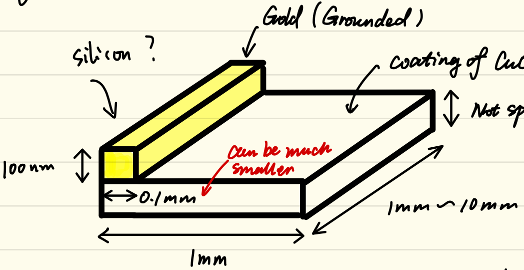
New Decoherence Device

New Device design



coating of CuO or use a GaAs on Si plate

purchase $100

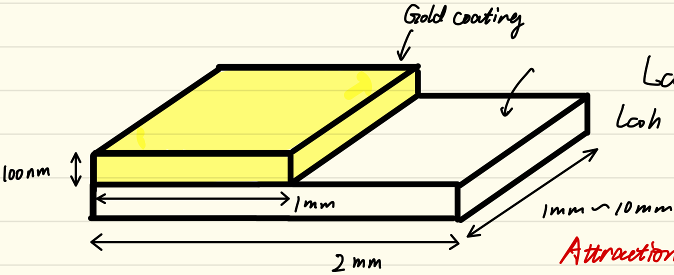
Not specified

$500 4~6 pieces

AFM

Check the beam vertical velocity distribution

MgO (Aceton, Methnol
Sonicate)



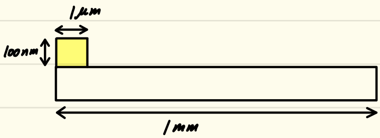
Lcoh >> Height

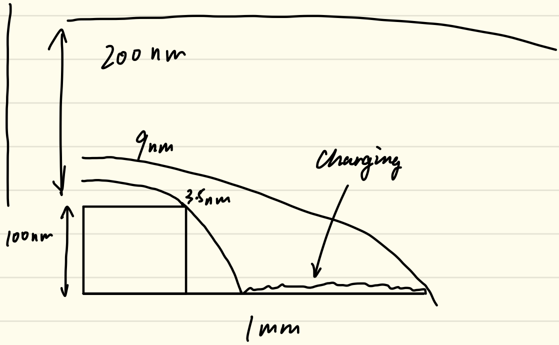
Lcoh ~ 3Height

Attraction by gold is too strong

Minimum Initial Height

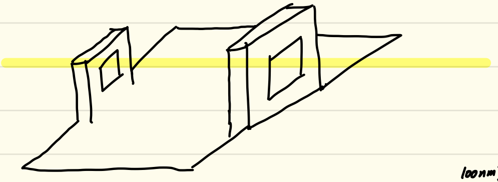
beam
width
10μm

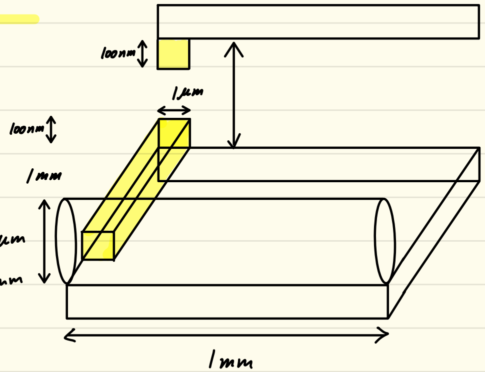




Some thoughts about how to align the beam

aiming structure



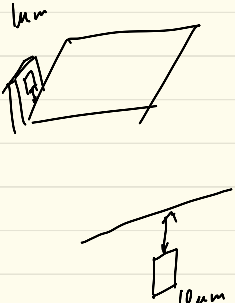


tolerance angle $\frac{10\mu m}{1mm} \sim \frac{10}{1000} = 10^{-2}$

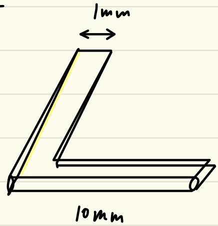
$\frac{1\mu m}{1mm} \sim 10^{-3}$

$\frac{1\mu m}{10mm} \sim 10^{-4}$

or



10µm

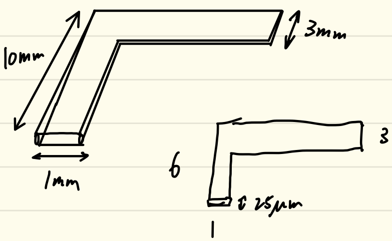


30µm ~ 1µm

beam size

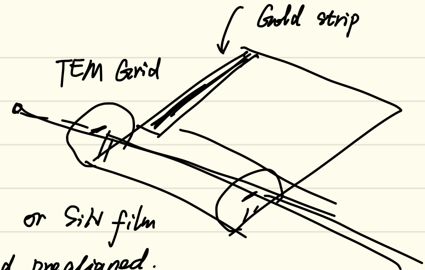
12µm 0

3µm

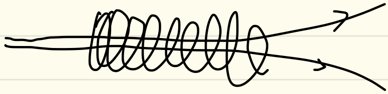


$\frac{1\mu m}{1mm} = \frac{10^{-6}}{10^{-3}} = 10^{-3}$

$\frac{1\mu m}{10mm} = \frac{10^{-6}}{10^{-2}} = 10^{-4}$



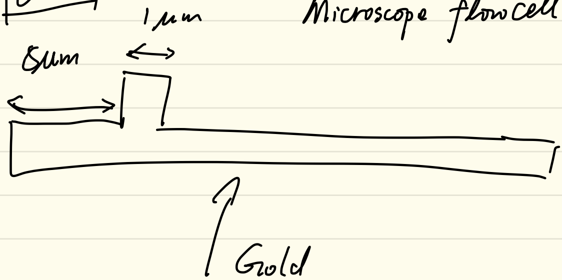
or SiN film
and prealigned.

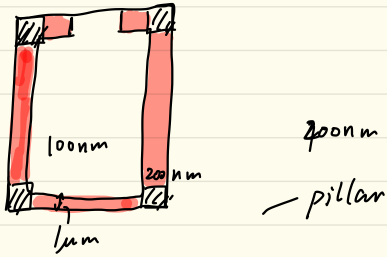


use solenoid

$\boxed{\text{Check}}$

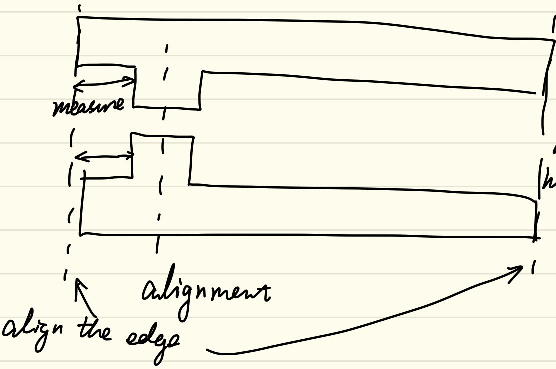
UV hardening
Microscope flowcell

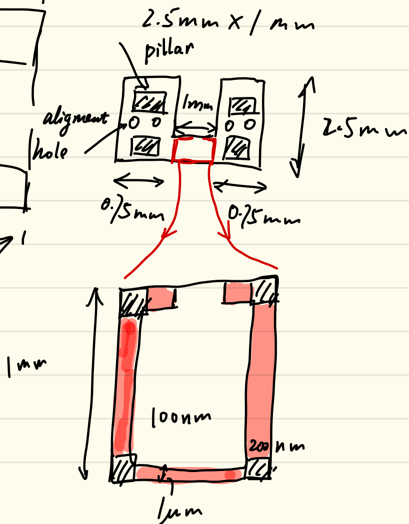




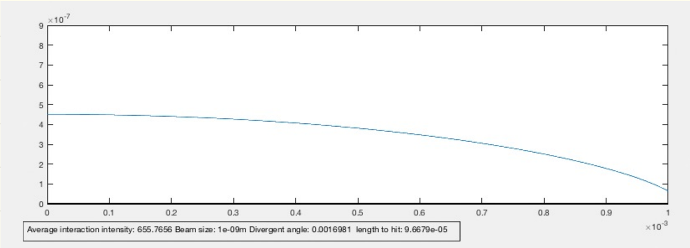
① Figure out the correct number

② Make a sketch

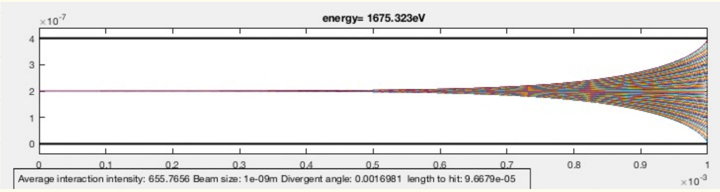




To see if I can do it
e- lithogriphy



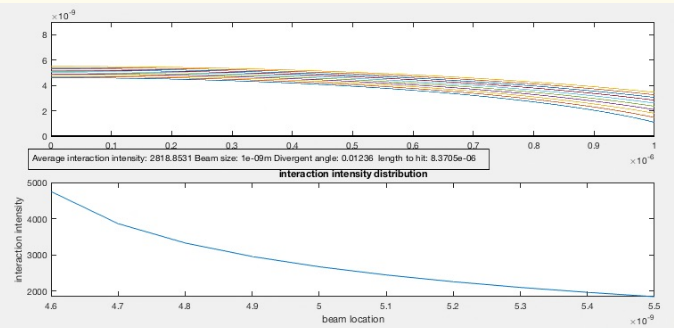
1mm single side gold needs to be 450nm away from it.



Beam width is $\boxed{\text{0.39nm}}$

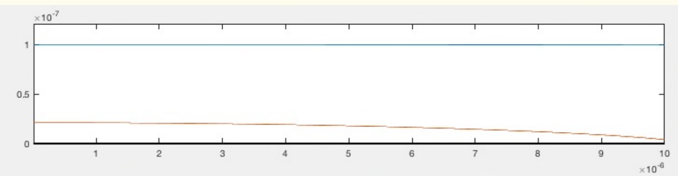
1mm double side gold. Only center beam could pass through

If we have bump at the begining, it will be even less



1μm single side gold.

About $\boxed{\text{4.5nm}}$ is limit height. To pass through 1mm non-image charge area Height needs to be $\boxed{\text{28 nm}}$

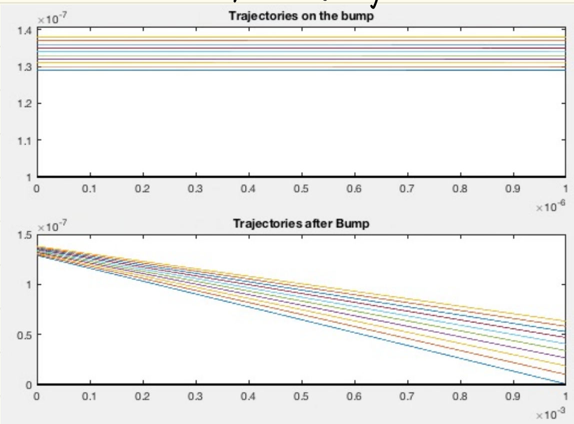


10μm single side gold

$\boxed{\text{100 nm}}$ high beam is almost not affected.

About $\boxed{\text{21 nm}}$ is the limit

Gold bump — Gold surface



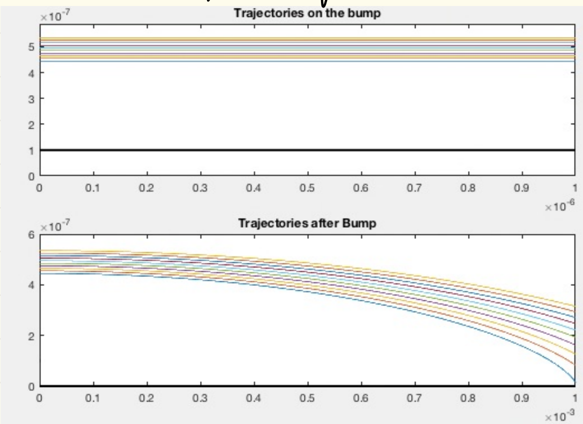
1um single side gold wall 100nm heigh

the limit to pass the whole device 1mm

Si $\boxed{128\ nm}$ height

silicon is assumed as no image charge

Gold bump — Si surface



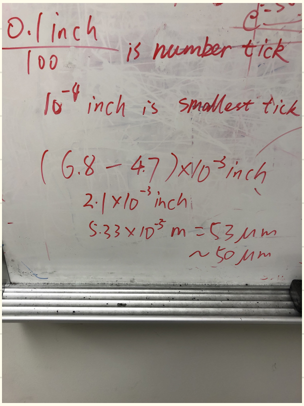
1um single side gold wall 100nm heigh

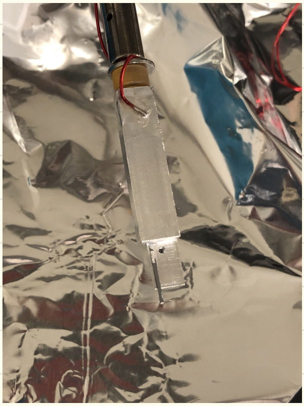
the limit to pass the whole device 1mm

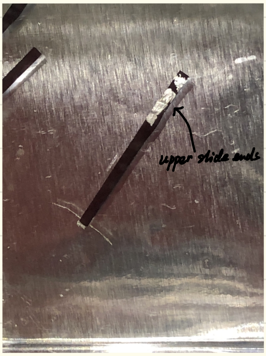
Gold is $\boxed{435nm}$ height

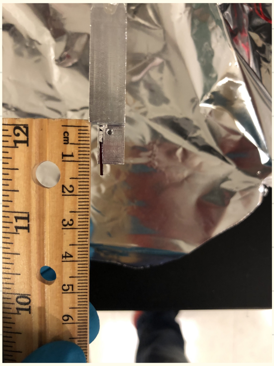
How to avoid charging effect? Can we extend gold strip?

