Effect of atomic hydrogen exposure on electron beam polarization from strained GaAs photocathodes

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Maud Baylac,

JLab

Background

- Early days at JLab, wet chemical etching provided unreliable results: sometimes good, sometimes bad QE

- Since 1995, atomic hydrogen cleaning provides high QE and reproducible results at JLab

- Other labs have corroborated the ability of this method (MAMI, Nagoya, Bates, SLAC)

- RF dissociation better than DC dissociator

Hints

- Polarization varied from wafer to wafer originating from the same manufacturer
- Variation in polarization across small wafers (12 mm diameter)
- What was JLab doing differently from SLAC?

⇒ Study effect of hydrogen cleaning on wafer properties

Wafer ID

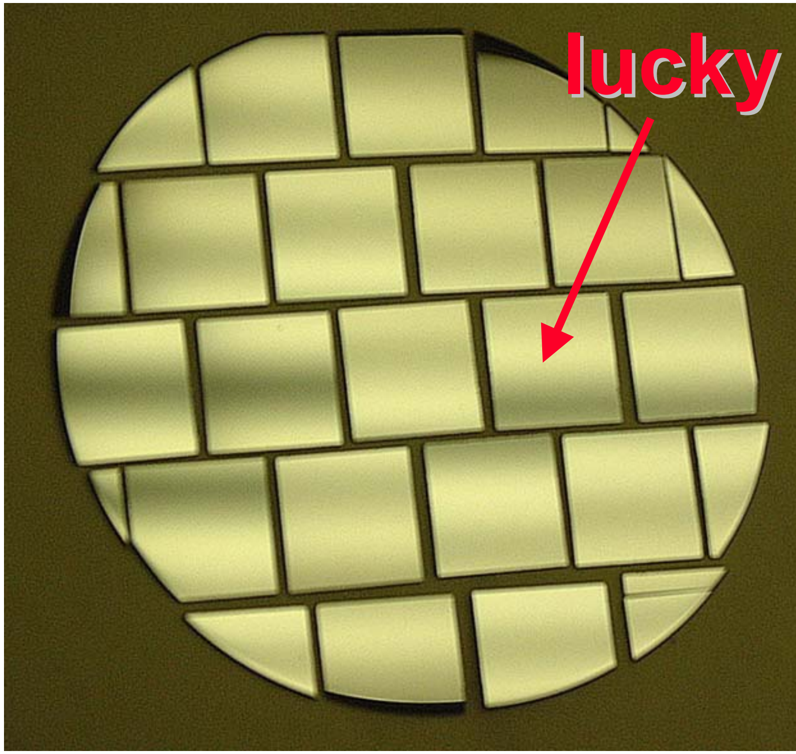
Bandwidth Semiconductor (formerly *SPIRE*)

- MOCVD-grown epitaxial "Spin-Polarizer" wafer

- 3" wafer, on 625 μm thick substrate

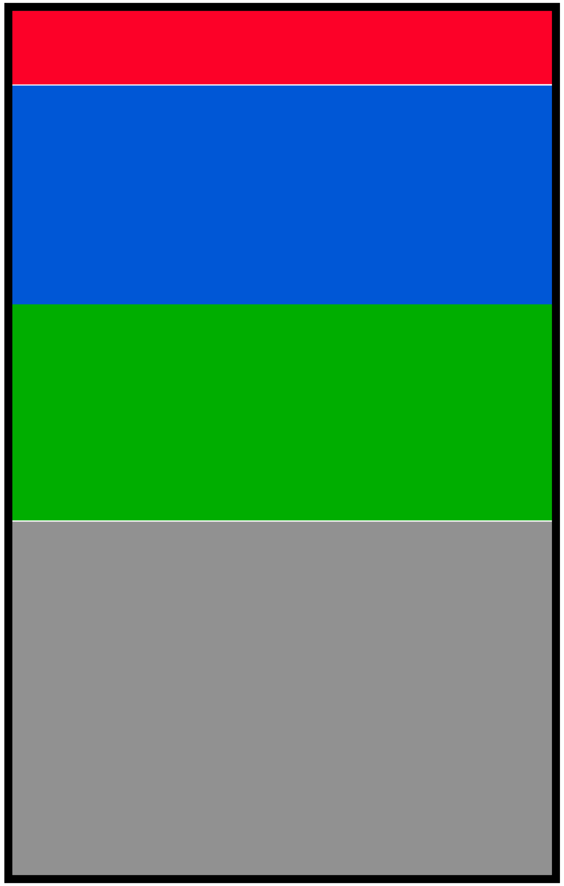
- No wet chemical treatment (no anodization, no acid or base etching, no degreasing)

