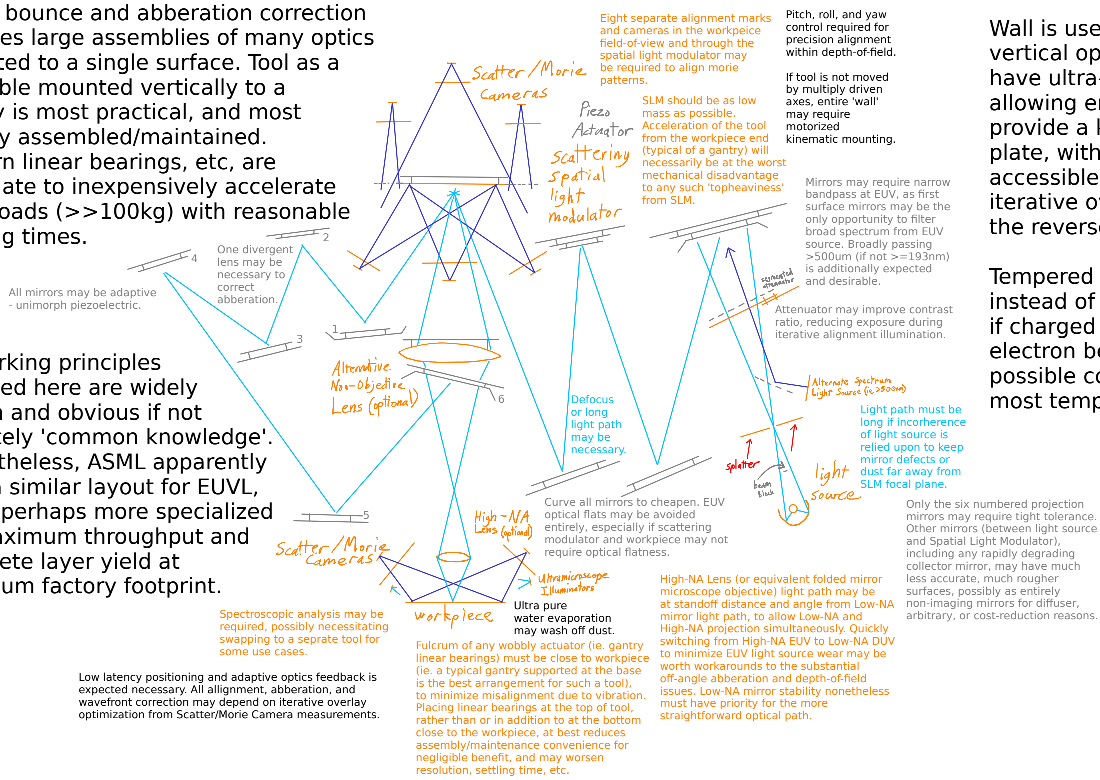
flatTool

Accelerating Wall of Large Heavy Optics

Mirror bounce and abberation correction imposes large assemblies of many optics mounted to a single surface. Tool as a flat table mounted vertically to a gantry is most practical, and most quickly assembled/maintained. Modern linear bearings, etc, are adequate to inexpensively accelerate such loads (>>100kg) with reasonable settling times.

All working principles depicted here are widely known and obvious if not definitely 'common knowledge'. Nevertheless, ASML apparently uses a similar layout for EUVL, albeit perhaps more specialized for maximum throughput and complete layer yield at minimum factory footprint.



Wall is used as a dedicated vertical optical table, and may have ultra-fine-thread bushings allowing entire surface to directly provide a kinematic adjustment plate, with the adjustable screws accessible to stepper motors (for iterative overlay optimization) at the reverse side.

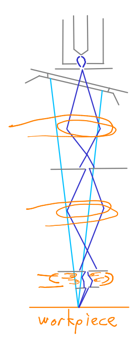
Tempered glass may be used instead of aluminum or invar alloy if charged particle deflection (ie. electron beam distortion) is a possible concern. Apparently most tempered glass is float glass.

Fabricating higher resolution components between interconnects fabricated by photolithography, is possible by adding a particleBeam and/or scanningProbe tool . Cycling of workpiece through etching will allow a tool to resolve marks for overlay produced by another tool, alligning overlay between tools.

Improving resolution of multiple patterning photolithography beyond optical overlay resolution (ie. <<2nm) by particle beam or scanning probe microscope overlay alignment is expected *infeasible* due to thermal expansion between solid components >>2nm . Productively compact, efficient, low-capital, and pervasive, to overlay entire optical beampaths, for any purpose, may not be possible.

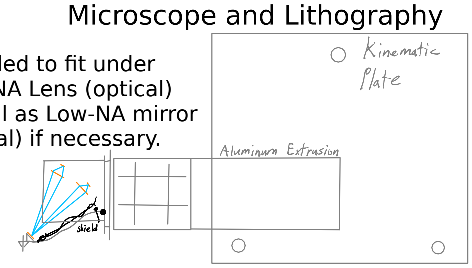
Scanning Electron Microscope and Lithography

If optional High-NA Lens (refractive light optical) is not added, electron optics may be attached to standoffs, with particularly long standoffs towards the top of the column, resulting in an electron beampath mostly offset from the light optical beampath.