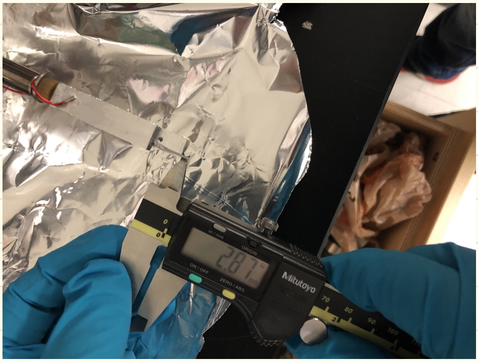
Test Gap

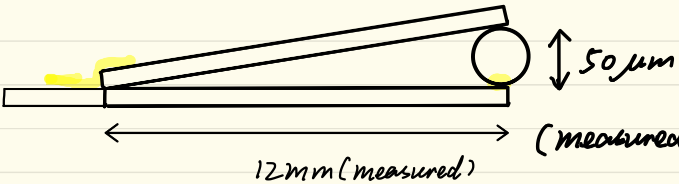








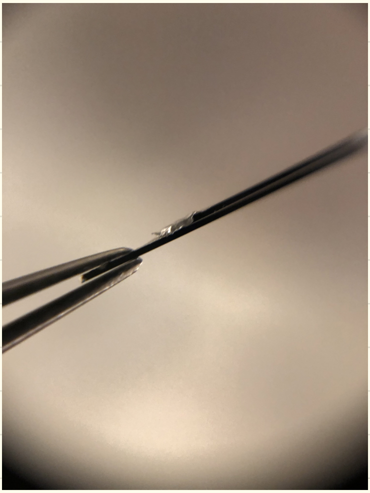


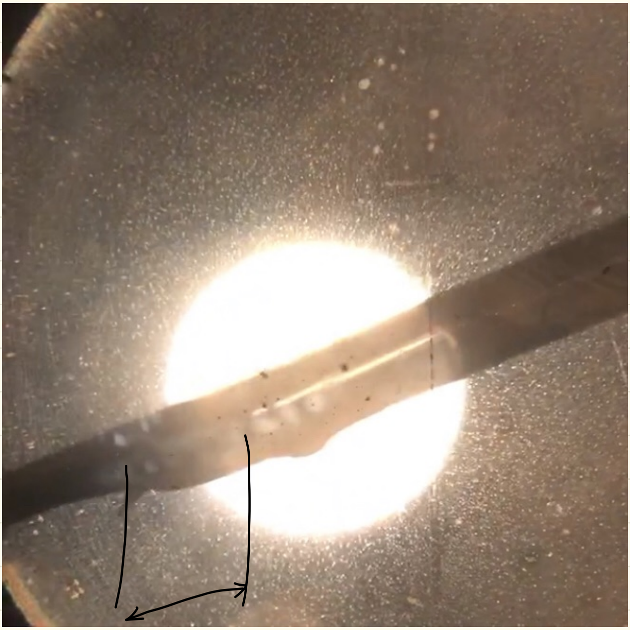


(measured from optical microscope)

Experiment see experimental log 20191007 Search-gap

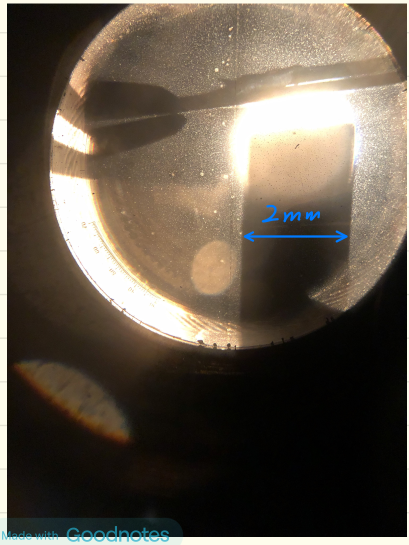
Can only go to about half way of the gap. then the diffraction pattern disappears. (It could be the angle is not correct)



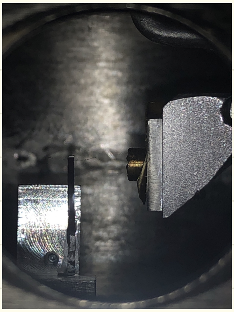


Zoom in

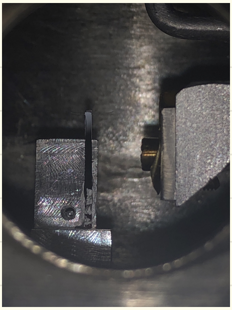
silver paste blocked part is about 1mm



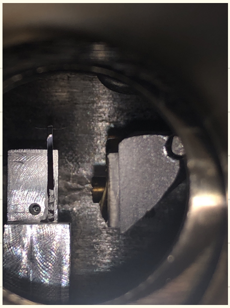
Total effective length is 12mm with 1mm blocked at this end



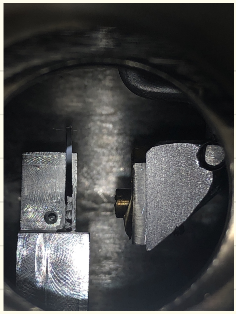
position = 0 mm



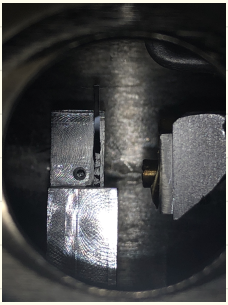
position = 5 mm



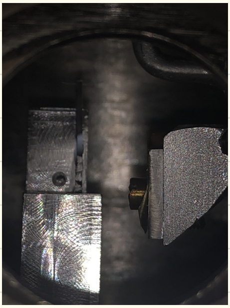
position = 9 mm



position = 10 mm



position = 12 mm

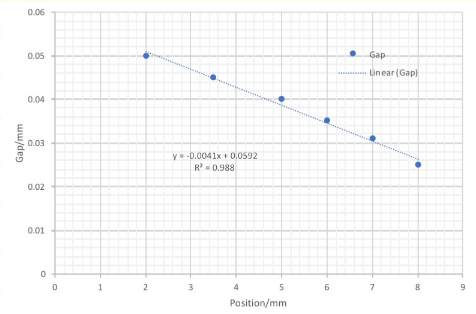


position = 14 mm

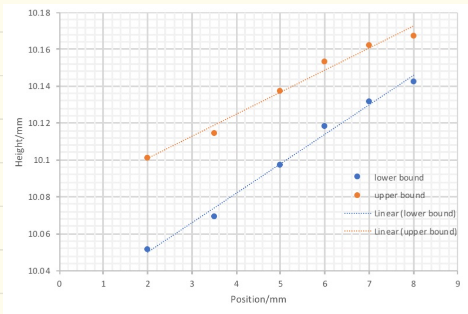
Position is the reading of holder's translation stage

At position = 14 mm, the beam is just blocked

At position = 10 mm, silver paste covers the sample



Gap (mm) vs. position



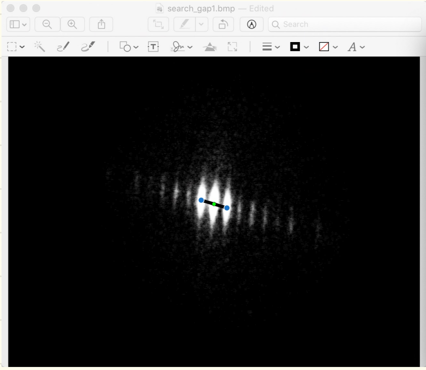
upper bound and lower bound of the gap. vs. position

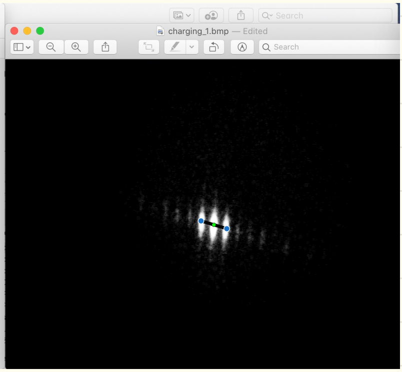
According to fitting function, the position is 14 mm the gap = 1.8 μm (chart 1 prediction)
the gap = 2.6 μm (Chart 2 prediction)

The beam can only be observed before 10 mm.

Check beam property at different location

The periodicity seems to be changed using previous data analysis's problem

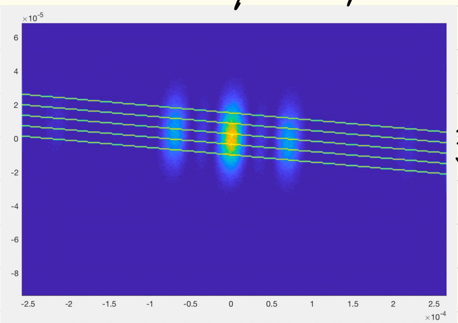




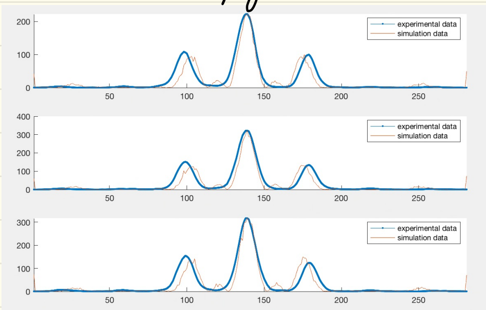
current diffraction pattern previous diffraction pattern

The bar on both pictures are in the same size. Quadrupole lens are in the same setting (130 x 130)

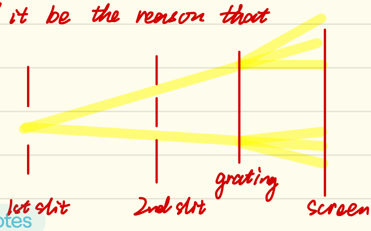
Simulation (matches previous experiment)



Cross-line profiles

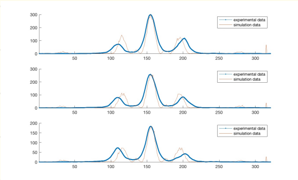


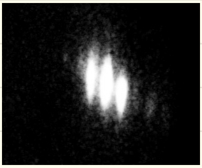
Could it be the reason that two different paths have different path length



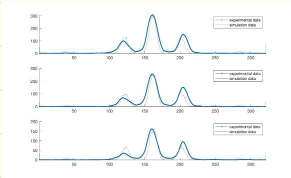
adjusted quadrupole lens magnifying parameter from 34 to 36. The simulation (fitted with previous copper experiment) can match the experimental data without field.

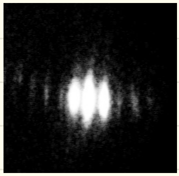
A set of data at different locations (data at taken in the center of the gap)



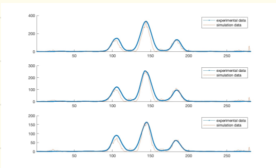


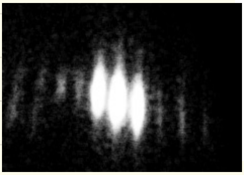
position = 10.23 mm



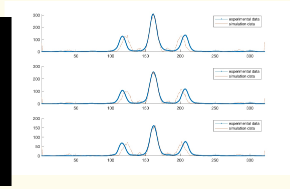


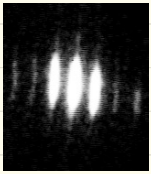
position = 9.614 mm



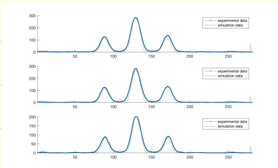


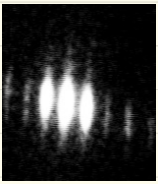
position = 9 mm



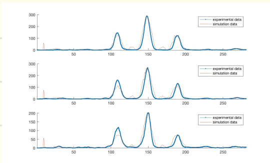


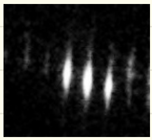
position = 7.8 mm



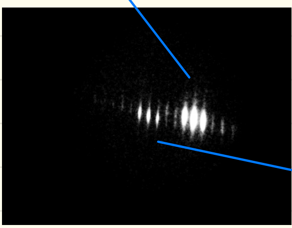


position = 5.8
(right pattern)





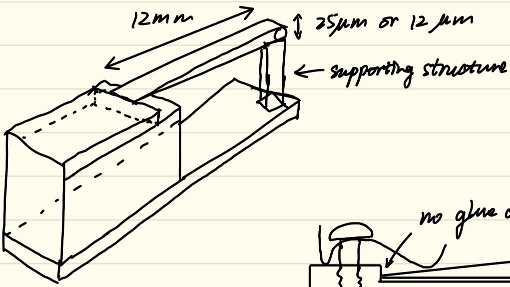
position = 5.8
(left pattern)

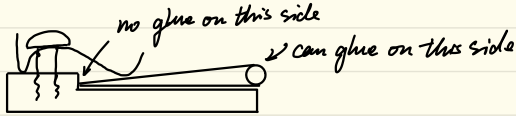


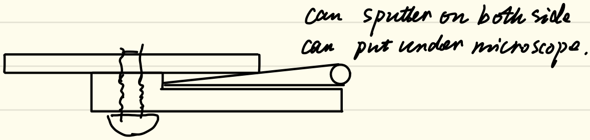
At position = 10.23 mm and 9 mm, the peak distance is bigger and the width is larger. It might be caused by charging effect. Like that in the copper experiment.

According to the results above, the silver paste which is used to glue two Silicon plate might block two ends of the gap. Thus, we need to find a way to make the gap without using the silver paste glue

We want to continue with silicon gap structure. If succeed, a gold coating needs to be added to get intermediate results.

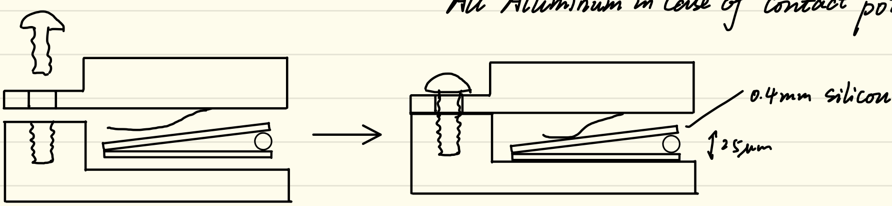


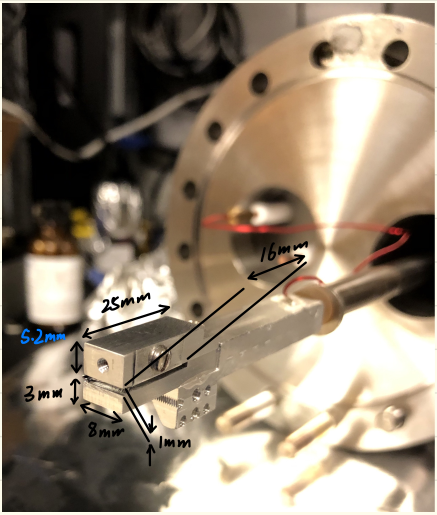


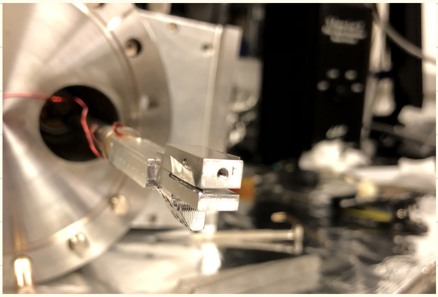


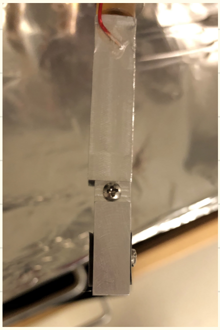
Design first trial

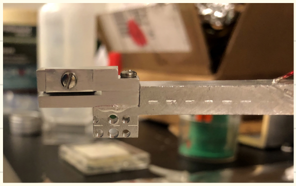
All Aluminum in case of contact potential

