to avoid any damage to laser diode.

4.1 Collimating Trap beam from Fiberport

Aim the beam to a wall about 5m away and adjust flat head screws on Fiberport until spot size is smallest. You need two people to do this. One with the IR card about 5m away, while the other adjusts fiber port. Then ensure that beam is parallel by using one and then two alignment plates on ER6 cage rods as shown on Figure 4.1.1. Use iris adjusted to smallest aperture and make sure the beam intensity is same through both alignment plates.

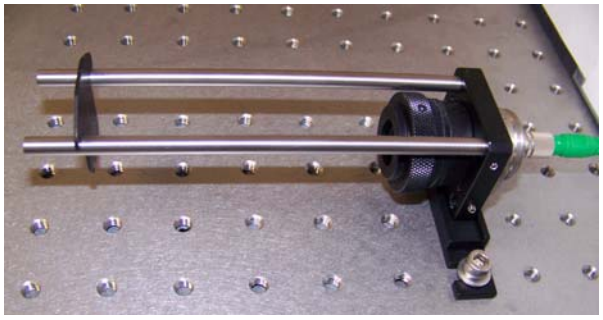


Figure 4.1.1 Align Fiberport

Attach the Fiberport section to KCB1 without the iris. Mount these as shown in Figure 4.1.2 and ensure that beam is aligned through diaphragm (on KCB1) and alignment plate by steering with knobs on KCB1. Remove the KCB1 and put it aside, it will later be used for the coupling into the vertical path of the microscope. Adjust the second KCB1 in the same way.

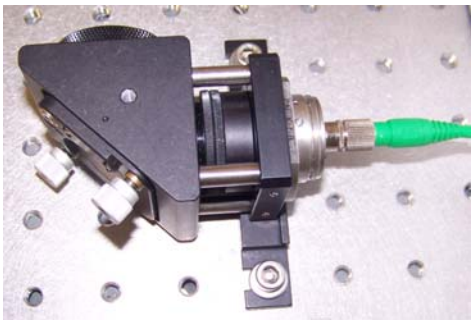


Figure 4.1.2 Adjust Right Angle Mirror Mounts KCB1

4.2 Beam Expander Section

Build the beam expander segment. Connect adjustable ring iris (SM1D12D) to a lens tube coupler (SM1T2). The other side of the lens tube coupler is connected to a SM1 Rotating Adjustable Focusing Element (SM1V10). A one

inch lens tube is now connected to the SM1V10 to provide enough adjustment of the overall length of the expander element. Use the Adapter with External SM05 Threads and Internal SM1 Threads (SM1A1) to attach the beam expander (BE02-M) and finally a 0.5" inch lens tube (SM1L05).

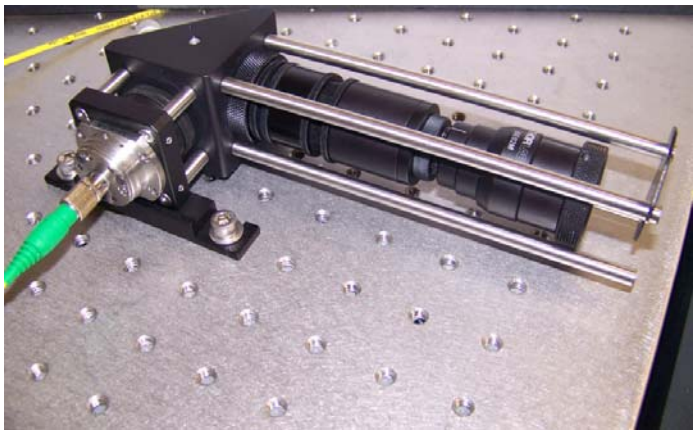


Figure 4.2.1: Building beam expander segment

Then you need to ensure that beam direction is maintained, with the use of an alignment plate. Note that you need to build this segment before connecting ER rods shown in picture. After building the expander section check that the beam after the beam expander is collimated over at least 5m. As with the FiberPort, starting with a visible light source and observing the beam after it has propagated several meters will make it easier to quickly adjust the beam expander. Then replace the visible light source with the 980 nm source for fine tuning of the beam's collimation. A SI050 (not included) shearing interferometer with a SIVS (not included) attachment can be used to qualitatively measure and subsequently adjust the collimation of the beam with a high degree of precision. For IR beams an IR viewer (not included) is required to see the fringes. Please observe proper laser safety procedures. The usage of the shearing interferometer is optional, although it is useful in situations where a long beam path is not feasible. A shearing interferometer was not used to build any of our test setups or the tradeshow demo systems since excellent results were achieved by simply using an IR viewing card to check the collimation of the beam.