- Sample cleaved (15.5 mm), then mounted



M05-5866, sent on 4-5-01

"Spin-Polarizer" wafer per SLAC specs. (from Bandwidth Semiconductor)



Strained GaAs (0.1 μm)

$GaAs_{1-x}P_x$, x=0.29 (250 μm)

$GaAs_{1-x}P_x$, $0<x<0.29$ (250 μm)

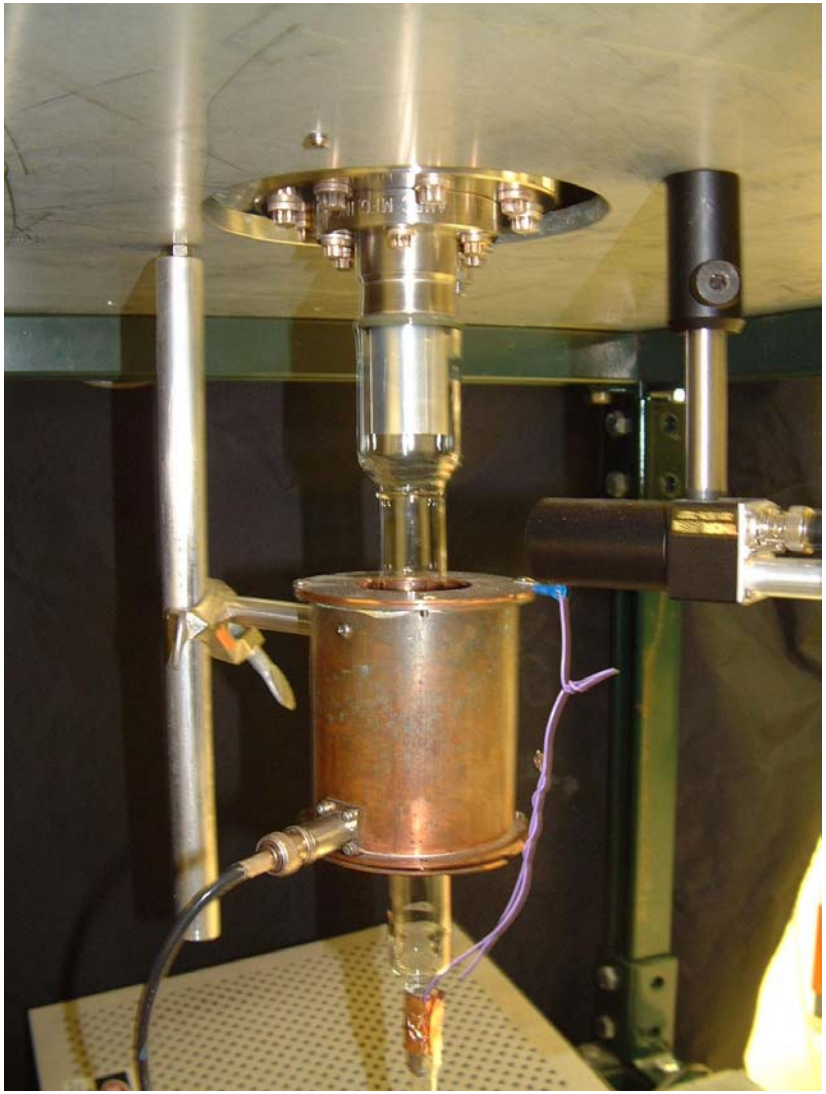
p-type GaAs substrate

Test Plan

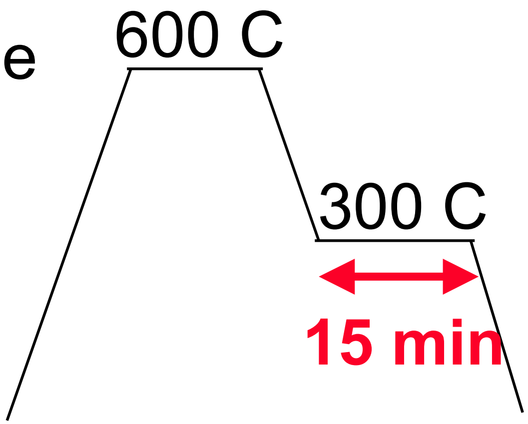
- Wafer cleaved and loaded onto stalk,
- Stalk installed in gun vacuum chamber, chamber evacuated & bake (250 C)
- Wafer heated 2 hours at ~ 570 C (estimated wafer temperature)
- NEA activation (Cs+NF_3) in gun chamber, QE scan of wafer
- 100 keV beam :