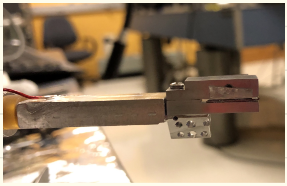








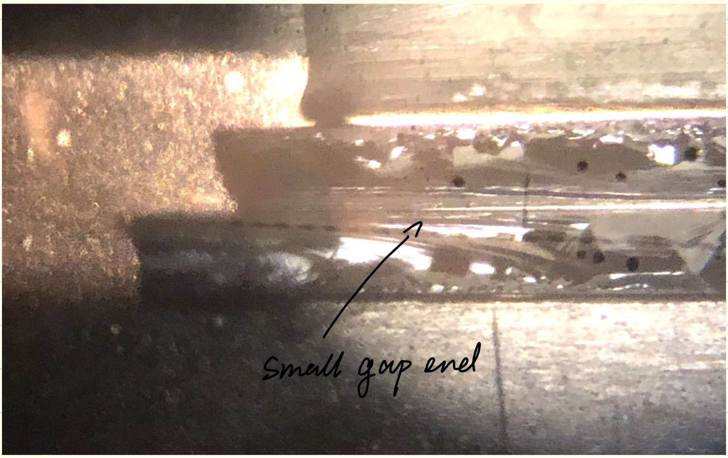


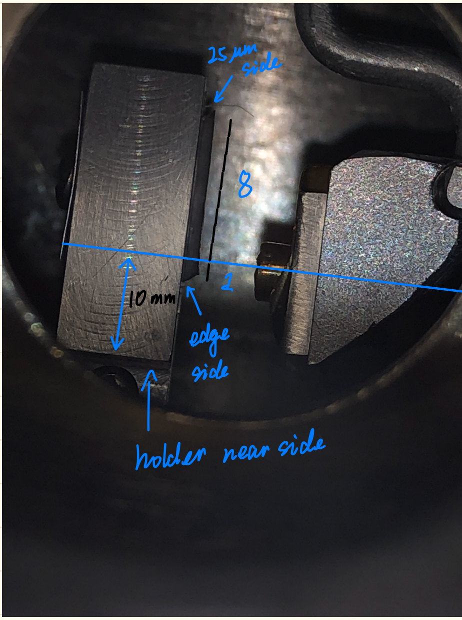


sample inside is about 13mm
effective length is slightly smaller

Wire diameter is 25μm

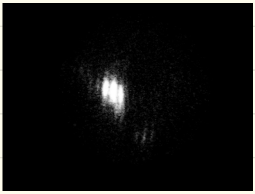
Silicon plate is about 1mm wide
0.4mm thick

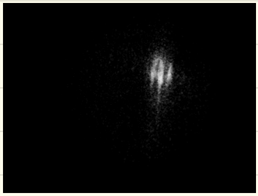


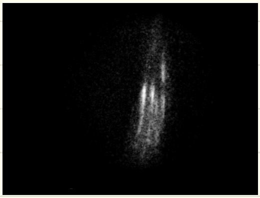


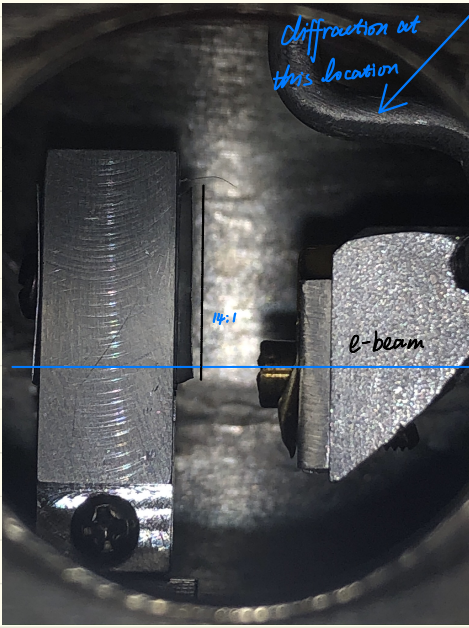
Sample holder translation stage can only move the sample from the blue line labled to the holder's near side.

diffraction pattern →









At location $x = 1.978\ mm$

Estimated gap is $25\mu m \times \frac{1}{14+1} = 1.67\mu m$

It's already hard to observe any diffraction pattern. Difficulties comes from charging?

Compare it with coated device (coat a wall)

How to improve the diffraction pattern

① Make the gap smaller

② Coat a gold wall

How much beam has been block?

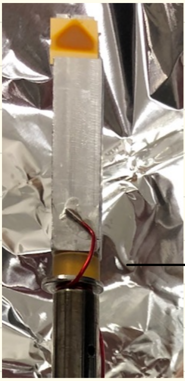
How to align it if there's no large gap?

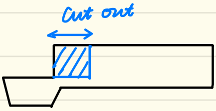
Integrate a pico motor to control the tilted angle

Made with Goodnotes

Since our sample holder translation stage's moving range is too limited, we have to make the holder shorter

$$\Delta x_1 = 7mm \sim 9mm$$





$\Delta x_1 + \Delta x_2 \simeq 15mm$

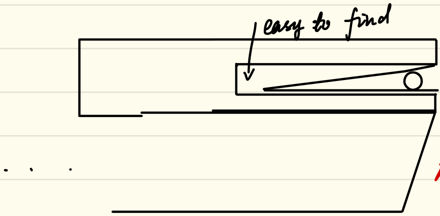
In this way, I can get the transition.

→ The insulator (5-7mm) can be removed (need to be measured)

$\Delta x_2''$

Insulator cannot be removed, but red wire is removed

New sample holder is put in but the angle is changed. Cannot find the gap easily now. Need to develop a way to find out the gap.



① Find the floor position of the holder.

② Move up 0.4mm should reach the gap.

Found the gap but it was somehow not assembled properly. The biggest gap is 55 μm.

The angle tolerance is $\frac{55\times10^{-6}}{1\times10^{-3}} = 5.5\times10^{-2}$ rad $= 3.15$ degree

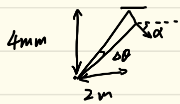
position	15mm	16.64mm	16.64 − 0.164 = 16.476 mm (refine angle there)
gap	10μm	0 μm	1μm

$$\Delta\theta = \frac{1\mu m}{1mm} = 10^{-3} \text{ rad}$$

$$\frac{10\mu m}{12.5cm} = \frac{10^{-5}}{12.5\times10^{-2}} = 8\times10^{-5} \text{ rad} \sim 10^{-4} \text{ rad}$$

should have 10 ticks tolerance

If I turn 1 tick, the diffraction pattern is disappeared. But if I move up and down, the pattern will come back. It doesn't match estimation ?

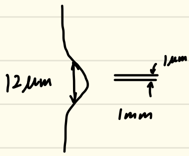


$\sqrt{4^2+2^2} \simeq 4.47$ mm

10^{-4} rad $\cdot$ 4 mm = 4×10^{-7} m = 0.4 μm

10^{-4} rad $\cdot$ 4.5 mm = $10^{-4}\times4.5\times10^{-3}$ = 0.45 μm

horizontal displacement will not exceed 0.5 μm

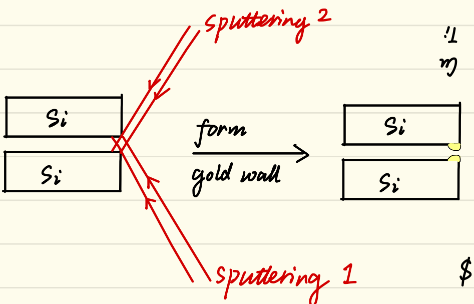


$\theta = \frac{1\,\mu m}{1\,mm} = 10^{-3}$ rad $\Delta\theta = \frac{10\,\mu m}{12.5\,cm} = 0.8\times10^{-4} \sim 10^{-4}$ rad (angle change with 1 tick adjustment on rotation stage)

What distort the pattern at the end (close to 1 μm)

Test charging effect see "Holder-gap-charging[ ]" ✓

There's charging effect. To try to eliminate charging effect. We can test the same gap with coating a gold wall



Gold target (Send email)

Fake sample

Measure the thickness (AFM)

\$50 – 100 material

20hr × \$5 = \$100

Making Gold Gap.

① Simply sputter some full gold coated pieces and mount them with a single wire

Use glasses or Si plates and can use a little taps to fix the gap.

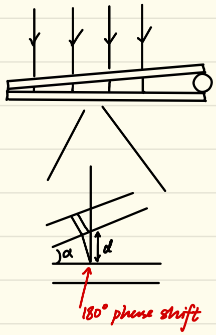
② Use precision saw to cut unprotected gold mirrors

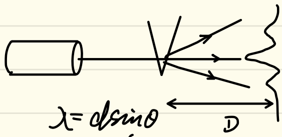
Measuring gap distance

① Make gold coating semi-transparent and use interference to determined the gap distance.

② Measure the trend of the distance and estimate the gap distance when it is small.

③ Use laser to do diffraction and measure fringe distance





$\lambda = d\sin\theta$

$600\,nm = 10^{-6}\,\theta$

$600\times10^{-3} = \theta$

$\theta = 0.6\,rad = 34.4°$

Bright fringe $d_B = \frac{\lambda}{2}N$

Dark fringe $d_D = \frac{\lambda}{2}(N+1)$

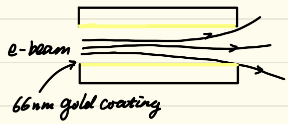
$D = \frac{\Delta x}{\tan\theta} \rightarrow \Delta x = D\tan(34.4°)$

$= 6.84\,cm$

fringe distance $\Delta d = \frac{\lambda}{2\alpha} = 0.12\,mm$

$$= \frac{600\,nm}{2\cdot\frac{25\,\mu m}{10\,mm}} = \frac{6\times10^{-7}}{2\times\frac{25\times10^{-6}}{10\times10^{-3}}} = 1.2\times10^{-4}\,m$$

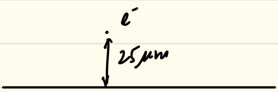
When put in gold gap, it is pretty hard to determine the gap distance because of Coulomb force



only limited beam can go through the gap (effective gap is smaller)

The 25 μm gap cannot be measured since the result is 12 μm which is the height of the beam.

(This explaination is not correct according to estimation)

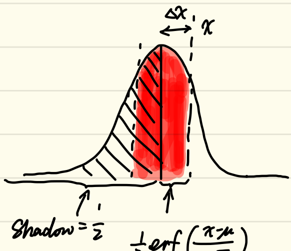


$$a = \frac{ke^2}{mr^2} =$$

$$\Delta h = \frac{1}{2} a \left(\frac{l}{2v}\right)^2 = \frac{1}{2}\frac{ke^2}{mr^2}\left(\frac{l}{2v}\right)^2 = \frac{1}{2}\frac{9\times10^9\times(1.6\times10^{-19})^2}{9.1\times10^{-31}\times(25\times10^{-6})^2}\cdot\left(\frac{1\times10^{-3}}{2.42\times10^7}\right)^2$$

$$= 3.46\times10^{-10}\, m$$

The gap should be small because of tungsten wire lost. One way to measure the gap is to measure counts with the same intensity beam at diferent location. Convert counts to gap width according to Gaussian distribution integral.



For $P(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-(x-\mu)^2/2\sigma^2}$ (Normal distribution)

$$D(x) = \int_{-\infty}^{x} P(x')dx' = \frac{1}{2}\left[1 + erf\left(\frac{x-\mu}{\sigma\sqrt{2}}\right)\right]$$

error function

Red Area $= erf\left(\frac{\Delta x}{\sigma\sqrt{2}}\right)$

$2\sigma =$ beam width $\sim 12\mu m$

Unnormalized $\quad P(x) = A e^{-(x-\mu)^2/2\sigma^2} \longrightarrow D(x) = \int_{-\infty}^{x} P(x')dx' = A\cdot\sqrt{2\pi\sigma^2}\,\frac{1}{2}\left[1 + erf\left(\frac{x-\mu}{\sigma\sqrt{2}}\right)\right]$

$$\text{Red Area} = \underbrace{A\sqrt{2\pi\sigma^2}}_{=B}\, erf\left(\frac{x-\mu}{\sigma\sqrt{2}}\right) \qquad B = A\sqrt{2\pi\sigma^2} = 5100$$

$$\text{Counts} = 5100\, erf\left(\frac{\Delta x}{6\mu m\sqrt{2}}\right)$$

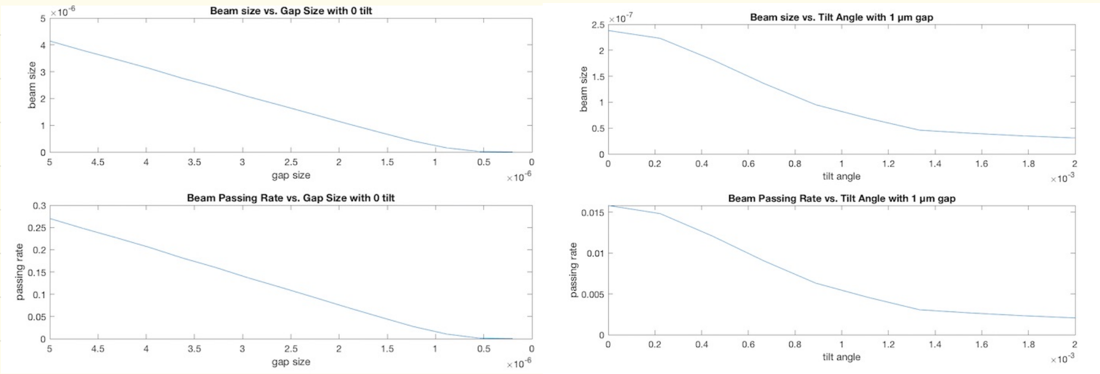
$$erfinv\left(\frac{\text{Counts}}{5100}\right) = \frac{\Delta x}{\sqrt{2}\cdot 6\times10^{-6}} \longrightarrow \sqrt{2}\times 6\times10^{-6}\, erfinv\left(\frac{\text{Counts}}{5100}\right) = \Delta x$$

Add tilt in gap simulation and find out the trend when changing angle.

Calculate passing trend

Beamsize $= 2\Delta x$ (B_s). the corresponding portion the beam $\mathrm{erf}\left(\frac{\Delta x}{\sigma\sqrt{2}}\right)$

$$\text{percentage} = \frac{\mathrm{erf}\left(\frac{B_s/2}{\sigma\sqrt{2}}\right)}{1} = \mathrm{erf}\left(\frac{B_s/2}{B_w/2\cdot\sqrt{2}}\right) = \mathrm{erf}\left(\frac{B_s}{B_w}\frac{1}{\sqrt{2}}\right) \quad (B_w \sim 12\mu m)$$

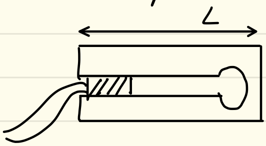


Beam passing is linear to gap size. 10^{-3} rad tilt can reduce half of the beam.