4.3 Vertical segment

Mount the wide band hot mirror in the mounting cube C6W and build the vertical path of inverted microscope.

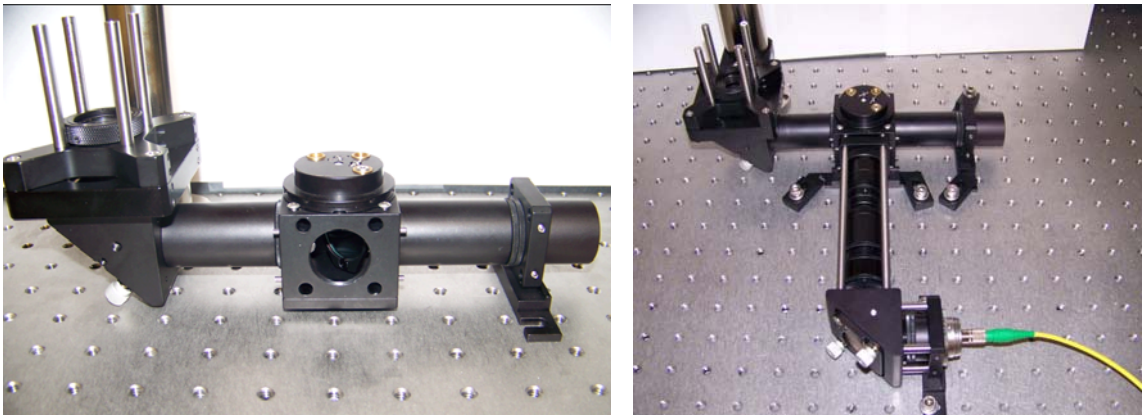


Figure 4.3.1: (left) Center cube, C6W connected to lens tubes and KCB1 for vertical beam steering; (right) The beam expander segment shown connected to the center C6W

After attaching the vertical steering mirror on KCB1 as shown in Figure 4.3.1 (left), use 4 ER5 or ER6 rods, LCP02, and two diaphragms to achieve a bull's eye vertical alignment as shown in Figure 4.3.2. This is done by slowly rotating the B4C and watching alignment through both diaphragms with an IR card for instance, if your trap beam is IR. The B4C is used to align beam through lower diaphragm (when it is mostly open, and then slowly closed) while the knobs on KCB1 are used to align beam through upper diaphragm. If KCB1 is right-angle-reflection adjusted, you will only need to make a few turns on the knob to get the bull's eye alignment through both diaphragms.

Figure 4.3.2: Building the vertical segment and aligning trap beam vertically

4.4 Mounting Objective and Condenser

The objective is mounted on an SM1Z using an SM1A10 adapter as shown in Figure 4.4.1 (left). Below the translator is an adjustable ring iris. The condenser is mounted in a 60mm cage plate (LPC01) through an SM2 adapter. Use the ER rods with appropriate length (ER8 or longer) to align mounted condenser segment to objective

segment as shown in Figure 4.4.1 (left). Then construct the segment that mounts on the condenser as shown in Figure 4.4.1 (right). This includes the cage cube (C6W) which is used to mount the second wide band hot mirror.

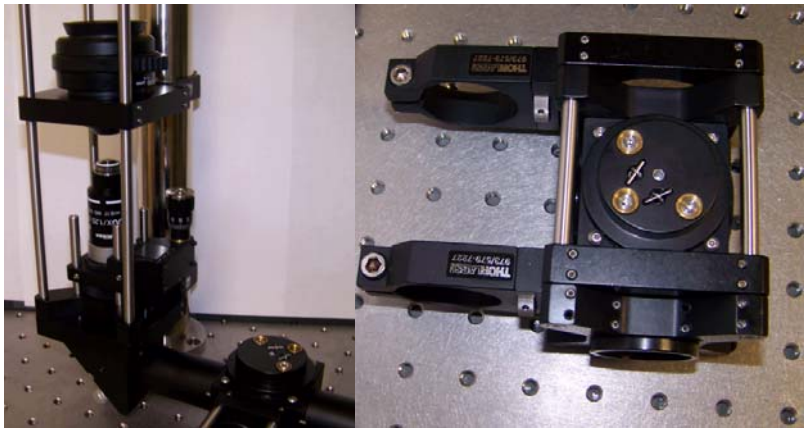


Figure 4.4.1: (left) Objective and condenser mounted. (right) Segment above condenser to hold white light source and image condenser back focal plane on Quadrant Detector