  QE, polarization vs. wavelength and vs. wafer location
- Break vacuum, remove wafer from gun
- Load in portable hydrogen cleaning chamber, pump down
- Expose wafer to atomic hydrogen

Hydrogen cleaner
http://www.jlab.org/accel/inj_group/h2/portable_H2.html



Hydrogen cleaner



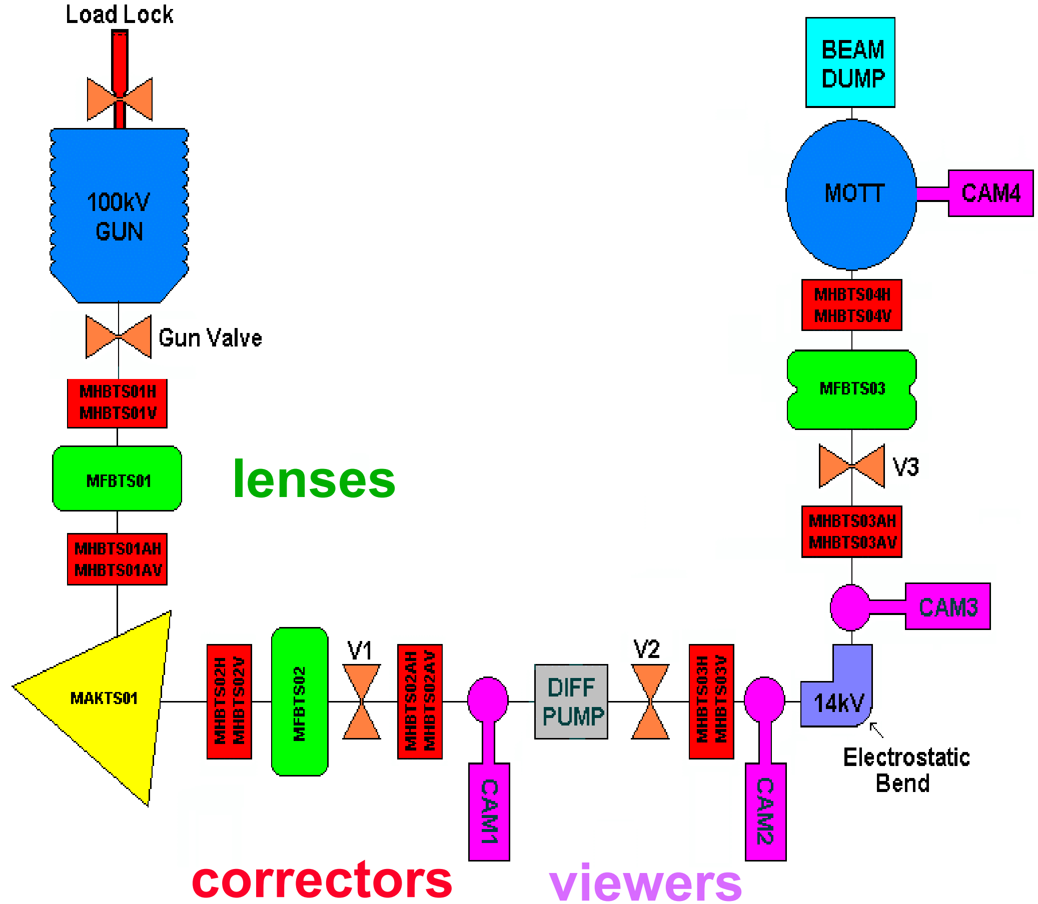
- H2 dissociation via RF inductive discharge
- Power ~ 20 W at 100 MHz
- Pressure ~ 15 mTorr
- Normal incidence
- Parameters adjusted then, wafer surface exposed
- Dose measured with an “ion counter” at bottom of dissociator, conditions kept identical from one cleaning to the next