$1\mu m$ gap's passing rate is about 1% $100K \xrightarrow{1\%} 1K$ (useable)

$10K \longrightarrow 0.1K$ (rather long time data taking)

Make a New sample holder with delicate height and angle adjustment.



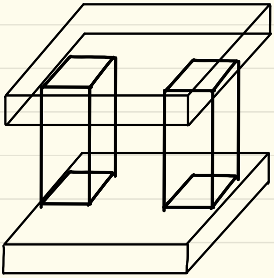
$$\frac{10\,\mu m}{L} = 10^{-4}\,rad \rightarrow L = 0.1\,m$$

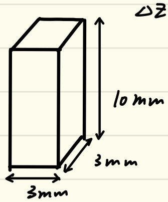
$$\frac{\Delta z}{1\,cm} = 10^{-4}\,rad \rightarrow \Delta x = 10^{-6}\,m = 1\,\mu m$$

$10\,\mu m \rightarrow 200\,V$

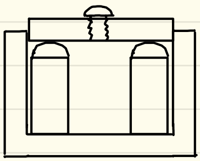
$1\,\mu m \rightarrow 20\,V$

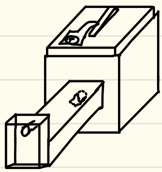
$$\frac{10\,\mu m}{1\,cm} = \frac{10^{-5}}{10^{-2}} = 10^{-3}\,rad \qquad \frac{1\,\mu m}{1\,cm} = 10^{-4}\,rad$$

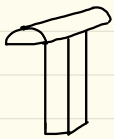


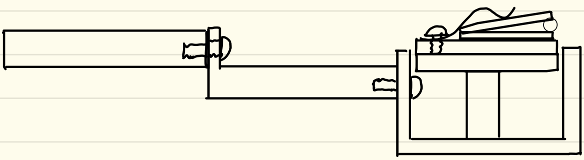


$\Delta z = 8\,\mu m$ with $75\,V$

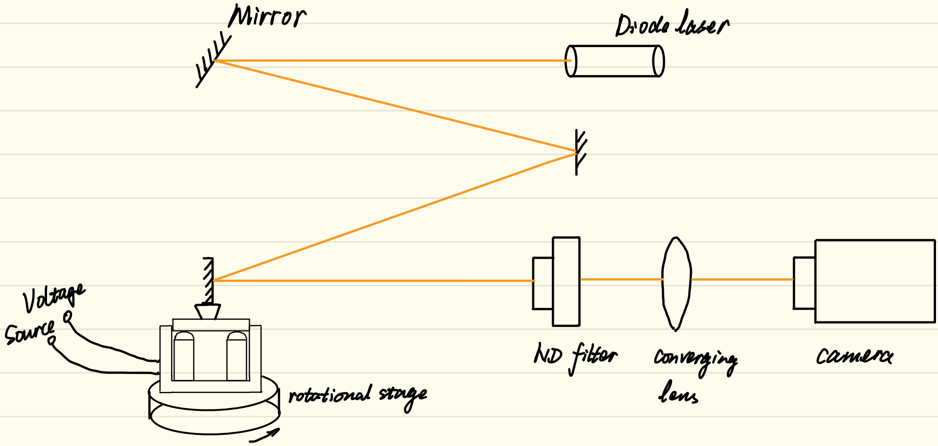








Test tilting device in the new sample holder



piezo can move up and down up to 10 μm.

The beam on the camera will move. Using fitting program to calculate the movement and corresponding moving angle.

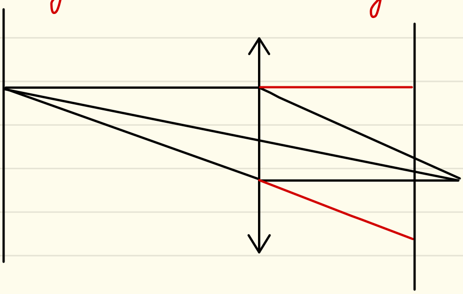
Rotational stage can be a reference for the measurement.

Recording the relation between voltage and angle data as a calibration.

① eliminate all background light ✓

② try to make vertical changes on the camera or work out the math

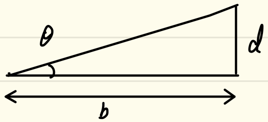
converging lens will make changes smaller



focal length is 5 cm

Removed converging lens

d ~501.6 μm from measurement



$\theta b = d$

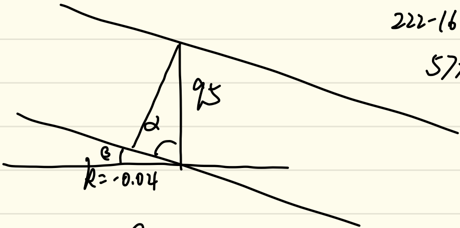
$\theta = \frac{501.6\ \mu m}{51.5 cm} = \frac{2\Delta l}{a}$

$a = 1.25 cm$
$b = 51.5 cm$
Δl is length change in piezo

$\Delta l = \frac{da}{2b} = \frac{501.6\times10^{-6}\times 1.25\times10^{-2}}{2\times 51.5\times10^{-2}} \sim 6.08\ \mu m$

$\sim 7.26\ \mu m$

164-96 = 68
222-165 = 57
57×8.8 = 501.6 μm



$95 \sin\alpha =$

$\tan\beta = -0.04$

95 pixel ~0.84 mm

$\frac{0.84\times10^{-3}}{95} = 8.84\times10^{-6}$

9.5 μm ± 15% (from Thorlab)

Rotate the holder horizontally and compare.

510 pixels

			horizontal rotational stage/mm
Rotate horizontal rot	20200117	move5_1	4.935
		move5_2	4.9
		move5_3	4.865
		move5_4	4.82

Linear

rotational stage rotates $\dfrac{(4.935-4.82)\times10^{-3}}{3\times10^{-2}} = \theta \sim 3.8\times10^{-3}$

$d = 2\theta \cdot b$ $\quad d = 510$ pixels $= 510\times 9\,\mu m \sim 4590\,\mu m$

$4.59\times10^{-3}\,m$ (measured using camera)

$2\cdot 3.8\times10^{-3}\cdot 51.5\times10^{-2} = 3.91\times10^{-3}\,m$ (predicted)

15% difference

Putting box into vaccum chamber

drill a hole or glue old device? (Cold device needs to remake coil)

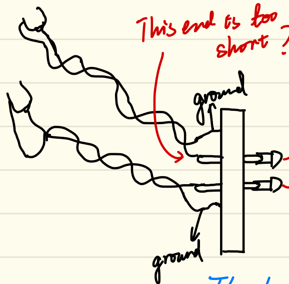
use silver paste to glue

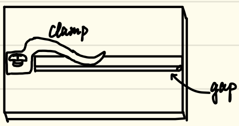
Need to talk to Instrument shop

shield with metal web

Cannot use solder probably

use connectors and Kapton tape to insulate





The holder is rotating when moving in the horizontal direction

20200206

Made with Goodnotes

Trying to find out blocking angle at different locations.

system matically calibrate rotational stage in small gap, should also calibrate with PET

Data is taken in excel sheet 2.

Calibrate rotational stage with laser.

laser spot moves 7cm, spot to Si Mirron distance is ~125 inch

↓

0.05 inch movement over 12.5cm long arm.

$\Delta\theta = (7\times10^{-2}) / (125\times2.54\times10^{-2}) = 2.2\times10^{-2}$

$\Delta\alpha = (0.05\times2.54\times10^{-2}) / (12.5\times10^{-2}) = 10^{-2}$ on rotational stage

$2\Delta\alpha \sim \Delta\theta$ because of reflection it seems to be correct

$5\times10^{-3} >> \frac{1\mu m}{1.5mm} \sim 6.7\times10^{-4}$

transmission and angle gives different answer.

Calibration for the PZT — PZT seems to move far smaller than expected ~1 μm

the gap — the gap is not closed at all

Under the inspection of microscope. The gap does exist. However, it's significant larger than expected (about 50 μm > 25 μm wire diameter)

The rotation stage has a significant backlash. Insert a piece of paper to tighten the bearing helped a lot.

PZT moves fine outside the chamber. Inside the chamber, we add a piece of Si to test the tilt

Use the wire as a indicator of the electron beam.

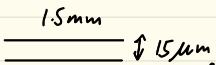
From the newest experimental result

Calculating from counts, we reach to 100 nm range

sample length is 1 cm. wire is 15 μm diameter

the diffraction pattern is not as sensitive as simple geometry indicating

for example:



angle tolerance is about $\frac{15\,\mu m}{1.5\,mm} \sim 10^{-2}$ however, we can move more than that about $\frac{5\,mm}{12\,cm} \sim 0.04$

Estimate pattern motion when tilt the gap

In experiment angle-rotation data $X = 17.8\,mm$ Gap size $\sim 2\,\mu m$

pattern moved $\sim 60\,\mu m$ with ~ 0.05 inch on micrometer (rotational)

$\downarrow$ simple geometry

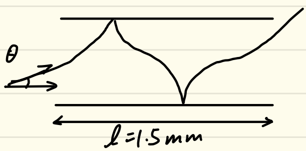
$$\underbrace{\frac{0.05 \times 2.54 \times 10^{-2}}{12.5 \times 10^{-2}}}_{\Delta\theta_{exp} = 10^{-2}} \times 25 \times 10^{-2} \sim 2 \times 10^{-3} \gg 60 \times 10^{-6}$$

① Geometry

$$\frac{2\,\mu m}{1.5\,mm} \sim 1.3 \times 10^{-3}$$ From close to close $\Delta\theta_g \sim 2.6 \times 10^{-3}$

② With image charge.

③ With specular reflection inside the gap

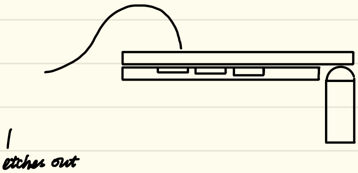


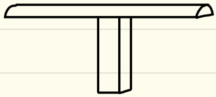
movement $\sim l\theta$

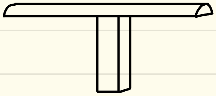
$$1.5 \times 10^{-3} \times 10^{-2}$$

$$\simeq 1.5 \times 10^{-5} \sim 15\,\mu m$$

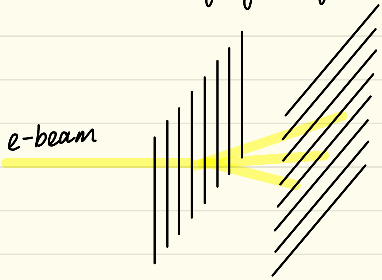
Another design for the Gap exp.







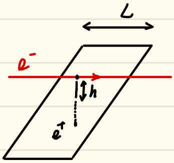
Using grating to conduct experiment



aperture ≈ 50 nm

periodicity = 150 nm

decoherence intensity $I \propto \frac{t}{h^2}$ ← flight time above the surface



$I \propto \frac{L/v}{h^2}$

suppose v doesn't change

$I \propto \frac{L}{h^2}$

best trajectory:

for plane surface exp.

$$I_b \propto \frac{10^{-2}}{(2\times10^{-6})^2} \sim 2.5\times10^{9}$$

for horizontal grating

$$I_b \propto \frac{150\times10^{-9}}{(2\times10^{-9})^2} \sim 3.75\times10^{10}$$

Worst trajectory:

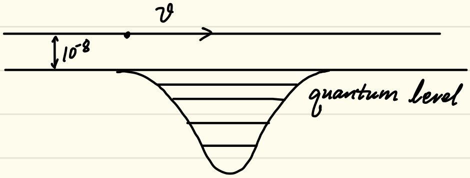
for plane

$$I_w \propto \frac{10^{-2}}{(10\times10^{-6})^2} \sim 10^{8}$$

for horizontal grating

$$I_w \propto \frac{150\times10^{-9}}{(25\times10^{-9})^2} \sim 2.4\times10^{8}$$

Decoherence in Cross grating experiment



perturbation theory

$H = H_0 + W$

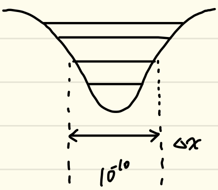
$$P_{if} = \frac{1}{\hbar^2}\left|\int_0^t e^{i\omega_{fi}t} W_{fi}(t')dt'\right|^2$$

$$= \frac{|W|^2}{\hbar^2}\left|\frac{\sin(\omega_{fi}t/2)}{\omega_{fi}/2}\right|^2 ;\ P \ll 1$$

[9.28] in Griffith

$$W = \frac{q^2}{4\pi\varepsilon_0 d} = \frac{(1.6\times10^{-19})^2}{10^{-8}} \times 10^{10} = 2.5\times10^{-20} \Longrightarrow \frac{|W|^2}{\hbar^2} \sim \frac{(2.5\times10^{-20})^2}{(10^{-34})^2} \sim 6.25\times10^{28}$$

Calculate ω_{fi} Harmonic Oscillator $E = \frac{1}{2}kx^2 = \frac{1}{2}m\omega^2x^2$



$$1eV \sim \frac{1}{2}\times10^{-30}\times\omega^2(10^{-10})^2$$

$$1.6\times10^{-19}\times2\times10^{30}\times10^{20} = \omega^2$$

$$\omega = \sqrt{3\times10^{31}} = 5\times10^{15}$$

$$\hbar\omega = \frac{5\times10^{15}\times10^{-34}}{1.6\times10^{-19}} \sim 3eV$$

$$t = \frac{\Delta x}{v} = \frac{10^{-8}}{2.4\times10^{7}} \sim 4\times10^{-16}$$

$$P = 6.25\times10^{28}\times\left|\frac{\sin(5\times10^{15}\times4\times10^{-16}/2)}{(5\times10^{15})/2}\right|^2 = 1.6\times6.25\times10^{-3} \sim 10^{-2}$$

$$\left|\frac{\sin(1)}{2.5\times10^{15}}\right|^2 = 0.16\times10^{-30} = 1.6\times10^{-31}$$

Made with Goodnotes

Atomic vibration energy

$\omega \sim THz = 10^{12}$ $\qquad \hbar\omega = 10^{12} \times 10^{-34} = \frac{10^{-22}}{1.6\times10^{-19}} \sim 10^{-3}\ eV$