Scanning Probe Microscope and Lithography

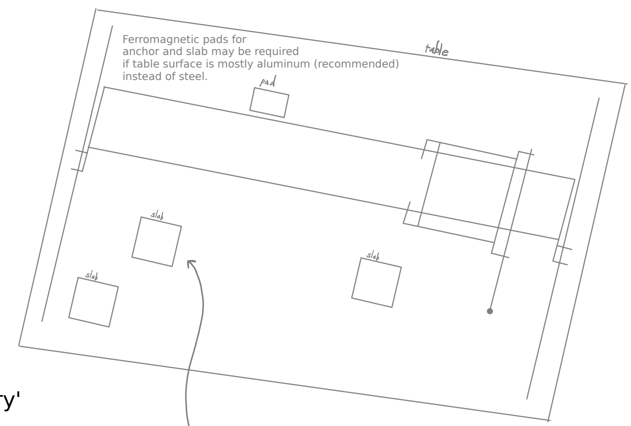
Intended to fit under High-NA Lens (optical) as well as Low-NA mirror (optical) if necessary.



Dip pen may necessitate overlay before writing to desired region. Removal of excess material from alignment marks may be necessitated subsequently.

Positioning

Gantry Six Axis (Pitch/Roll/Yaw, X/Y/Z) on Rigid Table



Multiply driven axes allow slight flexure actuation, causing causing minor X/Y/Z rotation adjustment as well as the large desired X/Y/Z translation .

Highly geared stepper motors with extreme steps per rotation (ie. >>2000steps/rev >>16microsteps/rev) must be used to meet precision expectations (<<30nm).

Tool Z-axis (depth) linear axis straightness tolerances may be less stringent due to low-latency closed-loop feedback.

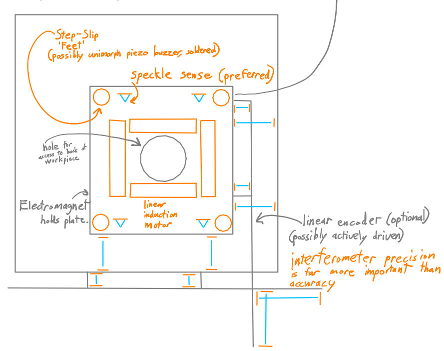
Parking anchors may be used in at least several different arrangements to improve rigidity (and mechanical/vibrational connection to slab) during actions (eg. holographic exposure) requiring an entire field of view to remain transiently stable in all dimensions to <<1nm . Slight adjustments, particularly on rotational axes, may continue after anchoring to apply finer frame tensions. Electromagnetic attachment is suggested.

Reinforcement may be made to the 'gantry', adding additional aluminum, carbon fiber, or wood, backing materials. Particularly, the sides of the 'gantry' may be stiffened by expanding to rectangular, rather than single-post, resulting in rigidity as might be more expected of a cube shaped machine, whileretaining the accessibility and modularity of a sliding gantry.

Composite reinforcement of gantry and similar by combining aluminum extrusions with such bulk materials as wood is well proven by accurate measurements showing substantial decreases in deflection per weight without significantly diminishing stability.

Slab with Six Axis Actuator

Air may be supplied to table or only to slab. Linear motor drive may be induction (aluminum plate), switched reluctance (steel plate), and/or hybrid stepping (permanent magnet array plate, presumably halbach array).



Step-Slip 'feet', possibly unimorph piezo actuators, combine both exceptionally precise motion from expansion with more sudden actuation for continuous motion at <<1nm.

Linear induction motors may allow well defined pulses of mechanical energy to overcome stiction while still keeping minimum travel distance at <<1nm.

Speckle sense, interferometers, linear encoders, etc, may have sufficient precision and stability across long travel motions of short duration to keep overlay alignment at some distance from visible overlay markers. Any position tracking other than overlay through the tool optical path can only briefly track overlay relative to that position, so interferometer precision is far more important than accuracy.

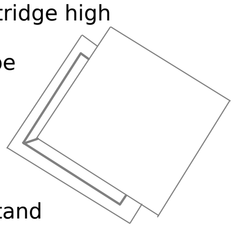
Any position tracking (ie. interferometers, speckle sense, linear encoder, etc) may not be necessary for non-experimental purposes, if overlay markings can be included at adequate intervals in workpieces.

Polishing slab and underlying table (or pad) to near typical (though not EUV) long-wavelength optical flat standards (at least across a small area) may allow an 'air cushion' to overcome stiction without degrading high vacuum (though perhaps not ultra-high-vacuum). Such polishing can be done by a small robot much like a slab itself, measuring level relative to gravity precisely by optical pendulum sensor.

Cartridge Associated with Slab

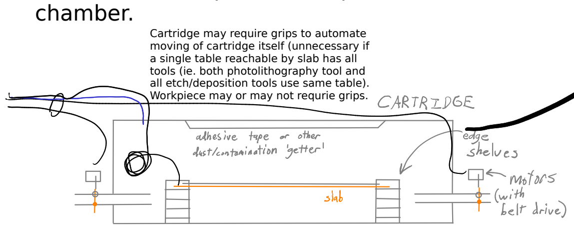
Workpieces never leave their moving slabs (from raw materials to photolithography through etching, etc).