Remove the ER rods used for alignment objective and condenser, and mount segment above condenser as shown in Figure 4.4.2. Then you can mount the white light segment atop through an SM1Q shown in Figure 4.4.2.You can now connect the camera segment as shown in

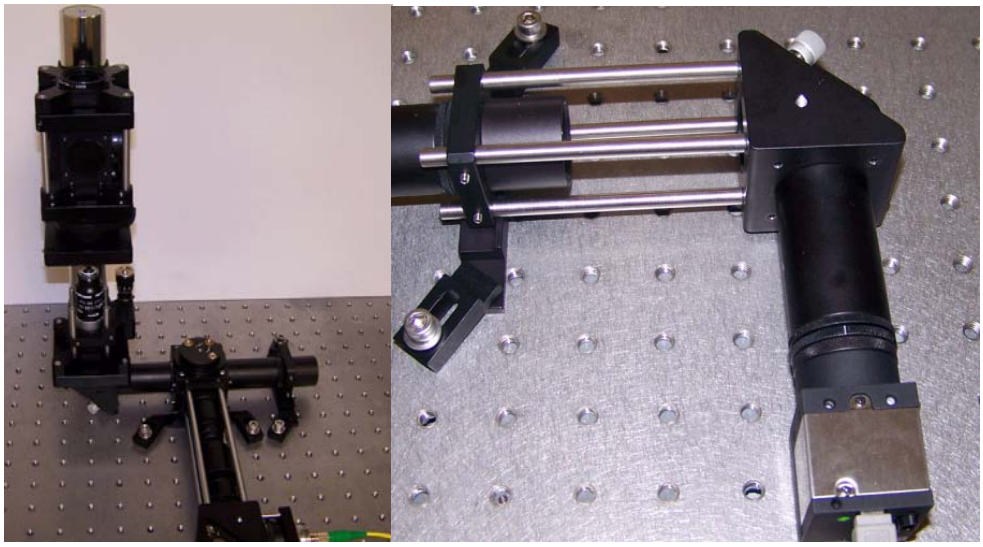


Figure 4.4.2: (left) Objective and condenser segments mounted. (right) The camera segment mounted.

Your system is now complete and you can proceed to your particular application. If you will need to do force measurements, then continue below for the quadrant detector setup guidelines.

4.5 Quadrant Detector Segment (optional Force Measurement Module)

Adjust the B4C on the C6W so that the trap beam is reflected through the diaphragm attached to the C6W. Ensure that beam direction is parallel, and centered as shown in Figure 4.5.1, using an alignment plate.

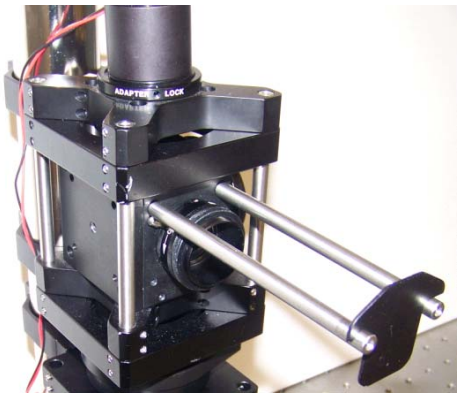


Figure 4.5.1: Initial alignment of beam to quadrant detector. Atop is the white light source on an SM1Q.

Then connect an SM1A1 to the QD, attach an SM2T2, and then an HPT1. On the other side of the HPT1, connect a lever activated iris SM1D12 as shown in Figure 4.5.2 (left). The SM1D12 will spatially filter the beam before the detector. The HPT1 also has mounted in it, an appropriate ND filter to keep beam power on quadrant detector below 10mW.