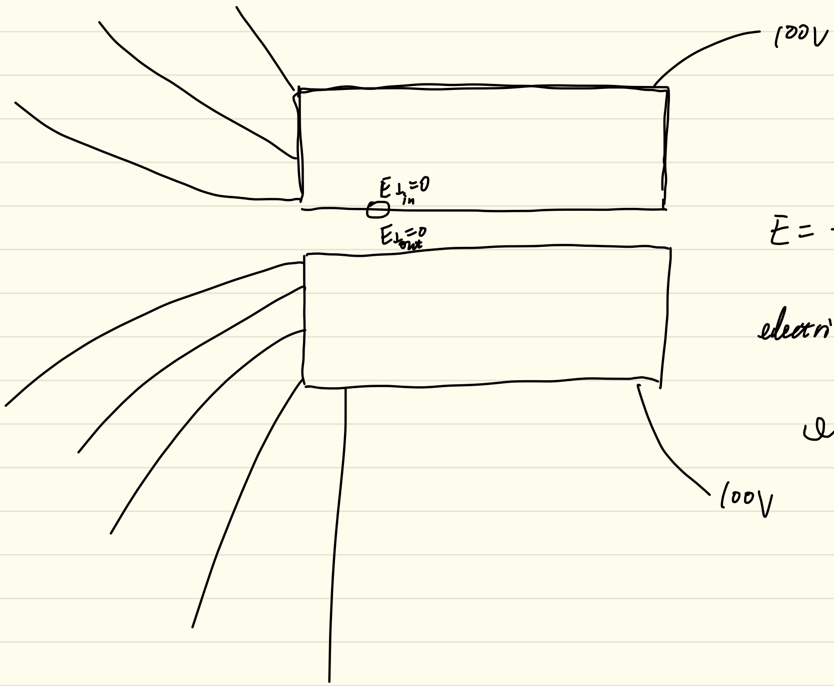
$E = \frac{1}{2} m \omega^2 x^2 \sim \frac{1}{2}$

$$P = 6.25\times10^{28} \times \left| \frac{\sin(10^{12} \times 4\times10^{-16}/2)}{(10^{12})/2} \right|^2 = \left| \frac{\sin(2\times10^{-4})}{\frac{1}{2}\times10^{12}} \right|^2 \times 6.25\times10^{28}$$

$$= (4\times10^{-16})^2 \times 6.25\times10^{28}$$

$$= 16\times10^{-32} \times 6.25\times10^{28}$$

$$= 10^{-2}$$



$E = \frac{\sigma}{\varepsilon_0}$

electric field

Derivation check in Peter's NJP and theory

Δx is path distance. y is beam height

$$\tau_{dec} = \tau_{rel}\left[\left(\hbar/\sqrt{4mkT}\right)/\Delta x\right]^2, \quad P = \frac{e\rho v^2}{16\pi y^3} = \frac{d}{dt}\left(\frac{1}{2}mv^2\right) = mv\dot{v}, \quad \tau_{rel} = \frac{v}{\dot{v}}$$

(Moore and Scully 1986)

$$P = \frac{mv^2}{\tau_{rel}} = \frac{e\rho v^2}{16\pi y^3} \rightarrow \tau_{rel} = \frac{16\pi y^3 m}{e\rho} \rightarrow \tau_{dec} = \frac{16\pi y^3 m}{e\rho} \cdot \frac{\hbar^2}{4mkT} \frac{1}{(\Delta x)^2}$$

$$= \frac{y^3 h^2}{e\rho\pi kT} \frac{1}{(\Delta x)^2} = \frac{h^2}{e\rho\pi kT} \frac{y^3}{(\Delta x)^2}$$

In Peter Beierle's paper $\tau_{dec} = \frac{4h^2}{e\rho\pi kT} \frac{y^3}{(\Delta x)^2}$

In Scheel and Buhmann theory

$$\Gamma_{th}[c] = -t\frac{e^2 kT r_p(0)}{2\pi\varepsilon_0\hbar^2}\left[\frac{1}{2y} - \frac{1}{\sqrt{(2y)^2+(\Delta x)^2}}\right], \quad r_p(0) = \frac{2\varepsilon_0}{\sigma}, \ \sigma \text{ is conductivity}$$

$$= 2\varepsilon_0\rho$$

$$= -t\frac{e^2 kT \cancel{2\varepsilon_0}\rho}{\cancel{2}\pi\cancel{\varepsilon_0}\hbar^2}\left[\frac{1}{2y} - \frac{1}{\sqrt{(2y)^2+(\Delta x)^2}}\right]$$

$$= -t\frac{e^2 kT\rho}{\pi\hbar^2}\left[\frac{1}{2y} - \frac{1}{\sqrt{(2y)^2+(\Delta x)^2}}\right]$$

$$\tau^{Buhmann} = \frac{\pi\hbar^2}{e^2 kT\rho}\left[\frac{1}{2y} - \frac{1}{\sqrt{(2y)^2+(\Delta x)^2}}\right]^{-1}$$

Peter's result $\frac{\pi\varepsilon_0\hbar^2}{e^2 kT\rho}\left[\frac{1}{2y} - \frac{1}{\sqrt{(2y)^2+(\Delta x)^2}}\right]^{-1}$ Need to remove ε_0

$$\tau^{Zurek} = \frac{4\hbar^2}{\pi e^2 k_B T \rho} \cdot \frac{y^3}{(\Delta x)^2} \qquad \tau^{Buhmann}_{dec} = \frac{\pi \hbar^2}{e^2 k_B T \rho}\left[\frac{1}{2y} - \frac{1}{\sqrt{(2y)^2+(\Delta x)^2}}\right]^{-1}$$

for $\Delta x \ll y$ (Why?)

$$\frac{\pi \varepsilon_0 \left(\frac{h}{2\pi}\right)^2}{e^2 k_B T \rho}\left[\frac{1}{2y} - \frac{1}{[(2y)^2+(\Delta x)^2]^{1/2}}\right]^{-1} \longrightarrow \frac{\pi \varepsilon_0 h^2}{e^2 k_B T \rho \cdot 4\pi^2} \cdot \left[\frac{1}{2y} - \frac{1}{2y\left[1+\left(\frac{\Delta x}{2y}\right)^2\right]^{1/2}}\right]^{-1}$$

$$〃 \left[\frac{1}{2y} - \frac{1}{2y\left[1+\frac{1}{2}\left(\frac{\Delta x}{2y}\right)^2\right]}\right]^{-1} \longrightarrow 〃 \left\{\frac{1}{2y}\left[1 - \left[1+\frac{1}{2}\left(\frac{\Delta x}{2y}\right)^2\right]^{-1}\right]\right\}^{-1}$$

$$〃 \left[\frac{\frac{1}{2}\left(\frac{\Delta x}{2y}\right)^2}{2y}\right]^{-1} \longrightarrow 〃 \left[\frac{(\Delta x)^2}{16 y^3}\right]^{-1}$$

$$\frac{\pi \varepsilon_0 h^2}{e^2 k_B T \rho\, 4\pi^2} \frac{16 y^3}{(\Delta x)^2} = \frac{4 h^2}{e^2 \pi k_B T \rho} \frac{y^3}{(\Delta x)^2} \neq \tau^{Zurek} = \frac{4\hbar^2}{\pi e^2 k_B T \rho} \cdot \frac{y^3}{(\Delta x)^2}$$

---

for $y \ll \Delta x$

$$\frac{\pi \varepsilon_0 \left(\frac{h}{2\pi}\right)^2}{e^2 k_B T \rho}\left[\frac{1}{2y} - \frac{1}{[(2y)^2+(\Delta x)^2]^{1/2}}\right]^{-1} \longrightarrow 〃 \left[\frac{1}{2y} - \frac{1}{\left[\left(\frac{2y}{\Delta x}\right)^2+1\right]^{1/2}\Delta x}\right]^{-1}$$

$$〃 \left[\frac{1}{2y} - \frac{1}{\Delta x\left[1+\frac{1}{2}\left(\frac{2y}{\Delta x}\right)^2\right]}\right]^{-1} \longrightarrow 〃 \left[\frac{\Delta x + \frac{1}{2}\frac{(2y)^2}{\Delta x} - 2y}{2y\Delta x\left[1+\frac{1}{2}\left(\frac{2y}{\Delta x}\right)^2\right]}\right]^{-1} \quad \ldots$$

Made with Goodnotes

Compare Machnikowski with Zurek

$$\frac{4\cancel{\hbar^2}}{\cancel{\pi e^2 k_B T}\rho}\frac{y^{\cancel{3}}}{\cancel{(\Delta x)^2}} \Bigg/ \frac{32\varepsilon_0\cancel{\hbar^2}k_{Fermi}}{\cancel{\pi e^2}m\cancel{k_B T}}\frac{y^{\cancel{2}}}{\cancel{(\Delta x)^2}}$$

$$\frac{4y}{\rho} \Bigg/ \frac{32\varepsilon_0 k_{Fermi}}{m}$$

$$\frac{4ym}{32\rho\varepsilon_0 k_F} = \frac{ym}{8\rho\varepsilon_0 k_F}$$

10^{29} difference

Learning Master Equation and Canonical Models

(Decoherence and the Quantum-to-Classical Tranzition, Maximillian A. Schlosshauer)

Spin Model
- low temperature (μK)
- localized spin-type modes
- strong coupling, independent of number of spins in the enviroment (sometimes, with exceptions)

Enviroment — interact — Central System

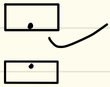
Decoherence

Harmonic Oscillator Model
- delocalized Bosonic field modes
- normal temperature (not close to absolute zero)
- week coupling

- coupling strength scales with number of oscillator N $\propto 1/\sqrt{N}$

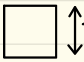
All modes summing up yeilds a value independent of N. In thermodynamics limit $N \to \infty$

Simulate Charging effect in the grating experiment

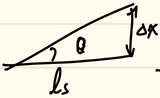


$10\mu C/m^2 \sim 10^{-5} C/m^2$

$$\frac{1.6\times10^{-19}C}{(10^{-7})^2} = \frac{1.6\times10^{-19}}{10^{-14}} = 1.6\times10^{-5} C/m^2$$



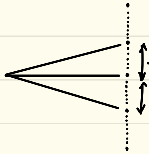
$1e^- / 100nm$



$\lambda = d\theta$

$$\frac{3\times10^{-11}}{10^{-7}} = \theta$$

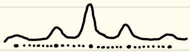
$3\times10^{-4} = \theta$



$l_s\theta \sim 5\times10^{-3}\times3\times10^{-4} = 1.5\times10^{-6}m$

$$\frac{1.5\times10^{-6}}{10^{-7}} = 15e^-$$

It should be a single charge line



Charge distribution

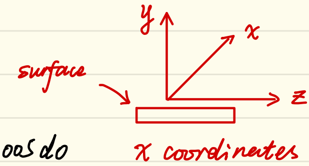
$\lambda = d\sin\theta$

$\mathrm{asin}\left(\frac{\lambda}{d}\right) = \theta$

$\Delta x = \tan\left(\mathrm{asin}\left(\frac{\lambda}{d}\right)\right)\cdot l_s$

How Peter Calculate Decoherence

From his code




```
do i=1,2001
    near_field_x(i)=-5d0+(i-1)*.005d0
endodo
```

```
m=2,500
  i=890,1112
    j=2002-i
      total_decoherencetime(i)=1.0d0/inversezurektime
```

i is position index

inversezurektime = numerator/((4d0*h**2)*(trajectory(m)**3))

$4h^2 y^3$

numerator=(Pi*(q**2)*kbolt*Tkelvin*resistivity*((i*(5d-6)/1000d0)-(j*(5d-6)/1000d0))**2)

$$\pi q_e^2 kT\rho\cdot\left(i\frac{5\times10^{-6}}{1000}-j\frac{5\times10^{-6}}{1000}\right)^2=\pi q_e^2 kT\rho\left(\frac{5\times10^{-6}}{1000}\right)^2(i-j)^2=\pi q_e^2 kT\rho(5\times10^{-9})^2(i-j)^2$$

$\pi q_e^2 kT\rho(\Delta x)^2$

$$\tau_{zurek}=\frac{4h^2}{\pi e^2 k_B T\rho}\frac{y^3}{(\Delta x)^2}$$

Zurek = exp(-delt * inversezurektime)

---

sp_1 = slit1 position $\quad$ sp_2 = slit2 position $\quad$ surfaceheight = Sf

$y_1=0$ $\quad x$ $\qquad\qquad y_1'=y_2$

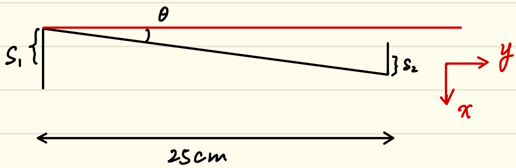
$y_2=v_0\cos\theta$ $\quad$ initial v_x $\qquad\qquad y_2'=0$ $\quad a_x=0$

$y_3=sp_1+(31\times10^{-2})*((sp_2-sp_1)/(25\times10^{-2}))$ $\quad y$ $\qquad\qquad y_3'=y_4$ $\quad v_y$

$y_4=v_0\sin\theta$ $\quad$ initial v_y $\qquad\qquad y_4'=-\dfrac{kq_e^2}{4(y_3+S_f)^3 m_e}=a_y$

trajectory(i) = y(3) + surfheight $\quad y+S_f$

$\theta=\mathrm{atan}[(sp_2-sp_1)/(25\times10^{-2})]$



Made with Goodnotes

m=1,500 (time step)

trajectory(m) = y(3) + surfheight $= y_3 + S_f$

y(3) = y(3)+(y(4)*delt) $y_3 = y_3 + y_4\, dt$

y(4) = y(4)+(yprime(4)*delt) $y_4 = y_4 + y_4'\, dt$

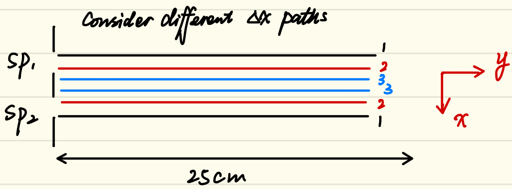
yprime(4) = -k*q_0*q_0/(4*(y(3)+surfheight)*(y(3)+surfheight)*me)

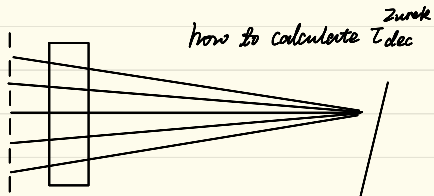
$$y'(4) = -\frac{kq_0^2}{4(y_3+surfheight)^2\, me}$$

$surfheight = 1.834 \times 10^{-6}$

dt delt = endoftim/500 (time step) $length = 10^{-2}$

endoftim = length/v_0 $V_0 = 2.42 \times 10^{7}$





Firstly, consider how decoherence time modify coherence length

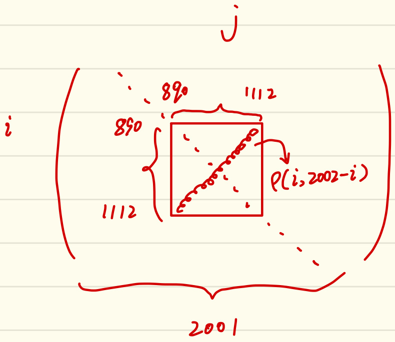
In code

```
do m=1,1
 do i=890,1112 !it is unecessary to calculate the change at the tails, suff small
   j=2002-i
    numerator=(Pi*(q**2)*kbolt*Tkelvin*resistivity*((i*(5d-6)/1000d0)-(j*(5d-6)/1000d0))**2)
      inversezurektime=numerator/((4d0*h**2)*(trajectory(m)**3))

    zurek=dexp(-delt*inversezurektime)
    reduced_diagonal(i)=rho_1p5(i,j)*zurek
 enddo
enddo
```