Mc.Alpine & Schildknecht, Proceeding of the IRE, 1959 (2099)

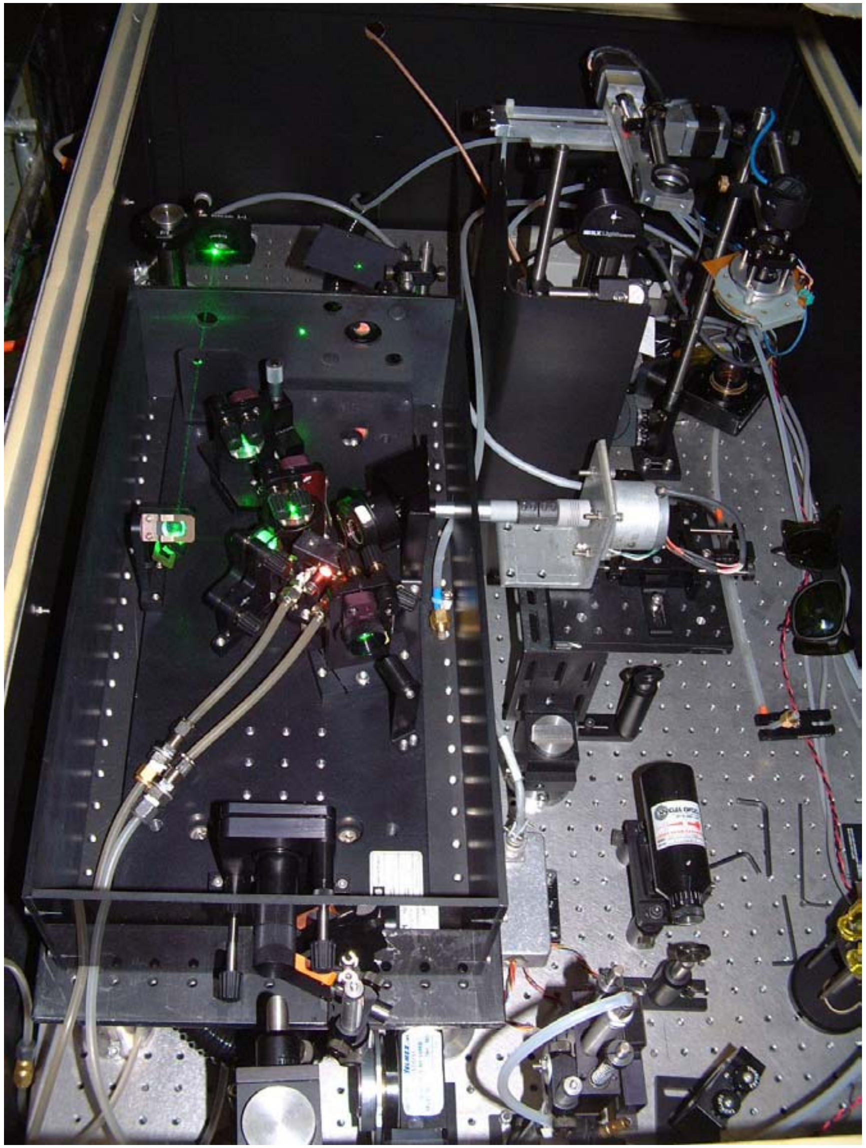
Test gun

- 100 keV DC beam