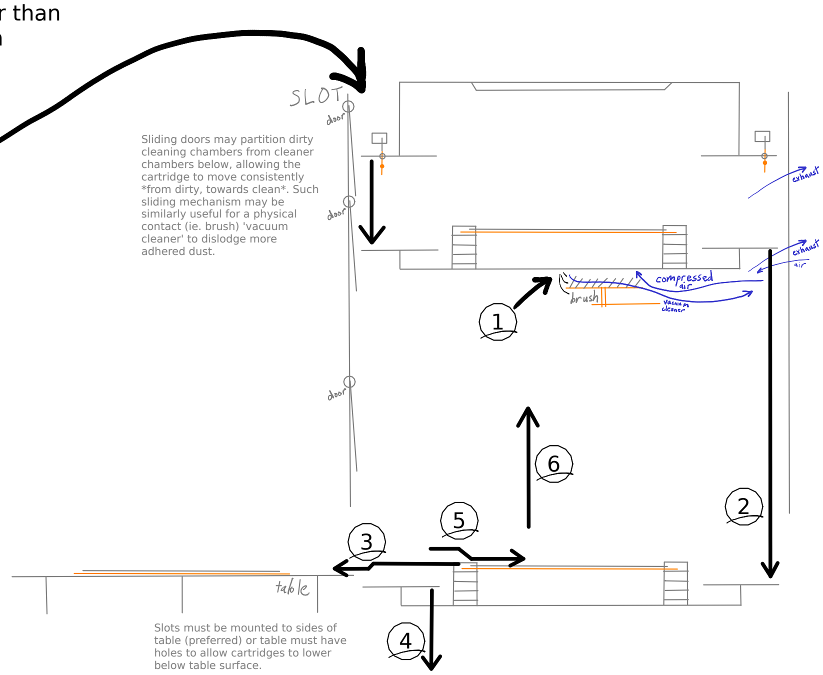
Cartridge is usual metal plate construction, though not necessarily the usual box shape. Soldered aluminum or 308L/347 welded stainless steel 304 (high temperature) plate construction. However, there is no reason for cartridge high temperature. If workpiece must be kept in vacuum, transparent plastics are not recommended, having less strength to withstand atmospheric pressure.



1. Clean bottom surface of cartridge.
2. Lower bottom of cartridge through inner dust protection door until desired slab is at or slightly above table height.
3. Move slab laterally onto table.
4. Lower or raise bottom of cartridge until desired shelf is at or slightly below table height.
5. Move slab laterally onto shelf.
6. Raise bottom of cartridge.

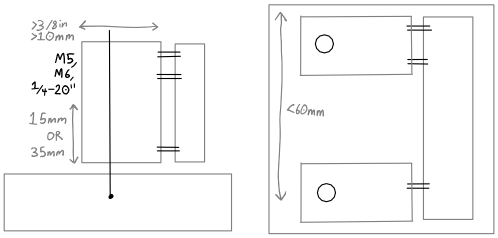
Drop down cartridge allows selection of desired slab from edge shelves by approximate Z-axis distance, minimizes dust contamination, and uses vertical space (rather than horizontal floor space) for seprate decontamination chamber.





Optical Mounting and Alignment

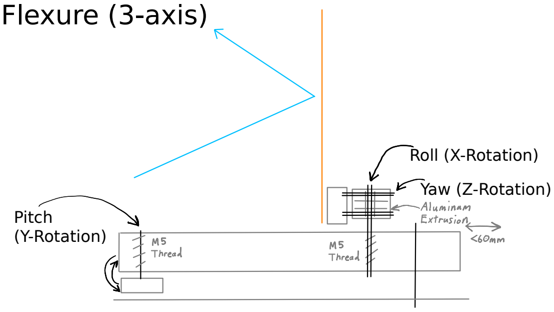
Threaded Rod Bolted Plate
Tilt and Offset (4-axis each)



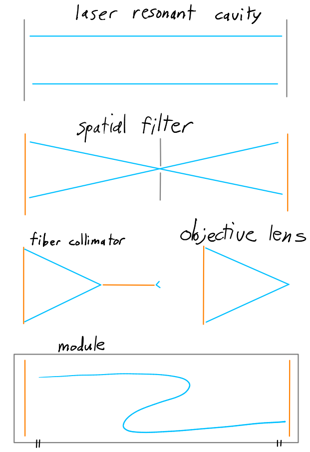
Manufacturing is by hand-held drill and 3D printed jig .

Opposing force to adjustment screws may be provided by doubling screws or by highly compressed spring.