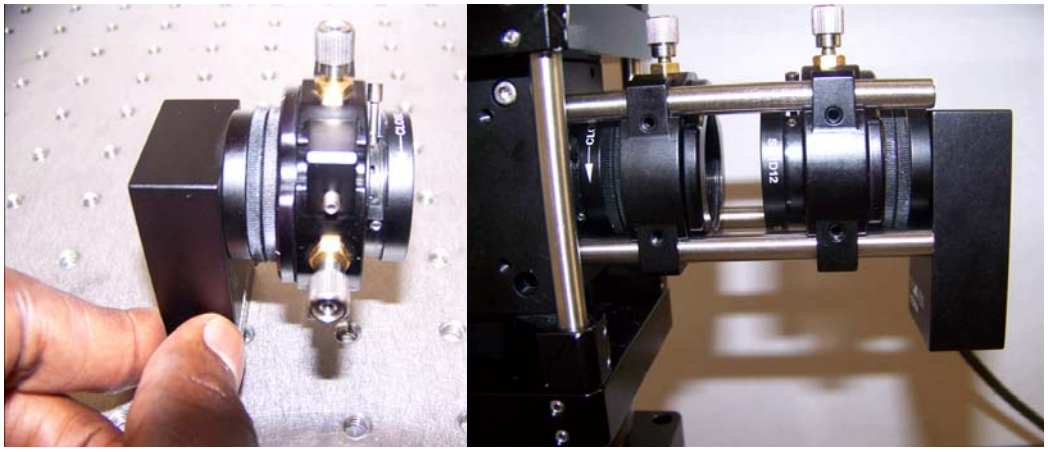


Figure 4.5.2 (Left) The quadrant detector connected to an HPT1. (Right) Mounting the Force calibration segment to the C6W

Then mount the appropriate focusing lens on another HPT1 and connect this to the SM1D12 on the C6W through an SM2T2 as shown in Figure 4.5.2 (right). Slide the QD segment along the ER3 rods and close remaining space with a short lens tube, SM1L05. The first HPT1 is used to make small adjustments to the focusing lens while the second HPT1 give small adjustments to the QD.

4.6 Sample Stage and Holder

Build up the sample holder as shown in Figure 4.6.1. A groove in the slide holder defines the position for the microscope slide. Since the oil immersion objective might push the slide from the bottom during the imaging process we used tape at both ends of the glass slide to keep it in place.

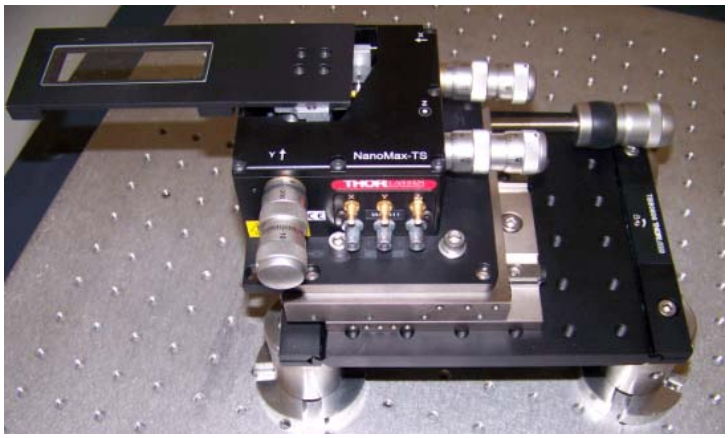


Figure 4.6.1: The sample stage and holder

5. Software Package

The optical trapping kit comes with the standard software which is included with the electronic and nano positioning parts, i.e. it includes the powerful APT software package to control the sample positioning stage and to read out the quadrant detector signal as well as the application software for the DCU camera. The kit does not include any routines that will analyze the data and calculate force/stiffness values. The ActiveX based software modules can be used to develop custom applications (e.g. using LabWindows CVI, Visual C++, Matlab, HPVEE). A procedure of how to approach this data analysis can be found in 'Calibration of optical tweezers with positional detection in the back-focal-plane, Review of Scientific Instruments 77, 103101, 2006'. The screen shots on the right hand side show the QPD and Strain Gauge Controller software on top (included with OTKBFM) and the piezo controller software and CCD camera software at the bottom (included with OTKB (OTKB/M)