- Wavelength tunable Ti:Sapp

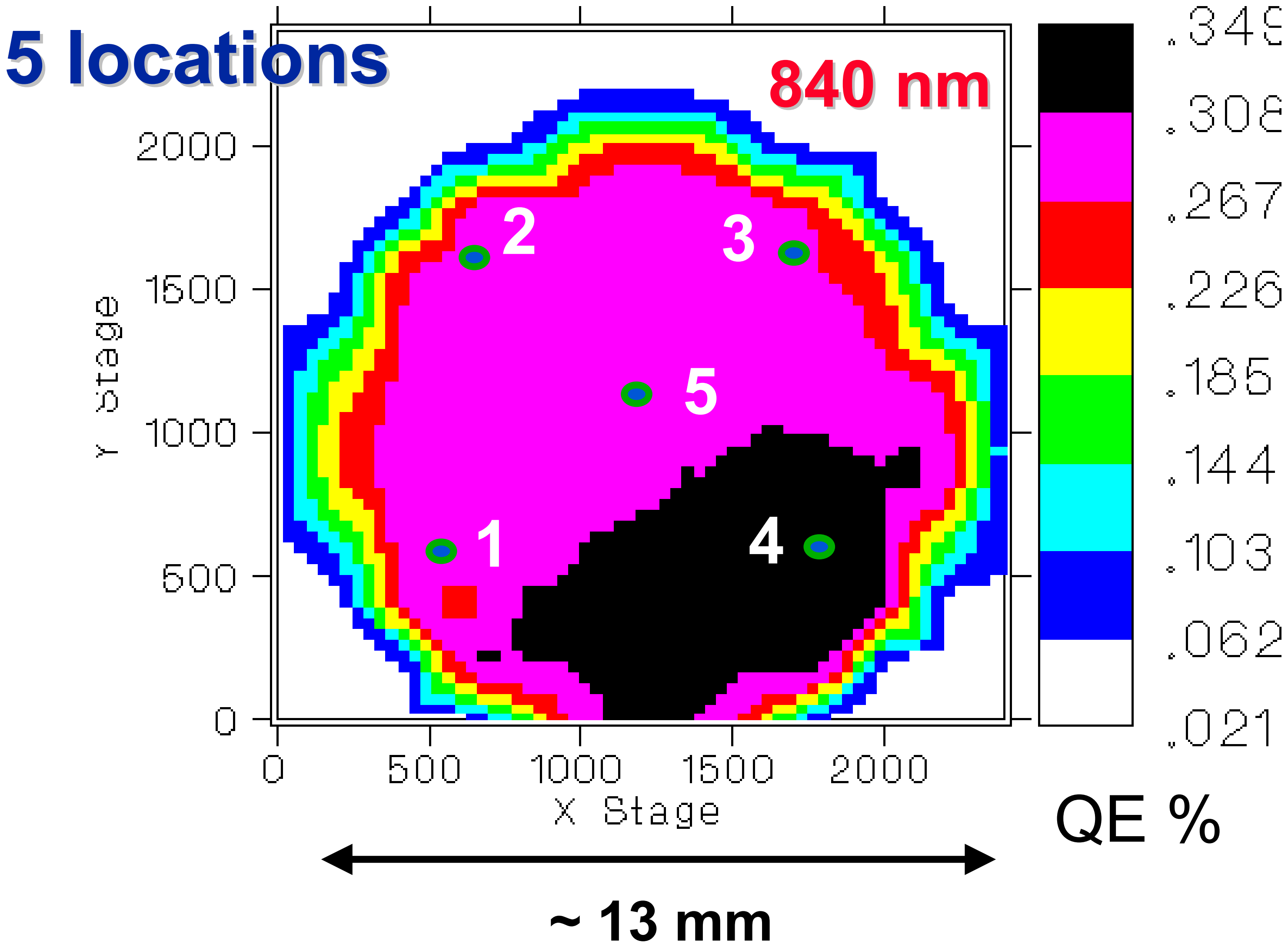
  (750-850 nm)
- 10 Hz helicity reversal
- Mott polarimeter : P_e
- Beam dump : QE