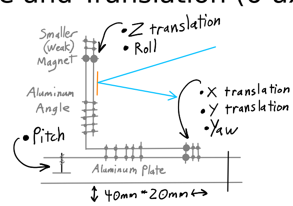
Threaded Rod Bolted Extrusion and Plate
Flexure (3-axis)



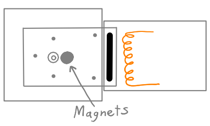
Accurate Alignment
Use Cases



Threaded Rod Bolted Plate and Magnetic Sliding Plate
Flexure and Translation (6-axis)

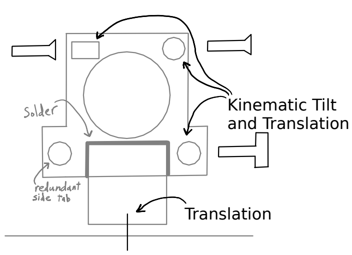


Magnetic Sliding Plate (2-axis)



Adjustable translation and rotation. Magnetic ties are laterally held by epoxy. Electromagnetic tool allows grab and release with minimal disruption. Once a correct position is set, this may be clamped under more pressure from standard aluminum extrusion brackets.

Conical Screw Double Plate
Kinemitic Tilt, Kinematic Translation, Translation (4-axis)

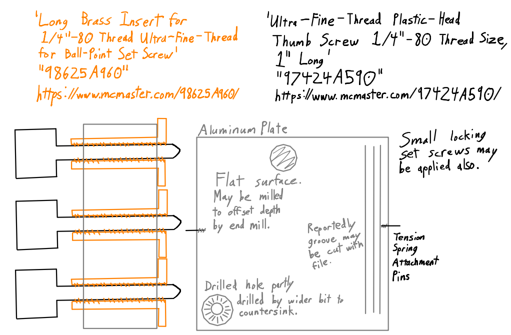


Kinematic mounting plate using only low-cost commodity components.

Cone shaped bearing surface of may metric machine screw heads is used to provide the point and rectangular contact areas for predictable Pitch, Yaw, and Y-Translation (3-axis) kinematic adjustments.

Angle corner bracket may add Z-translation (1-axis).

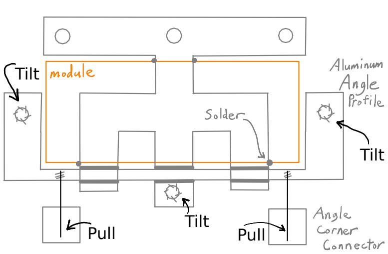
Kinematic Plate (3-axis)



Kinematic mounting plate not necessarily requiring any highly expensive materials or substantial machining job preparation. Reportedly, a drill press, usual drill bit, and file suffice, though an end mill bit may also be required if the flat surface must be offset to greater depth. May be especially suitable for stepper motor (>>2000steps/rev * 256microstep) actuation.

Credit to 'Dan Berard' , " https://dberard.com/home-built-stm/ " .

Flexure Tilt and Flexure Pull Plate (4-axis)



Pitch, Roll, Yaw, and axis height. May mount and align the beam input/output of a large module (eg. spatially filtered light source).

Manual iteration through adjustments may be necessary - some may be interdependent.

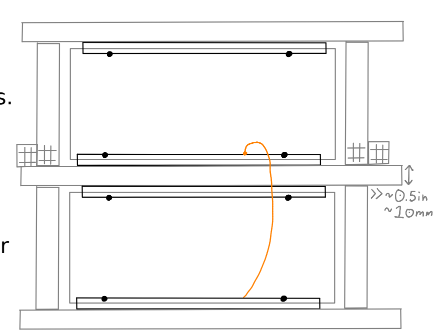
Accessible Rigid Enclosure

Substitutes soldered metal plate for compressed rubber sheets and aluminum extrusion corner posts.

May require particularly heavy plate (aluminum) or expensive composite (carbon fiber honeycomb). Aluminum extrusions may be more suitable for submodules, soldered sealed aluminum plate may be more appropriate if further adjustment will not be required.

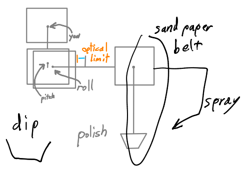
Consider orienting all readjustment screws and optical beam exits toward one 'front' access panel for user convenience.

Credit to 'Tech Ingredients' "YouTube" video 'nMonZHMTra4' .



Mirror, Lens, Workpiece (eg. silicon wafer) Grinding

Polishing



Abrasives are used.

Optically accurate surface is contoured by either equal abrasion across an area (flat), essentially random abrasion paths across a circular area (concave spherical), or similarly chosen abrasion (convex spherical).

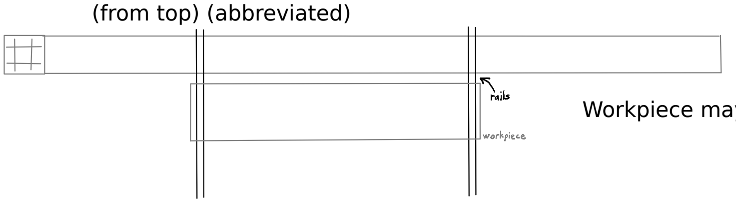
Optically flawless surface is productively corrected by abrasion at increasingly finer grit at areas identified by interferometric measurements at an optical fiber (<<1000pm accurate mirrors), a low-quality reference camera (<<100nm accurate mirrors and lenses as with telescopes), by interferometric measurements at another optical flat (<<1000pm accurate flats), or by leveling relative to gravity (<<1000nm accurate flat tables).