$zurek = e^{-\Delta t/\tau}$

τ is τ_{dec}^{zurek}



$\tau = \tau(i, m) = \tau(\Delta x, y)$

$\rho(i,j) * e^{-\Delta t/\tau}$ = reduced_diagonal

$j + i = 2002$

$\rho(i)\, e^{-\Delta t/\tau(i,m)}$ = reduced_diagonal

$\rho(\Delta x)\, e^{-\Delta t/\tau(\Delta x, y)}$ = reduced_diagonal

```
do i=1,2001
  norm=norm+reduced_diagonal(i)
enddo
  write(*,*) 'norm=',norm
do i=1,2001
  reduced_diagonal(i)=reduced_diagonal(i)/norm
enddo
```

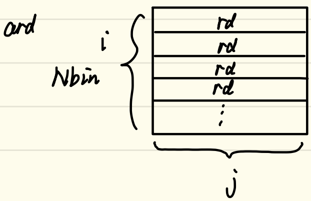
Normalization

Nbin = 1100

```
do i=1,Nbin
 if (binlower(i).le.finalheight) then
  if (finalheight.le.binupper(i)) then
   binvalue(i)=binvalue(i)+1d0
!    if (binlower(i).ge.-1.82d-5) then
!     if (binupper(i).le.1.82d-5) then
!       write(16,*) s1,' ',s2
!     endif
!    endif
   do j=1,2001
    accum_reduced_diagonal(i,j)=accum_reduced_diagonal(i,j)
+reduced_diagonal(j)
   enddo
  endif
 endif
enddo
```

ard(1,2) = ard(1,2) + rd(2)

ard(1,3) = ard(1,3) + rd(3)



Machnikowski decoherence

$$\tau_{dec}^{Mach} = \frac{32\epsilon_0 h^2 k_{Fermi}}{\pi e^2 m k_B T}\left(\frac{y}{\Delta x}\right)^2 = 1.2$$

```
do m=1,1
 do i=890,1112 !it is unecessary to calculate the change at the tails, suff small
   j=2002-i
     xsquared=((i*(5d-6)/1000d0)-(j*(5d-6)/1000d0))**2
     taur_inverse=coefficient/(trajectory(m)**2)
     taud_inverse=(Pi/32.0d0)*taur_inverse*xsquared/(lambdadb)**2
     mach=dexp(-delt*taud_inverse)

reduced_diagonal(i)=rho_1p5(i,j)*mach
 enddo
enddo
```

$$\lambda = \frac{2\pi\hbar}{\sqrt{2m_e k_b T}}$$

$$coef = \frac{q_e^2}{2\pi\epsilon_0\cdot\epsilon_i\cdot\hbar\cdot k_{Fermi}}$$

$$(\Delta x)^2 = (i-j)^2(5\times10^{-9})^2$$

$$\tau_r^{inv} = coef/y^2$$ y is electron height

$$\tau_d^{inv} = \frac{\pi}{32}\tau_r^{inv}(\Delta x)^2/\lambda^2$$

$$mach = e^{-dt\cdot\tau_d^{inv}}$$

$$\tau_d^{inv} = \frac{\pi}{32}\frac{q_e^2}{y^2 2\pi\epsilon_0\cdot\epsilon_i\cdot\hbar\cdot k_{Fermi}}\cdot\frac{(\Delta x)^2}{4\pi^2\hbar^2}\cdot 2m_e k_b T$$

$$= \frac{\cancel{\pi}}{32}\frac{q_e^2}{y^2\cancel{2\pi}\epsilon_0\cdot\epsilon_i\cdot\hbar\cdot k_{Fermi}}\cdot\frac{(\Delta x)^2}{4\pi^2\hbar^2}\cdot\cancel{2}m_e k_b T$$

$$= \frac{q_e^2 m_e k_b T\,(\Delta x)^2}{32\pi^2\epsilon_0\cdot\epsilon_i\cdot\hbar^3\cdot k_{Fermi}(y^2\cdot 4)}$$

$q_e = e$, $\hbar = \frac{h}{2\pi}$, $\epsilon_i = 2$

$$= \frac{e^2 m_e k_b T\,(\Delta x)^2}{32\,\epsilon_0\pi^2(\frac{h}{2\pi})^3\cdot 8\cdot k_{Fermi}\cdot y^2}$$

$$= \frac{e^2 m_e k_b T\,(\Delta x)^2}{32\,\epsilon_0\cancel{\pi^2}\frac{h^3}{\cancel{8}\pi^3}\cdot\cancel{8}\cdot k_{Fermi}\cdot y^2}$$

$$= \frac{\pi e^2 m_e k_b T\,(\Delta x)^2}{32\,\epsilon_0 h^3 k_{Fermi}\cdot y^2}$$

Compare with original paper *machnikowskiTheoryWhichPath2006*

D is path distance, z_0 is path height

For $D \lesssim z_0$

$$\tau_d^{-1} = \frac{\pi}{32}\tau_r^{-1}\left(\frac{D}{\lambda_{dB}}\right)^2 \qquad \lambda_{dB} = 2\pi\hbar/\sqrt{2mk_BT}$$

$$\tau_d^{-1} = \frac{\pi}{32}\tau_r^{-1} D^2 \frac{2mk_BT}{4\pi^2\hbar^2} \qquad \tau_r^{-1} = \frac{e^2}{2\pi\epsilon_0\epsilon_i z_0^2 \hbar k_F}$$

$$= \frac{\pi}{32}\frac{e^2}{2\pi\epsilon_0\epsilon_i z_0^2\hbar k_F} D^2 \frac{2mk_BT}{4\pi^2\hbar^2}$$

$$= \frac{\cancel{\pi}}{32}\frac{e^2}{\cancel{2\pi}\epsilon_0\epsilon_i z_0^2 \cancel{\hbar} k_F} D^2 \frac{\cancel{2}mk_BT\cdot 2\pi}{\cancel{4\pi^2\hbar}\, h^3}$$

$$= \frac{e^2 mk_BT\, D^2\cdot 2\pi}{32\epsilon_0\epsilon_i z_0^2 k_F\, h^3} \qquad \epsilon_i = 1 + \chi_{ph} \approx 2$$

$$= \frac{\pi e^2 mk_BT\, D^2}{32\epsilon_0 k_F h^3 z_0^2}$$

Compared with Peter's paper
h^2 should be h^3

Howie's decoherence probability

$$P^{Howie} = \left(\frac{e^2 L\omega_m^2}{4\pi^2\hbar\sigma v^2}\right)\int_{\underset{\eta}{y/4\Delta x}}^{\infty}\frac{\exp(-s)}{s}ds$$

$1.5\,\Omega\,cm = 1.5\,\Omega(10^{-2})\,m = 1.5\times10^{-2}\,\Omega m$

Ωm

$$\int_\eta^\infty \frac{e^{-s}}{s}ds = E_i(-\infty) - E_i(-\eta) = -E_i(-\eta) = E_1(\eta)$$

$$P^{Howie} = \left(\frac{e^2 L\omega_m^2}{4\pi^2\hbar\sigma v^2}\right)E_1\left(\frac{y}{4\Delta x}\right)$$

Made with Goodnotes

Conductivity of GaAs

$$\sigma = en\mu_e + ep\mu_h$$

$$C \cdot \frac{1}{cm^3} \, cm^2/(Vs) = C/(V\cdot s\cdot cm) = A\cdot\cancel{s}/(kg\cdot m^2 s^{-3} A^{-1}\cdot\cancel{s}\cdot cm)$$

$$= A^2\, kg^{-1}\, m^{-2}\, s^3\, cm^{-1}$$

$$= 100\, kg^{-1}\, m^{-3}\, S^3 A^2$$

Conductivity SI unit: $Kg^{-1} m^{-3} s^3 A^2$

Quantum Decoherence Simulation Parallel to the surface

Initial density matrix of the free electron (partially coherent Gaussian beam)

$$\rho_{initial}(x,x') = \frac{1}{\sigma_0^{coh}\sqrt{2\pi}} \exp\left[-\frac{(x-x_0)^2}{2(\sigma_0^{coh})^2}\right] \exp\left[-\frac{(x')^2}{2(\sigma'_{ini})^2}\right] \quad (C.4)$$

x describes the direction of diagnal
x' describes the direction orthogonal to diagnal.
x_0 center of the Gaussian

In x' direction $w'_{ini} = 2\sqrt{2\ln(2)}\,\sigma'_{ini}$; Spatial width $w \equiv 2\sqrt{2\ln(2)}\,\sigma_0^{coh}$

$w' = w$ fully coherent $\quad$ $w' < w$ partially coherent

Considering decoherence process according to

Breuer H-P and Petruccione F 2002 Theory Open Quantum Syst. (Oxford: Oxford University Press) pp 232–42

$$\rho_{final} = \rho_{initial}\, e^{-\int_{t_i}^{t_f} dt/\tau_{dec}} \quad (C.5)$$

τ_{dec} is model dependent (Δx and $y(t)$) : $\rho_{initial}(m,n) \longrightarrow \Delta l \cdot |m-n| = \Delta x$
$y(t)$ depends on trajectory

After the surface

$$\rho_{final}(x,x') = \frac{1}{\sigma_0^{coh}\sqrt{2\pi}} \exp\left(-\frac{(x-x_0)^2}{2(\sigma_0^{coh})^2}\right) \exp\left(-\frac{(x')^2}{2(\sigma'_{final})^2}\right) \quad (C.6)$$

When decoherence occurred, $w'_{final} < w'_{initial}$

For each final position bin at the detector where electrons landed, the final density matrix at the detector is computed by ***incoherently adding*** *the individual matrices of each electron that reaches that bin. Making use of the ability to write a* ***partial coherent state*** *as a* ***sum of coherent (i.e. pure) states***

$$\rho_{final} = \sum_{n=1}^{\infty} c_n \rho_n^{coh} \qquad (C.7)$$

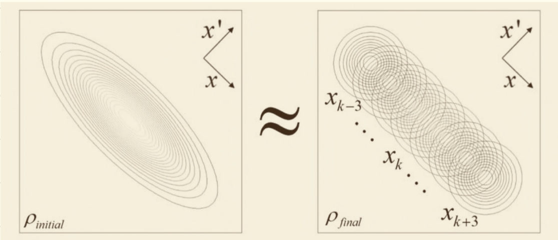
We can write it as a sum of Gaussian coherent states

$$\rho_{final} \approx \sum_{n=1}^{N} \exp\left[-\frac{(x_0 - x_n)^2}{2(\sigma_{env})^2}\right] \times \exp\left[-\frac{(x - x_0 - x_n)^2 + (x')^2}{2(\sigma_2^{coh})^2}\right]$$

$\sigma_2^{coh} = \sigma'_{final}$ describes the width of the reduced pure states after decoherence

coherence length L_{coh}

σ_{env} is the width of envolope of the convolution



See figure.

Partial coherent beam density matrix

||

Sum of coherent beam

Using equation $L_{coh} \approx \lambda_{dB}/\theta_{coll} \approx ad/W_{FWHM}$

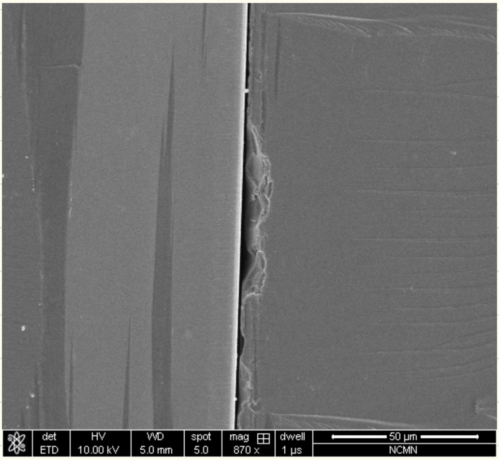
a : periodicity of grating.

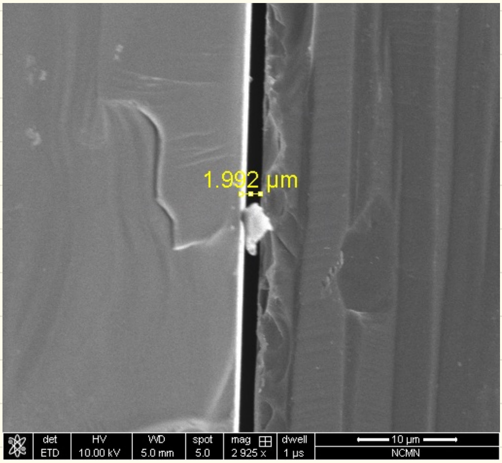
W_{FWHM} : width of the computed diffraction peaks in the far field.

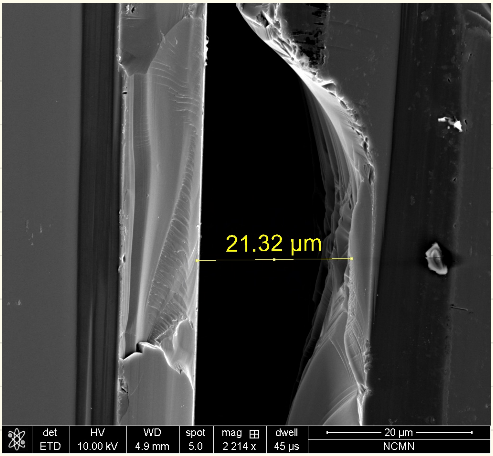
d : distance between diffraction peaks.