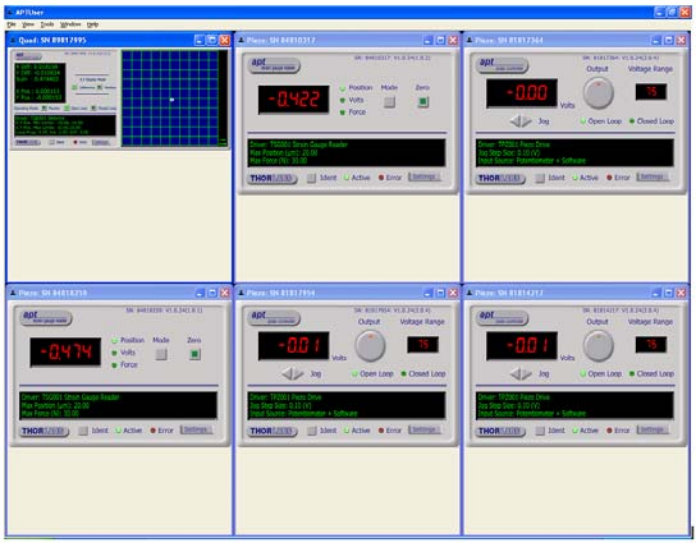


Figure 5.1 Application Screen

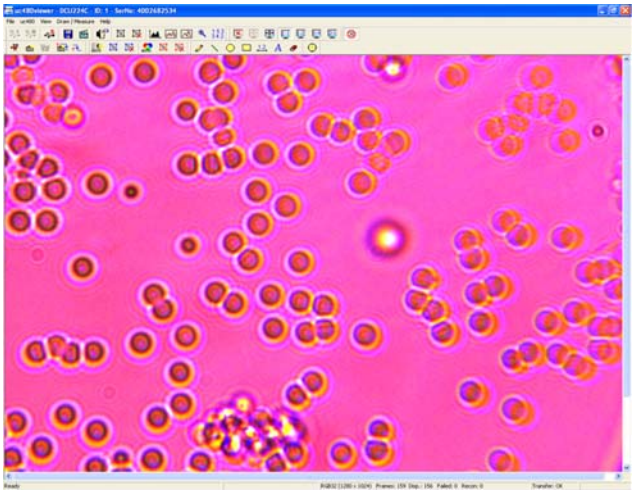


Figure 5.2 CCD camera application, 1 μm Silica beads. The bright spot near the center of the picture is the trapped bead.

Sample preparation

Sample and sample preparation materials are not included in the kit. We used 1 μm and 2 μm silica beads (Bangs Laboratories, Inc., product code SS04N/8620, SS04N/7995), as well as polystyrene beads in a phosphate buffer with Tween (0.1% Tween-20). Polystyrene beads were provided by D. Appleyard, Biological Engineering, MIT. Silica beads were diluted with de-ionized water.

For test measurements, a solution was mixed by first loading a bead solution and then some DI water into a pipette using a Accumax FA-1000 fixed volume pipettor (Lab Depot Inc.) The sample liquid was placed in a channel created between two strips of double sided tape on a microscope slide, after which a cover glass was added. The channel width was around 3 to 4 mm. Nail polish or vacuum grease can be used to seal the channel. The slide is placed upside down, cover glass facing towards objective, in the sample holder.

Additional Accessories

Following parts will be helpful to setup and operate the trap. They are not part of the 'Optical Trap Kit':

a) Powermeter PM100D with S130C measurement head
http://www.thorlabs.com/NewGroupPage9.cfm?ObjectGroup_ID=3341&pn=PM100D

b) Cage System Alignment Plate CPA1 or VC-1550CPT
http://www.thorlabs.com/NewGroupPage9.cfm?ObjectGroup_ID=2273

c) Appropriate laser goggle
http://www.thorlabs.com/newgrouppage9.cfm?objectGroup_ID=762

d) Fiber coupled laser source emitting in visible range
http://www.thorlabs.com/NewGroupPage9.cfm?ObjectGroup_ID=1500&pn=S1FC635

e) Shearing Interferometer with Viewing Accessory
http://www.thorlabs.com/NewGroupPage9.cfm?ObjectGroup_ID=2970&pn=SIVS

Acknowledgement

A special thanks to Matthew Lang, Dave Appleyard and S. Wasserman from Department of Biological Engineering, MIT who provided many suggestions and gave many useful hints.