Locations to apply abrasion need not be at all precise. Very low cost typical CNC hardware may be used for a dedicated multi-axis abrasion tool, open-loop positioning, sharing same table as other photolithography related tools.

Abrasives may be used as spray (preferred), dip (may complicate software), or sand paper belt (may complicate maintenance). Usually spray will be highly preferable in production, sand paper or similar may be useful experimentally.

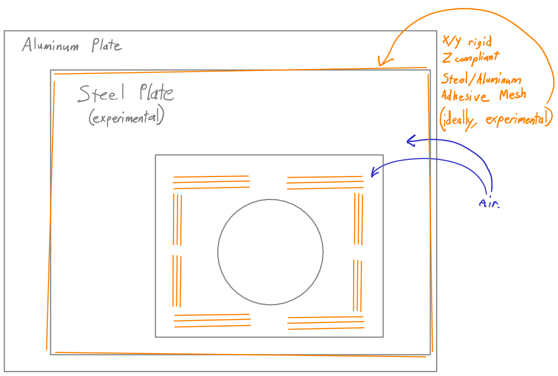
Workpiece Movement

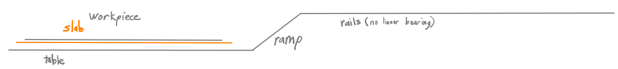
(from top) (abbreviated)



(from side)

Workpiece may slide on rails, which may be linear bearings.



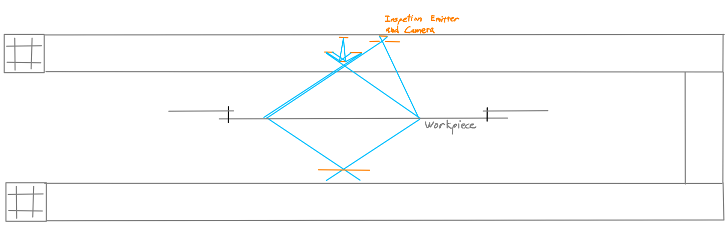


Rails may be metal plates with no linear bearings, or table may be used instead of rails. In such case, slabs may move workpieces.

Workpieces never leaving their slabs, slabs only moving onto ramps to rails when both sides must be accessed, is preferable if polishing or similar (eg. etch) may be integrated on one table surface with other tools (eg. image by photolithography).

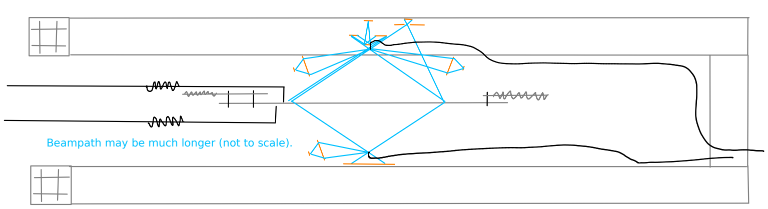
Thin edges at workpieces may remain during manufacturing in all plausible essential use cases - tapering a lens to an optically correct sharp edge is not necessary.

Inspection and Surface Correction



Workpiece may slide across rails and align between simple reference lens/mirror for interferometric measurement.

Slabs are preferred, though possibly not necessary, for their many precision axes and not requiring manual transfer of workpiece to add to other machinery.

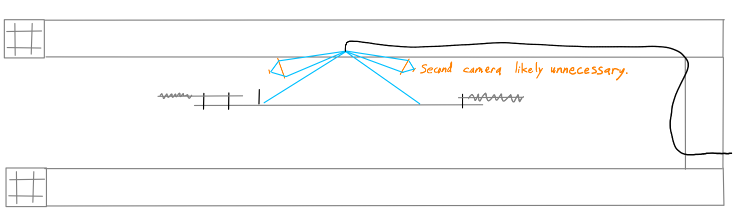


More complex reference optics may be necessary for especially small tolerances (ie. picometers for EUV mirror.)

Spot polishers may be pushed into the inspection area, especially for repeated iterative surface corrections.

Some optics (ie. mirror objectives) may require specialized smaller spot polishers, as smaller tolerances may imply smaller defect areas.

Evaporating cleaning spray may be required to remove polish particles prior to inspection measurements.



Surface correction of EUV mirrors may require deeply subwavelength interferometric analysis. Theoretically, the mirror grinding machine need only accommodate one optical fiber and one or two cameras, possibly with an array lens as a wavefront sensor.

EUV mirror roughness may be far more crucial (<50pm). Surface contour accuracy tolerance may be >>2nm.

Piezoelectric and Thermal Expansion Nanopositioning Actuators

Unimorph discs, or less available, piezoelectric cylinders, may tilt in X/Y axes or translate in Z axis, similar to, but much more precise than, kinematic plates.