Test gun (cont'd)



QE profile


5 locations
840 nm
2
3
5
1
4
2000
1500
1000
500
0
Y Stage
0
500
1000
1500
2000
X Stage
.349
.308
.267
.226
.185
.144
.103
.062
.021
QE %
~ 13 mm

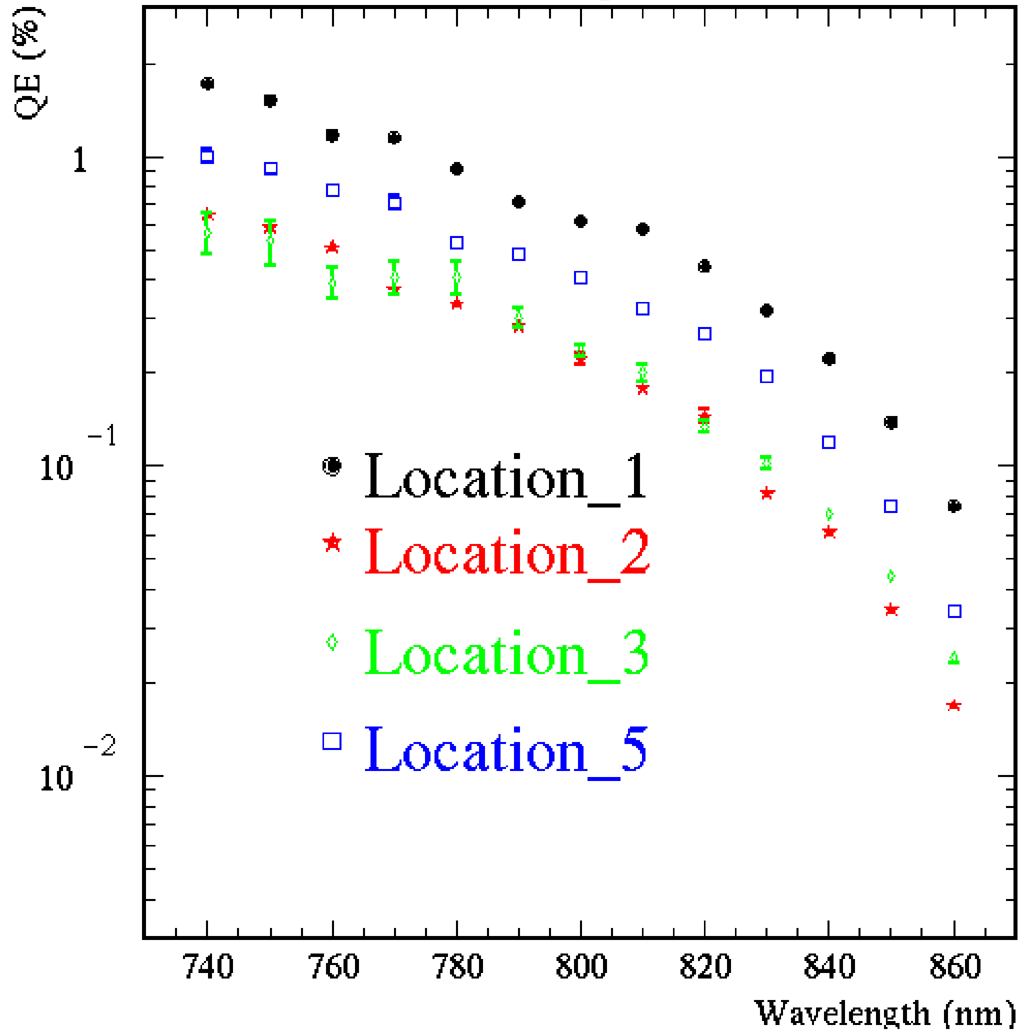