Bill of Material (Imperial, 110V Electronics)

Some Components will appear several times in the list since they are shown in the sequence as used in the setup. If Imperial/110V electronic items differ from Metric/230V electronic item the latter are shown in brackets.

Quantity	Item#	Description	Subsystem
1	PL980P330J	SM Fiber Coupled Laser, 980 nm, 330 mW, 14-Pin Butterfly Package	Laser, Mount, and Controller
1	ITC510	Laser Diode Driver and TEC Controller	
1	LM14S2	Laser Diode Mount, 14-Pin Butterfly Packages	
4	ER1	1" Long Cage Rods	Laser Collimation
1	CP02FP (CP02FP/M)	30 mm Cage Plate for the FiberPort	
1	SM1T2	SM1 Lens Tube Coupler	
1	SM1L03	0.3" Long SM1 Lens Tube	
1	PF10-03-P01	Ø1"" Protected Silver Mirror	
1	CPB1 (CPB1/M)	Bases for Cage System Plate	
1	KCB1	90° Kinematic Turning Mirror Mount	
1	PAF-X-7-B	FiberPort, Collimates the Output of a Single Mode Fiber, AR Coating 600 - 1050 nm	
4	CP02 (CP02/M)	30 mm Cage Plate	Beam Expander Section
8	ER6	6" Long Cage Rods	
1	SM1L05	0.5" Long SM1 Lens Tube	
1	SM1T2	SM1 Lens Tube Coupler	
2	SM1D12D	Ring Activated SM1 Iris Diaphragm	
1	SM1L10	1" Long SM1 Lens Tube	
1	SM1V10	Ø1" SM1 Rotating Adjustable Focusing Element, 1" Travel	
1	SM1A1	Adapter with External SM05 Threads and Internal SM1 Threads	
1	BE02M-B	2X Galilean Beam Expander, AR Coating: 650 - 1050 nm	
1	C6W	30 mm Cage System Cube with Ø6 mm Clearance Holes	Connect to Verticle Path
1	B1C(B1C/M)	Blank Cover Plate with Rubber O-Ring for C6W	
1	B4C (B4C/M)	Rotatable Kinematic Cage Cube Platform for C6W	
1	B5C	Ø1" Cage Cube Optic Mount For B4C (B4C/M)	
1	FM01	Wide Band Hot Mirror, Dia = 1", AOI = 0°, 1 mm Thick	
1	SM1L20	2" Long SM1 Lens Tube	
1	SM1T2	SM1 (1.035"-40) Coupler, External Threads	

Quantity	Item#	Description	Subsystem
1	DP14 (DP14/M)	Damped Ø1.5" Post, 14" (356 mm) Long	Vertical Segment (Inverted Microscope Path)
4	C1500 (C1500/M)	Compact P-Series (Ø1.5") Post Clamp	
3	LCP01 (LCP01/M)	60 mm Threaded Cage Plate	
1	KCB1	Right Angle Kinematic Mirror Mount, 30 mm Cage System	
1	PF10-03-P01	Protected Silver Mirror, Ø1" (25.4 mm)	
3	LCP02	30 mm to 60 mm Cage Plate Adapter	
1	SM1D12D	Ring Activated SM1 Iris Diaphragm	
1	SM1A10	Adapter with External SM1 Threads and Internal C-Mount Threads	
1	CD4390*	Nikon Oil Immersion objective CFI 100X, 1.25 NA, WD = 0.17 mm	
1	SM1Z	Z-Axis Translation Mount for 30 mm Cage, SM1 Threaded	
2	ER05	1/2" Long Cage Rods	
4	ER1	1" Long Cage Rods	
6	ER3	3" Long Cage Rods	
4	ER4	4" Long Cage Rods	
5	ER1.5	1.5" Long Cage Rods	
1	CD4391*	Nikon Condenser, 0.9 NA	
1	C6W	30 mm Cage System Cube with Ø6 mm Clearance Holes	
1	B1C (B1C/M)	Blank Cover Plate with Rubber O-Ring for C6W	
1	B4C (B4C/M)	Rotatable Kinematic Cage Cube Platform for C6W	
1	B5C	1" Cage Cube Optic Mount For B3C	
1	FM01	Ø1" Wide Band Hot Mirror, AOI = 0°, 1 mm Thick	
3	SM1CP2	End Cap External SM1 Threads	
4	ER8	8" Long Cage Rods, (Used for Alignment and Then Removed)	