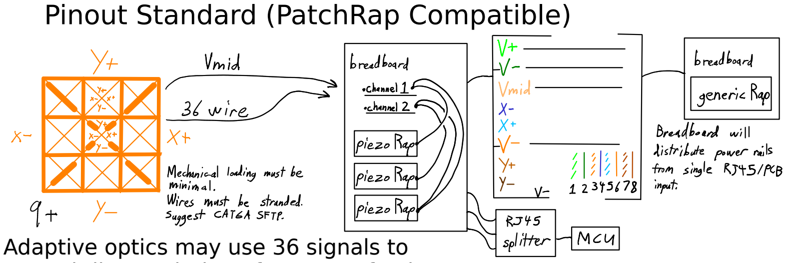
Reportedly, a typical piezo buzzer achieves 160nm/V sensitivity, with 0.01nm Z-axis (depth) precision being desirable . Reportedly, +/-15V and 62.5uV are usable. Reportedly, a +/-10V 16bit ADC would have a 305uV resolution, necessitating 'amplification with a gain of at least five or a more precise ADC' if 'feedback loop is active'.

Beyond tilt/tranlsation, piezoelectric actuators, especially unimorph discs, may deform an optical surface, allowing low-latency wavefront correction of an entire optical assembly. Such may improve overlay, or most importantly improve mirror fabrication tolerances (reducing manufacturing cost and measurement complexity).

Unimorph piezoelectric discs are divided into 36 segments, controlled by a combination of manual trimmer potentiometer adjustment, override inputs for manual control of logical groups (ie. override for all segments in addition to manual adjustment of individual segments), and DAC/ADC (ie. computer controlled adjustment or readout of manual settings).

PatchRap standards, breadboard compatibility of all PCBs, and Cat6A cabling, allows allow extremely rapid wiring of such extensive controls, minimizes noise/vibration, and minimizes cabling clutter.

Pinout Standard (PatchRap Compatible)



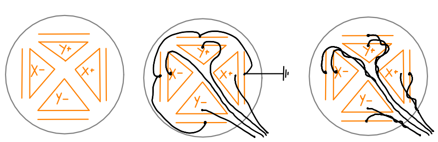
Adaptive optics may use 36 signals to control tilt/translation of 9 areas. If only tilt/translation of entire piezoelectric actuator is required, only 4 signal wires may suffice.

Differential wires (X+/X-,Y+/Y-) connect to breadboard rows, then to adjustable voltage sources (eg. piezoRap PCBs).

Overriding high-impedance voltage sources may connect to breadboard rows or through piezoRap 'NEXT' connectors, allowing manual adjustments of individual piezo segments and manual override of groups of individual piezo segments (ie. control tilt/translation for whole unimorph or one ninth of unimorph).

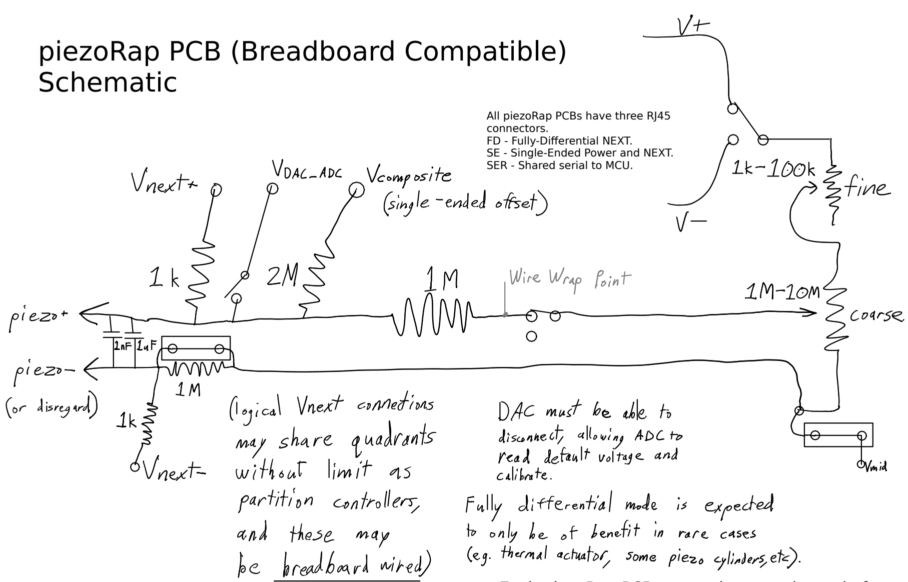
Multiple unimorph actuators, associated electronics, etc, may share high voltage (V+, V-, Vmid) through breadboard rails, and Cat6A wires may be connected directly to breadboard rows without any adapter (ie. piezoRap PCB).

Use high quality solderless breadboard in good condition, or solderable breadboard, or perfboard with wire wrap.



Fully differential control of piezoelectric actuators may be available if 'ground plane' is also segmented.
May experimentally reduce interdependence (improving manual control) or reduce noise.

piezoRap PCB (Breadboard Compatible) Schematic



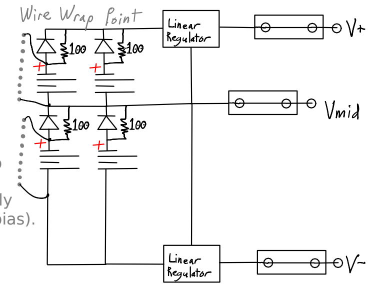
Each piezoRap PCB, managing one channel of four piezo segments, will require at least five of these adjustable voltage dividers. One each for X+, X-, Y+, Y-, and another for Vcomposite (Z+/Z-) . Six adjustable voltage dividers must be provisioned in PCB design to accommodate the possibility of some piezo cylinders with dedicated Z-axis wiring.