QE vs. wavelength measurements

QE max ~ 1.7%

at 740 nm

w/o any treatment

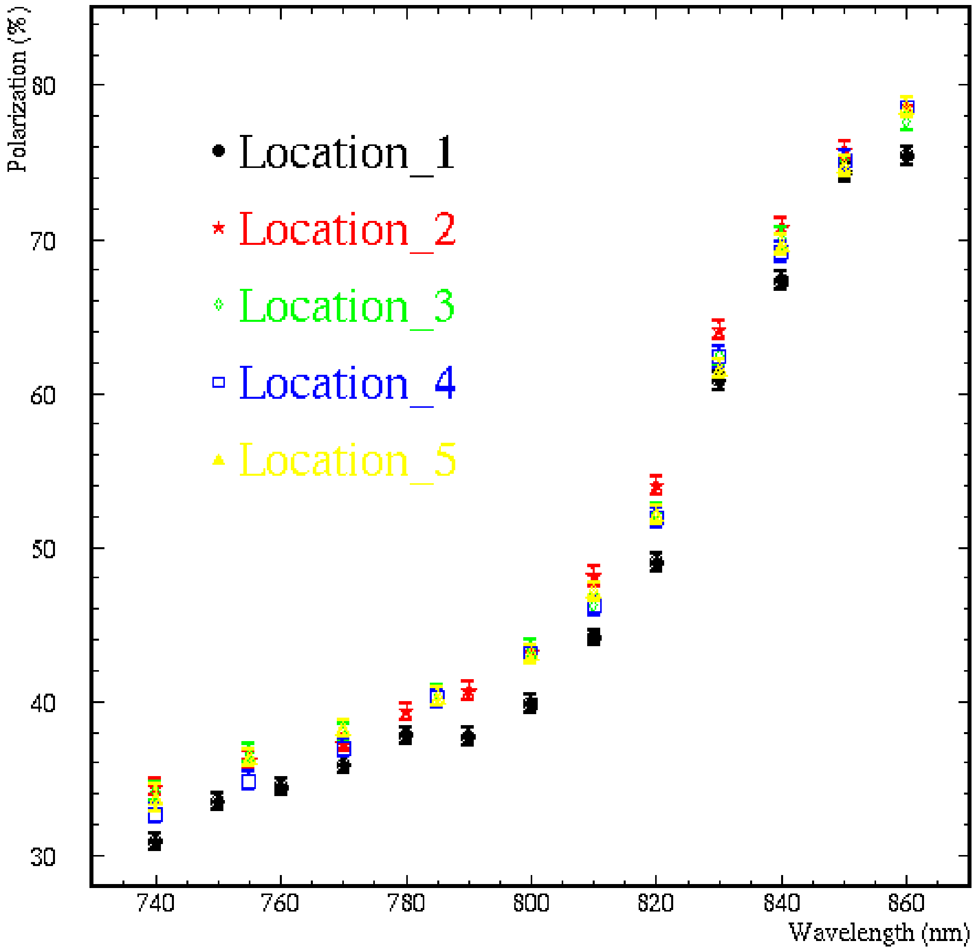
No H exposure



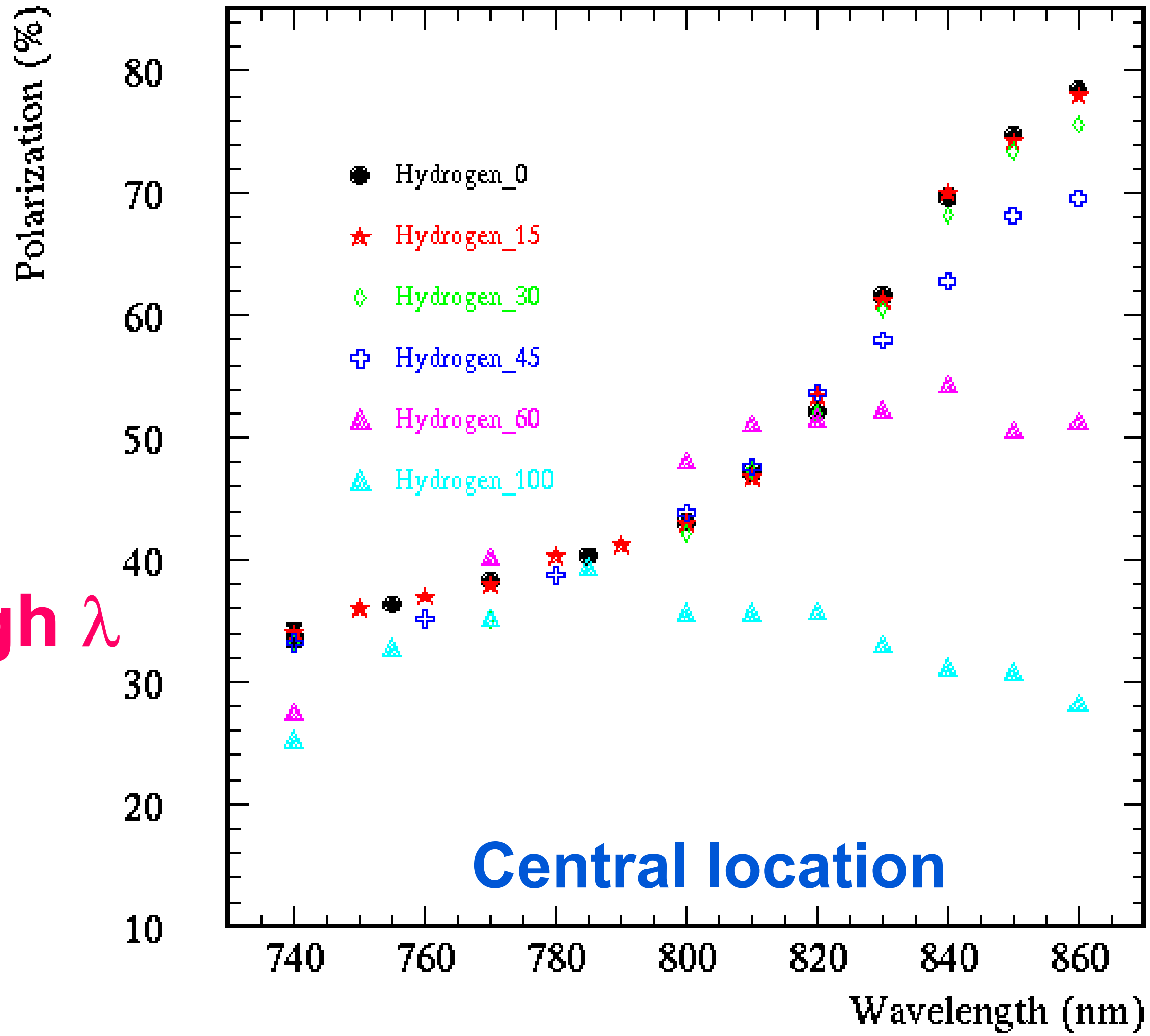
Polarization vs. wavelength measurements