Channel Making

1st trial process see PPT "Channel Making.pptx"



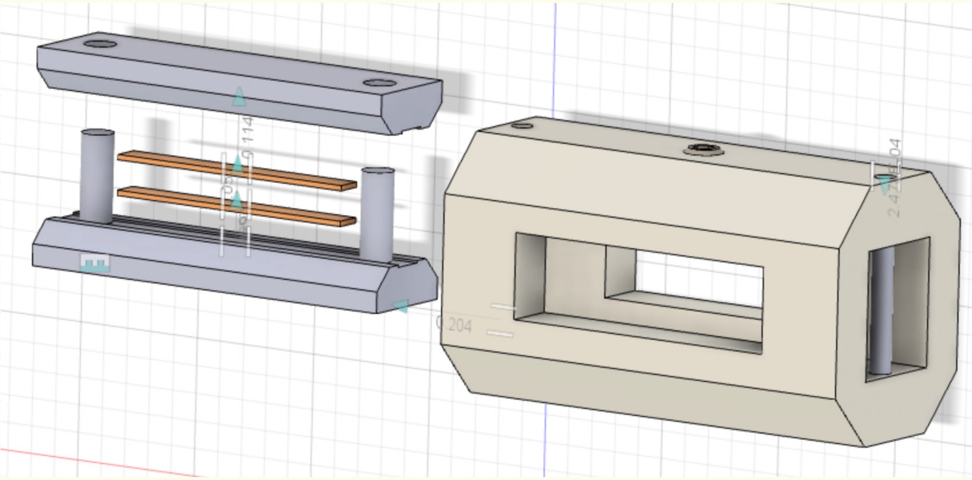




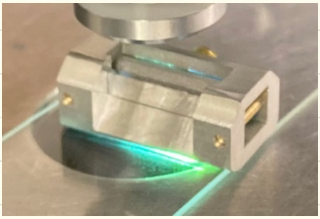
The smallest gap is ~1.5µm
Found some large dents
Cannot see channels on side view
The channel width should be 500µm

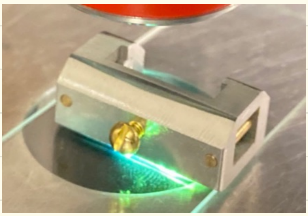
2nd trial of channel making

Made a device to carefully combaine the two slides

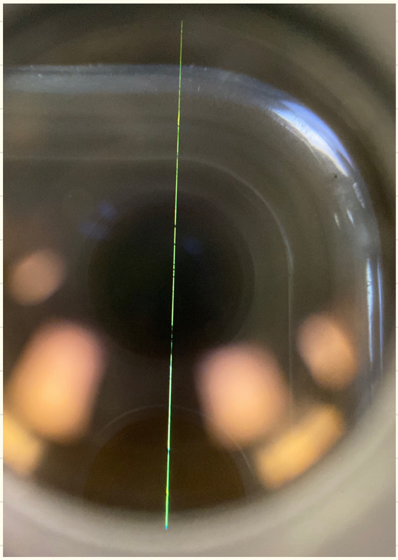


Under Optical Microscope

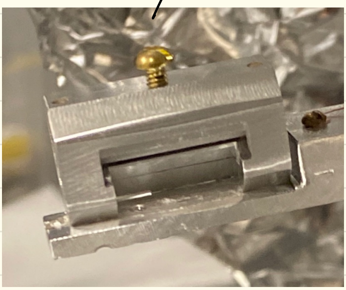


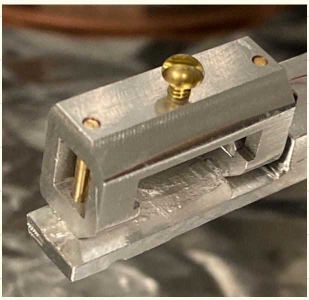


Gap Under Optical Microscope

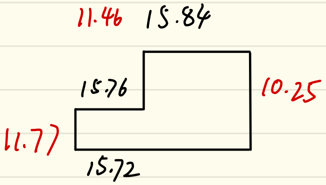


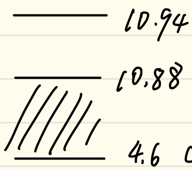
On the Experimental Holder





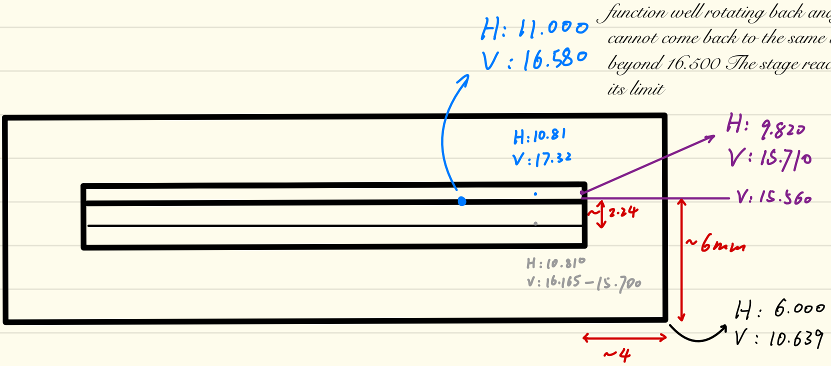
Horizontal — Vertical —   Experiment to find the gap



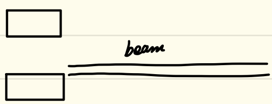


4.6 cannot see the beam

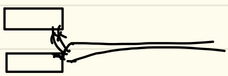
at this point, translation stage doesn't function well rotating back and forth cannot come back to the same location beyond 16.500 The stage reach its limit



①



blocked but cannot recover until move to a far location and move back



special charging effect Al_nOm?

It's not observed on other Al parts like holders

sharp edge modify the current?

lighting?   It happens in a lot of places

It also works fine in a lot of locations.

Sharpe edges with changing on oxidation

translation stage backlash ? ⊗

To recover the beam, cannot just move away from the spot, have to move back again

At some location, the stage works perfectly fine

correlation motion on the translation stage ? ⊗

At a spot where it can be moved left and right in a large scale, it will still happen

↓

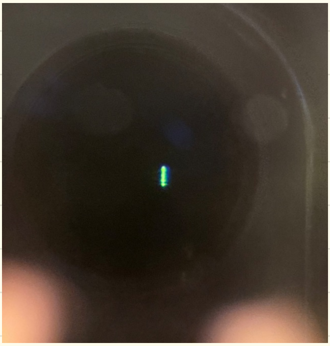
correlation motion is very large → can be noticed in other area

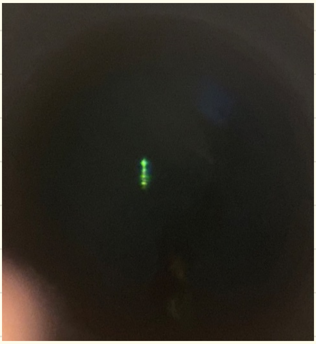
↓ should happen in other location

New 1st collimation slit

label C slit

1st trial on aligning the system

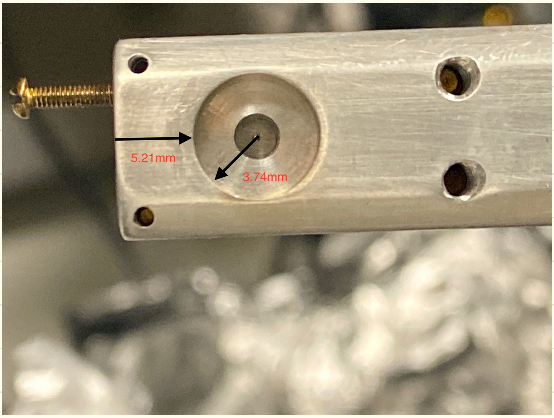

Before


After

After aligned, the beam counts were getting lower with time. Finally, it disappeared

The figures are showing the slit before and after the experiment.

Switched to label A slit. And it disappeared again

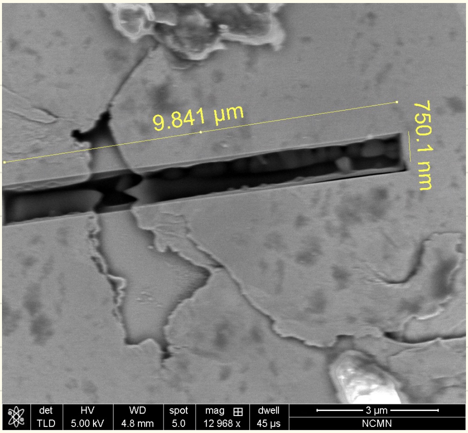


This is the mount of 1st collimation slit

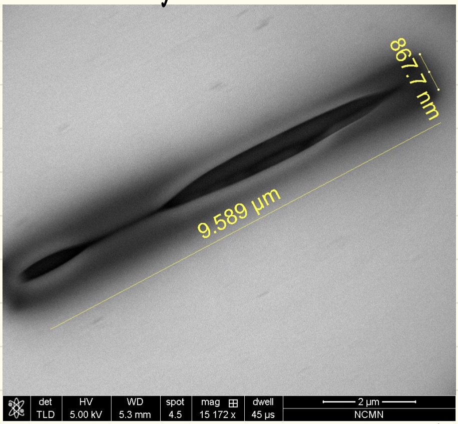
The distance measured are used to find the slit hole in the middle.

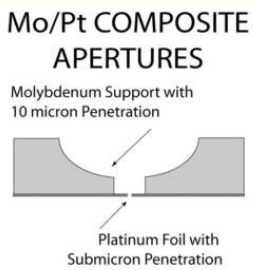
SEM Figures

side back to e-beam

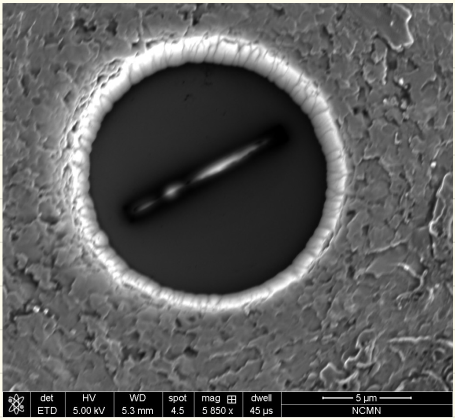


Side that face e-beam





Zoom



The slit seems to melt down and deformed

Estimate the energy that the material obsorbed.

e-beam energy:

$$P = 1.67\,\text{keV} \cdot 20\,\mu A = 1.67\times10^{3} \times 1.6\times10^{-19}\,V \cdot 20\times10^{-6}\,A$$
$$= 5.34\times10\times10^{-22}$$
$$= 5.34\times10^{-21}\,W$$

molar mass: 195.08 g/mol

platinum melting point: 1772°C

heat of fusion: 22.17 kJ/mol

density: 21.45 g/cm^3

area: $\pi r^2 = \pi\cdot(7.5\times10^{-6})^2 = 1.77\times10^{-10}\,m^2$

thickness: $1\times10^{-6}\,m$

$$\text{mass} = \text{area} \times \text{thickness} \times \text{density} = 1.77\times10^{-10} \times 10^{-6} \times 21.45\times10^{3}\ \text{kg}/\text{m}^3 \cdot \text{m}^3 = 3.8\times10^{-13}\ \text{kg} = 3.8\times10^{-10}\ \text{g}$$

$$\text{amount of substance} = \frac{\text{mass}}{\text{molar mass}} = \frac{3.8\times10^{-10}\ \text{g}}{195.08\ \text{g/mol}} = 1.95\times10^{-12}\ \text{mol}$$

$$E_f = \text{fusion energy} = H_f \cdot A_s = 22.17\times10^{3}\ \text{J/mol} \times 1.95\times10^{-12}\ \text{mol} = 4.32\times10^{-9}\ \text{J}$$

$$t = \frac{E_f}{P} = \frac{4.32\times10^{-9}\ \text{J}}{5.34\times10^{-21}\ \text{W}} = 8\times10^{-1}\times10^{12}\ \text{s} = 8\times10^{11}\ \text{s}$$

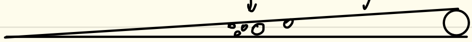
No enough energy to melt

Made with Goodnotes

New design

A movable gap will make the experiment much easier because of the difficulties listed below:

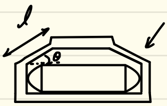
1. A tilt gap might fail if a dust block our way to smaller separation



At small gap range, it's very sensitive to angle. If we lost beam somewhere it is very hard to find it again.

2. The very small gap we design is also very hard to find.

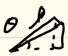
A piezo in a flexure



Amplification $= \dfrac{\cot\theta}{2} = A$

$\theta = 3°,\ A \sim 9.5$

$\theta = 5°,\ A \sim 5.7$



$l\cos\theta$

$2l\,|\Delta(\cos\theta)| = \Delta x$

$2l\,\sin\theta\,\Delta\theta = \Delta x$

$\Delta\theta = \dfrac{\Delta x}{2l\sin\theta}$

$\Delta h = l\Delta(\sin\theta)$

$= l\cos\theta\,\Delta\theta$

$= l\cos\theta\,\dfrac{\Delta x}{2l\sin\theta}$

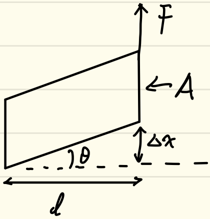
$\Delta h = \dfrac{\Delta x}{2}\cot\theta$

$= \Delta x \cdot \dfrac{\cot\theta}{2} = 10\,\mu m \cdot \dfrac{\overset{\sim 11.4}{\cot(5°)}}{2} = 57\,\mu m$

The distance is large but how to guarantee parallelism?

Made with Goodnotes

Shear Modulus



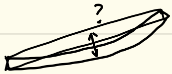
for silicon

$G = 60\ GPa$

$= 60 \times 10^9\ Pa$

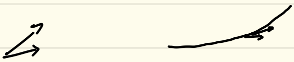
$$G = \frac{Fd}{A\Delta x} = \frac{F}{A} \cdot \frac{1}{\theta}$$

$$60\times10^9 = \frac{F\cdot(5\times10^{-3})}{280\times10^{-6}\cdot(1.5\times10^{-3})\cdot(25\times10^{-6})}$$



$$F = 6\times10^{10}\cdot 2.8\times10^{-4}\cdot 1.5\times10^{-3}\cdot\frac{25\times10^{-6}}{5\times10^{-3}}$$

$F = 126\ N$



$y = Ax^2$

$y' = 2Ax$

$y'' = 2A$

$$\theta = \frac{25\times10^{-6}}{5\times10^{-3}} = 5\times10^{-3}$$

$\theta = k_2 - k_1 = y_2' - y_1'$

$= \Delta(y') = y''\Delta x$

$$G = \frac{F}{A}\frac{1}{y''\Delta x}$$

$x = 5\times10^{-3}$ $y = A\times(5\times10^{-3})^2$

$25\times10^{-6} = 25A\times10^{-6}$

$A = 1$

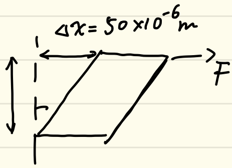
$y'' = 2$

$60\times10^9 \times 280\times10^{-6}\cdot(1.5\times10^{-3})\cdot 2\cdot(5\times10^{-3})$

$= (6\times10^{10})\cdot(2.8\times10^{-4})\cdot(1.5\times10^{-3})\cdot$

picomotor max load ~ 20 N

for Al $G = 25.5\ GPa = 25.5\times10^9\ Pa$



$G = \frac{Fd}{A\Delta x}$ (use half max load)

$$25.5\times10^9 = \frac{10\cdot15\times10^{-3}\sqrt{2}}{A\cdot 50\times10^{-6}}$$

$$A = \frac{10^2\times10^{-3}\cdot1.5\sqrt{2}}{5\times10^{-5}\times2.55\times10^{10}} \sim \frac{10^{-1}\times1.5\sqrt{2}}{10^5\times5\times2.55}$$

0.17×10^{-6}

$\sim 2\times10^{-7}$

$A = TW$ $\qquad T = 10^{-2}m$ $W = 10^{-5}m$?