Battery Portable Voltage Bias for Piezoelectric Actuator

Battery high voltage supply schematic.

3.4Vcell – 2.8Vcell Expected
3.05Vcell External Suggested

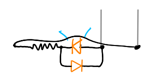
Wire wrap points are provided both to connect batteries (soldered to wrapping wire), and to connect piezo crystals directly to points along the stack of batteries (allowing essentially no-load permanent setting of piezo bias).



Linear voltage regulators may not be desirable considering the very low load, lithium battery stability, and loose tolerance of protectively preventing mechanical shock by keeping such circuit connected with batteries without external power long-term.
CR2032, CR2016, or 9V, lithium, suggested.

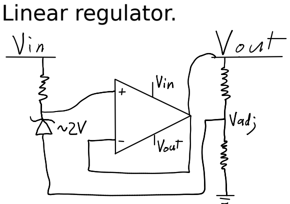
CAUTION: Beware risks of low impedance parallel connection (ie. charging).

Onboard voltage tester.



Onboard voltage tester.
Wrap wire onto pins to use as probes to check voltage and polarity at battery contacts.

Linear regulator.



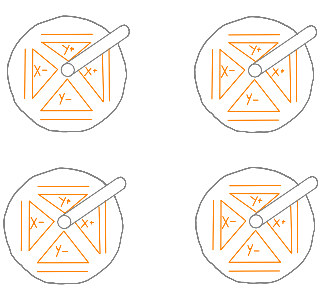
Unity gain voltage follower keeps Vout ~2V higher than Vadj.
Reverse diode polarity and OpAmp power polarity to achieve negative voltage regulator.

Actuator Mechanisms

Improved Rigidity Multi-Piezo Actuator

Unimorph piezoelectric actuators are versatile, inexpensive, precise, and widely available. Relatively heavy devices (ie. Spatial Light Modulator) may require more support than a thin unimorph piezo disc may provide, while more rigid piezoelectric cylinders may be expensive or rare.

Multiple actuators may be used as 'feet' with standoffs, similar to the individual screws of a kinematic mount. While rigidity may improve, travel range may be reduced.



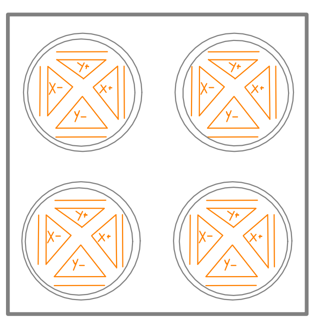
Piezoelectric cylinders are also electrically similar to piezoelectric unimorph disks, with roughly the same wiring reqirements, excepting that an additional dedicated Z-axis wire may be required, and all wires included may be fully differential.

Step-Slip Feet

Magnetically adhered (ie. not relying on gravity) plates (ie. slab) theoretically may be nanopositioned by driving unimorph piezo actuators with 'sawtooth' waveforms.

Piezo actuators used as such may not require the usual center standoff posts, and are expected to remain flat when not biased (ie. unpowered).

Irregular solder points and plate recesses may be required to accommodate expected flexing.



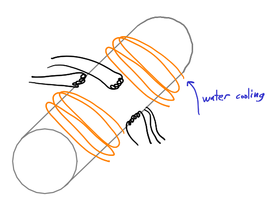
Thermal Expansion Nanopositioning Actuator

Pipe or aluminum extrusion may be used. Water cooling may run through center channel, from optics end to mounting end, causing the outside of pipe or the outside t-slots to cause expansion when heated, and contract back to original shape when heating is discontinued.

Drive circuitry is essentially similar to piezoelectric, excepting that actuation is necessarily dynamic, adjusted by low-latency feedback, and high power.

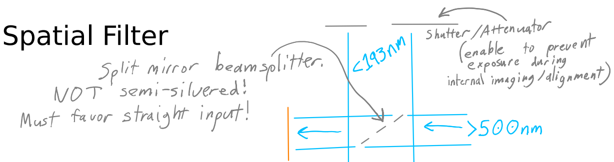
Artificial muscle bowden cables may or may not have better stability due to their heat dissipation, much greater length, and much lower thermal mass.

Bowden cables driving adjustment screws may have much better stability and precision.



Optical Beampath

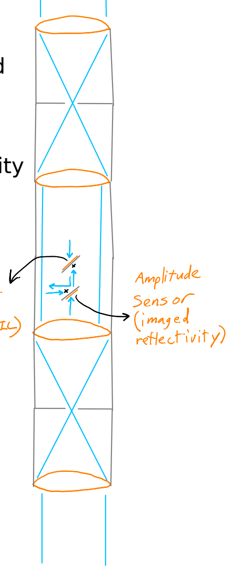
Spatial Filter

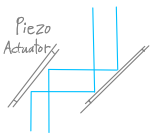


Chromatic abberation expected. Changes to beam wavelength will necessitate spatial filter geometry adjustment. Alternative input beam wavelength will be attenuated strongly.

Optical spatial misalignment attenuator and detector.