Quantity	Item#	Description	Subsystem
2	SM1L20	2" Long SM1 Lens Tube	Camera Segment
1	CPB1 (CPB1/M)	Bases for Cage System Plate	
1	LA1509-B	Ø1" BK7 Plano-Convex Lens, AR Coating: 650 - 1050 nm, f = 100.0 mm	
1	FES0750	Shortpass Filter, Cut-Off Wavelength: 750 nm	
2	SM1T2	SM1 Lens Tube Coupler	
1	CP02 (CP02/M)	SM1 Threaded 30 mm Cage Plate, 0.35" Thick	
4	ER4	4" Long Cage Rods	
1	SM1L10	1" Long SM1 Lens Tube	
1	KCB1	90° Kinematic Turning Mirror Mount	
1	PF10-03-P01	Protected Silver Mirror, Ø1" (25.4 mm), Thickness = 0.236"	
1	SM1A4	Adapter with External RMS Threads and Internal SM1 Threads	
1	DCU224C	CCD Camera, 1280 x 1024 Resolution, Color, USB 2.0	
1	SM1L20	2" Long SM1 Lens Tube	
1	TBB0606 (TBB0606/M)	Large Area Translation Stage	Sample Positioning
4	P2 (P50/M)	Mounting Post, Length=2"	
4	PB2	Mounting Post Base Ø2.48" x 0.40" High	
1	LNR50D (LNR50/MD)	50 mm TravelMax Stage, with differential Actuator	
1	DRV002	50 mm Travel Differential Drive, 12.7 mm Mount Bush	
1	MAX301 (MAX301/M)	3-Axis NanoMax, Fixed Diff. Drives, Closed-Loop Piezo Actuators	
1	AMA-SLH*	Sample Holder	
3	TPZ001	T-Cube 150 V Piezo Driver	
1	TCH002	T-Cube Controller Hub and Power Supply Unit	
1	LD1255	250 mA Precision Constant Current Laser/LED Driver	LED Light Source Assembly
1	PS-12DC-US (PS-12DC-EU)	Power Supply, ±12 VDC, 110-120 (220-240) VAC	
1	LD1255P	Optical Table Mounting Plate for the LD1255 Laser/LED Driver	
1	8060-2	Laser Diode/LED Socket for 5.6 mm Package, 2 Pin	
1	S1LEDM	SM1 LED Mount for TO-18, TO-39, and T1-3/4	
1	LEDWE-10	Epoxy Encased White LED, 2.6 mW, 10° Half Viewing Angle	
1	SM1Q	SM1 Quick Release Adapter Set	

Position Sensing Module - OTKBFM

Quantity	Item#	Description
2	SM1D12	SM1 Lever Actuated Iris Diaphragm (Ø0.8 - Ø12 mm)
2	SM1L05	1/2" Long SM1 Lens Tube
1	SM1V05	Ø0.5" SM1 Rotating Adjustable Focusing Element, 1" Travel
3	SM1T2	SM1 Lens Tube Coupler
2	HPT1	30 mm Cage Assembly, XY Translating Lens Mount
1	LB1258-B	BK7 B Coated Bi-Convex Lens, DIA = 12.7 mm, f = 30.0 mm
1	NE06B	Unmounted Ø1" Absorptive ND Filter, Optical Density: 0.6
4	ER4	4" Long Cage Rods
1	PDQ80A	Silicon Quadrant Detector, 400 to 1050nm
2	TSG001	T-Cube Strain Gauge Reader
1	TQD001	T-Cube PSD Auto Aligner

Revision History

Version1: January 2009

Version2: March 2009, added OTKFM

Version3: June 2009, added rotated setup allowing position of sample to be closer to trap position, added reference to alignment guide document

Version4: July 2009, updated to mounting closer to optical table, changed stage assembly

Version5: updated bill of material, alignment guide