Made with Goodnotes

$$P_{Joule} = \frac{e^2 \rho v^2}{16\pi y^3} \qquad P\Delta t \qquad \frac{e^2 \rho v^2}{16\pi y^3}\,\frac{l}{v} = \frac{e \rho v l}{16\pi y^3} \quad (eV)$$

For silicon

$$= \frac{1.6\times10^{-19} \times 10^{-2} \times 2.4\times10^{7} \times 10^{-2}}{16\times 3 \times (10^{-6})^3} = 8\times10^{-2}\times 10^{2} = 8\ eV$$

for gold

$$\frac{e^2 \rho v^2}{16\pi y^3}\,\frac{l}{v} = \frac{e \rho v l}{16\pi y^3} = \frac{1.6\times10^{-19} \times \overset{2.44}{10^{-8}} \times 2.4\times10^{7} \times 10^{-3}\times 1.5}{16\times 3\times (10^{-6})^3}$$

$$= \frac{2.44\times1.6\times2.4\times1.5\times10^{-5}}{48} = 0.12\times2.44\times10^{-5} = 0.29\times10^{-5} \sim 2.9\times10^{-6}\ J$$

for GaAs $\quad \frac{e\rho v l}{16\pi y^3} = \frac{1.6\times10^{-19}\times 5\times 2.4\times10^{7}\times10^{-2}}{16\times3\times(12\times10^{-6})^3} = \frac{19.2\times10^{-14}}{8.3\times10^{4}\times10^{-18}} = 2.3\ eV$

$\tau = t/p$ $\quad \tau_1$ $\quad \Delta t_1$

$R = p/t$ $\quad \tau_2$

$\int R\,dt = \text{total } \tau$ $\quad r_1 \quad r_2$

$\frac{}{\tau_1}$ $\quad \frac{\Delta t_2}{\tau_2}$

$\frac{\Delta t}{\tau_1}$

$\tau =$

$R = \frac{1}{\tau}$

$$\frac{\Delta t}{\tau} = \frac{\Delta t_1}{\tau_1} + \frac{\Delta t_2}{\tau_2}$$

$$\frac{1}{\sum_i \left(\frac{\Delta t_i}{\tau_i}\right)} \cdot \Delta t = \tau$$

Made with Goodnotes

Howie energy dissipation

$$\frac{d^2P}{dx\,dw} = \frac{2(Ze)^2}{\pi\hbar v^2}\int_0^\infty dk_y\,\frac{\exp(-2v_0z_0)}{v_0}\,\mathrm{Im}\{\lambda_e(\omega,k)\}$$

$\downarrow$ integrate over x $\quad \int dx = L$

$$\int\frac{d^2P}{dx\,dw}dx = \frac{dP}{dw}L = \frac{2(Ze)^2L}{\pi\hbar v^2}\int_0^\infty dk_y\,\frac{e^{-2v_0z_0}}{v_0}\,\mathrm{Im}\{\lambda_e(\omega,k)\}$$

$$L\cdot\frac{d^2P}{dw\,dk_y} = \text{〃}\ \frac{e^{-2v_0z_0}}{v_0}\,\mathrm{Im}\{\text{〃}\}$$

$$\frac{dW}{dx} = \int_0^\infty\frac{d^2P}{dx\,dw}\hbar w\,dw \xrightarrow{P \text{ has no } x \text{ dependence}} |W| = L\int\frac{dP}{dw}\hbar w\,dw$$

$$|W| = L\iint\frac{d^2P}{dw\,dq_{0y}}dq_{0y}\,\hbar w\,dw = L\iint\frac{d^2P}{dq_{0y}\,dw}\hbar w\,dw\,dq_{0y}$$

$\downarrow$ w_m cut-off

$$= \iint_0^{w_m}\frac{d^2P}{dq_{0y}\,dw}\hbar w\,dw\,dq_{0y}$$

Note that

$$\frac{d^2P(x_0,w,q_{0y})}{dw\,dq_{0y}} = \frac{e^2L}{2\pi^2\varepsilon_0\hbar v^2}\,\frac{\varepsilon_0 w}{\sigma}\,\frac{\exp(-2q_0x_0)}{q_0} = \frac{e^2L}{2\pi^2\hbar v^2\sigma}\,w\,\frac{\exp(-2q_0x_0)}{q_0}$$

$$\frac{dP}{dq_{0y}} = \frac{e^2L}{2\pi^2\hbar v^2\sigma}\int_0^{w_m} w\,\frac{e^{-2x_0\sqrt{(\frac{w}{v})^2+q_{0y}^2}}}{\sqrt{(\frac{w}{v})^2+q_{0y}^2}}dw = \text{〃}\ \frac{1}{-2x_0\cdot\frac{1}{2}\cdot 2(\frac{1}{v})\cdot\frac{1}{v}}\int_0^{w_m} d\exp\left(-2x_0\sqrt{(\tfrac{w}{v})^2+q_{0y}^2}\right)$$

$$= \frac{e^2L}{2\pi^2\hbar v^2\sigma}\,\frac{v^2}{2x_0}\int_0^{w_m} d\left[-\exp\left(-2x_0\sqrt{(\tfrac{w}{v})^2+q_{0y}^2}\right)\right]$$

$$= \frac{e^2L}{4\pi^2\hbar\sigma x_0}\left[\exp(-2x_0q_{0y}) - \exp\left(-2x_0\sqrt{\frac{w_m^2}{v^2}+q_{0y}^2}\right)\right]$$

$$= \iint_0^{\omega_m} \frac{d^2p}{dq_{0y}\,d\omega}\,\hbar\omega\, d\omega\, dq_{0y} = \int dq_{0y} \int_0^{\omega_m} \left(\frac{e^2 L}{2\pi^2 \hbar v^2 \sigma}\, \omega\, \frac{\exp(-2q_0 x_0)}{q_0} \right) \hbar\omega\, d\omega$$

$$= \frac{e^2 L}{2\pi^2 v^2 \sigma} \int_{2/\Delta y}^{\infty} dq_{0y} \int_0^{\omega_m} \omega^2\, \frac{\exp(-2q_0 x_0)}{q_0}\, d\omega \qquad \left(q_0 = \sqrt{\left(\frac{\omega}{v}\right)^2 + q_{0y}^2} \right)$$

Δy is beam separation

x_0 is beam height

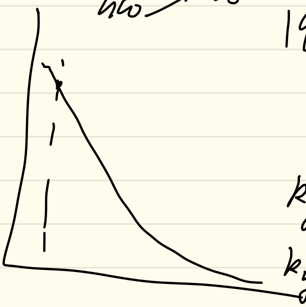
Cannot integrate analytically. Do numerically in Matlab.

$Q_y = \hbar k_y \Delta y > 2\hbar$

$\uparrow$

$k_y \Delta y > 2$

$\hbar\omega \to \infty$



$|q_{0y}| > \alpha/\Delta y$

$\uparrow$

wave number

$k_y = \alpha/\Delta y$

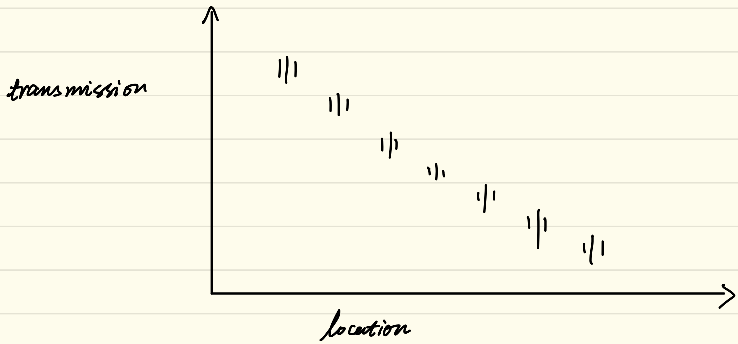
$k_y = 2/\Delta y.$

$$\frac{(k_y \hbar)^2}{2m} = E$$

$$\int \frac{\exp(-2x_0 q_{0y})}{q_{0y}}\, dq_{0y}$$

$$\int_{2x_0\alpha/\Delta y}^{\infty} \frac{\exp(-2x_0 q_{0y})}{2x_0 q_{0y}}\, d(2x_0 q_{0y})$$

$$\int_{4x_0/\Delta y}^{\infty} \frac{\exp(-x)}{x}\, dx$$



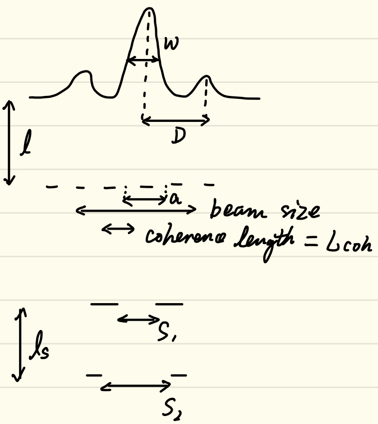
transmission

height

gap size

Classical Dominated Beam

Without decoherence



$$L_{coh} = \frac{Ch}{\Delta p_c} \qquad \Delta p_c = \overbrace{\frac{S_1+S_2}{l_s}}^{\Delta\theta_c} \cdot p \qquad w = \Delta p_c l / p$$

classical momentum divergence

for grating diffraction

$$\lambda = a \sin\theta \sim a \frac{D}{l} \longrightarrow D = \frac{\lambda l}{a}$$

The ratio

$$\frac{w}{D} = \frac{\Delta p_c l/p}{\lambda l/a} = \frac{Ch/(L_{coh}\, p)}{\lambda/a} = C\frac{a}{L_{coh}}$$

The ratio is a measure of L_{coh}.

With decoherence after the grating

1. In Howie's model, a horizontal momentum kick is performed on the flying electron $\Delta p > \frac{\hbar}{\Delta x}$ ← superposition states distance (50 nm ~ 500 nm)

$$\text{shift on screen} = \frac{h/2\pi}{L_{coh}} \frac{1}{p} \cdot l \sim w \longrightarrow \text{Contrast decrease}$$

2. In Zurek's model, the master equation shows the ensemble width will increase continueously if decoherence happened for a Gaussian wave

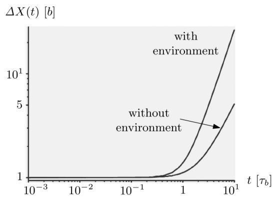


Fig. 3.7. Time evolution of the ensemble width $\Delta X(t)$ given by (3.92) for a Gaussian wave packet, as studied by Joos et al. [17]. The time t is measured in units of the characteristic localization timescale $\tau_b = 1/\Lambda b^2$, and $\Delta X(t)$ is plotted in units of the initial width $\Delta X(0) = b$ of the wave packet.

P.145 in the textbook

Decoherence and the Quantum-to-Classical Transition_Maximilian A. Schlosshauer

One needs to solve the master equation to get this.

Howie's theory

$$V = \left[e^{-b/(z/\mu m)^3} \right]$$

$$\tau_d = \frac{4h^2 z^3}{\pi e^2 k_B T \rho (\Delta x)^2}$$

$$V = e^{-(t/\tau_d)}$$

$$V = e^{-\left(\frac{t \pi e^2 k_B T \rho (\Delta x)^2}{4h^2 z^3}\right)}$$

$$\frac{2\alpha x_0}{\Delta y} = \frac{x_0}{4\Delta y}$$

$$V = e^{-\left[\frac{\pi e^2 k_B T \rho (\Delta x)^2}{4h^2} / (z/\mu m)^3\right]}$$

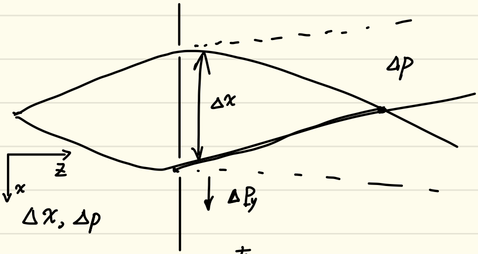
$$\alpha = \frac{1}{8}$$

$$\frac{t \pi e^2 k_B T \rho (\Delta x)^2}{4h^2} = b.$$

$$\frac{h}{8} \quad \frac{h}{4\pi}$$

$$t = \frac{10\,mm}{v}$$

Double slit



$$\frac{\hbar}{\Delta P_y} = \Delta x$$

$$\int_{\alpha/\Delta y}^{\infty} \frac{e^{-2x_0 q_y}}{q_y} \, dq_y$$

$$\int_1^2 x\,dx = \frac{1}{2}x^2\Big|_1^2 = \frac{3}{2}$$

$$\int_1^2 (2x)\,dx = x^2\Big|_1^2 = 3$$

$$\Delta y \cancel{\hbar} k > \alpha \cancel{\hbar}$$

$$k > \alpha / \Delta y$$

$$\int_1^2 \frac{(2x)}{2} d(2x) \xrightarrow{2x = y} \int_2^4 \frac{y}{2} dy$$

$$= \frac{1}{2}\frac{1}{2} y^2 \Big|_2^4$$

$$= \frac{1}{4}(16 - 4)$$

$$= 3.$$

How to connect coherence length to coherence ratio

Coherence length

l/l_0

decoherence ratio

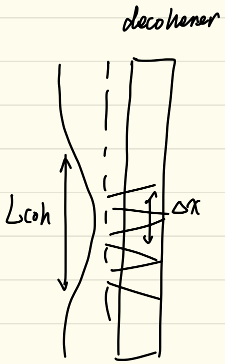
$t/\tau = R$

t decoherence time

τ flight time

$e^{-t/\tau} = V$

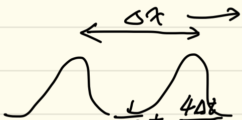
$e^{-R} = V$



$t/\tau = R$

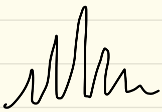
e^{-R}

$e^{-t/\tau} = V$



$\rightarrow t/\tau_{dec} = R$

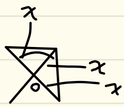
$\frac{1}{L_i^2} + \frac{4\Delta t}{A}$



$$e^{-x^2/L_i^2} \cdot e^{-\Delta t/\tau(2x)}$$

$$\tau = \frac{4h^2 z^3}{\pi e^2 k_b T P} = A \qquad \frac{1}{(2x)^2} = \tau(2x)$$

$$R = \Delta t/\tau(2x_{max})$$



$$e^{-x^2/L_i^2} \cdot e^{-\Delta t/\frac{A}{4x^2}} = \exp[-(\frac{1}{L_i^2} + \frac{4\Delta t}{A})x^2]$$

$$w' = \sqrt{\frac{1}{(\frac{1}{L_i^2} + \frac{4\Delta t}{A})}}$$ after decoherer

$2x$

New gold decoherence figure