Intended to improve stability with heavy or divergent external (ie. 193nm) light source.



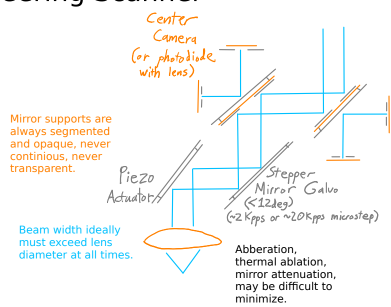


Placing a Piezo actuator stage AFTER any spatial filtering may allow removal of temporal coherence speckle.

Spatial filters position must be stable (not dynamic), as changes will disrupt overlay and depth of field.

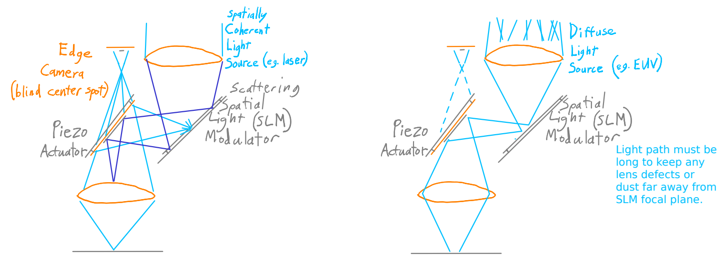
Especially ensures light source modules focus to diffraction limited point.

Beam Steering Scanner



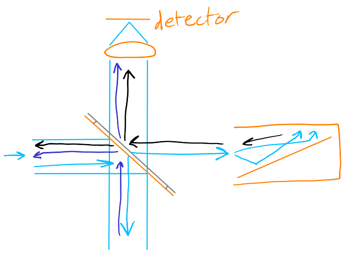
May be especially useful for rapidly moving a diffraction limited point, as with low coherence tomography, confocal tomography, and thermal lithography (ie. ablative).

Maskless Optical Projection Lithography (MOPL)

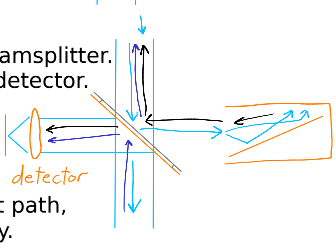


Scattering must occur either at the Spatial Light Modulator, or before with the diffuse light source itself being inherently scattered.

Beamsplitter

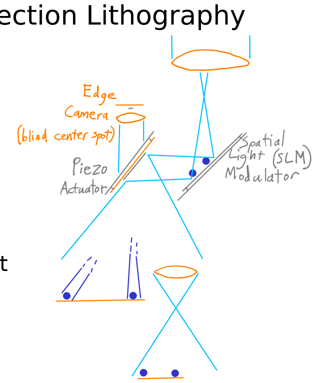


Highly reflective beamsplitter.
Source side-input.
Source-To-Detector
 2x Beamsplitter
 1x Wall



Weakly reflective beamsplitter.
Beam is off-axis from detector.
Source straight-input.
Source-To-Detector
 2x Beamsplitter
 1x Wall
Preserves original light path, may improve efficiency.
Weakly reflective materials may be *more commonly available*.

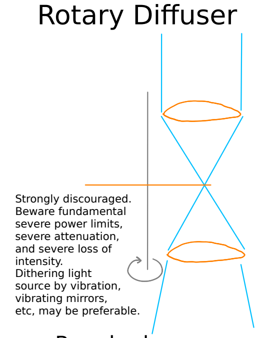
Laser Shadow Projection Lithography



Requires exceptionally spatially coherent light source and cannot directly focus to convergent diffraction limited points.

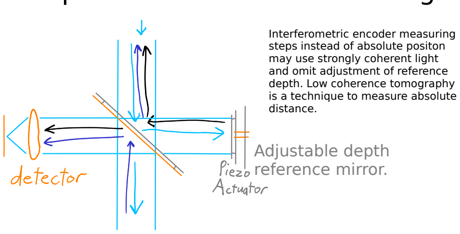
May be useful where wide field-of-view is more essential than resolution (eg. PCB fabrication).

Rotary Diffuser



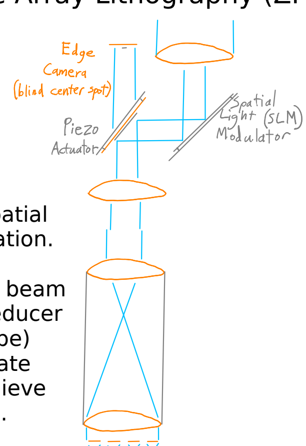
Rough glass or rough mirror rotary diffuser to remove spatial coherence, reducing speckle and widening illumination angles.

Optical low Coherence Tomography (OCT)



Optical low Coherence Tomography (OCT) will only show interferometric rings (aka. depth correlated oscillation) when reference is near equal distant from object. Input light must be extremely low coherence (ie. broad spectrum LED if not white light, not laser). Beamsplitter may be necessary ~50% reflective.

Zone Plate Array Lithography (ZPAL)



Coherent spatial light modulation.

May require beam expander/reducer (ie. 'telescope) and zone plate array to achieve useful focus.

Microscope, Telescope