- 100 keV Mott polarimeter
- Stat. error only
- Abs. systematics ~ 5-10%
- P_e^{max} ~ 79% at 860 nm
- Uniform on wafer

No H exposure



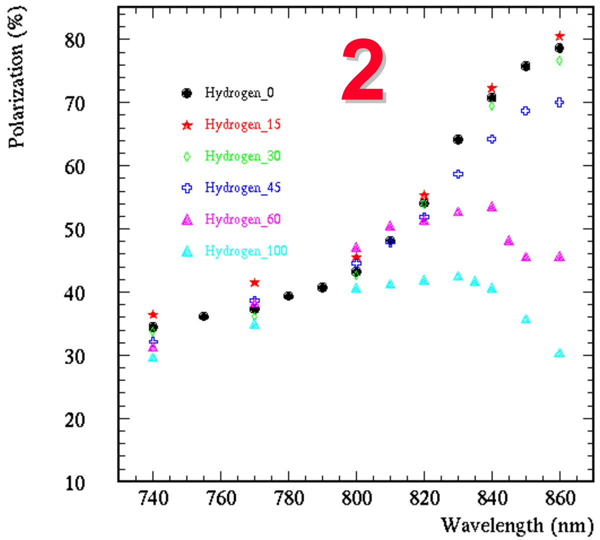
Polarization vs. cumulative H dose
(location 5)

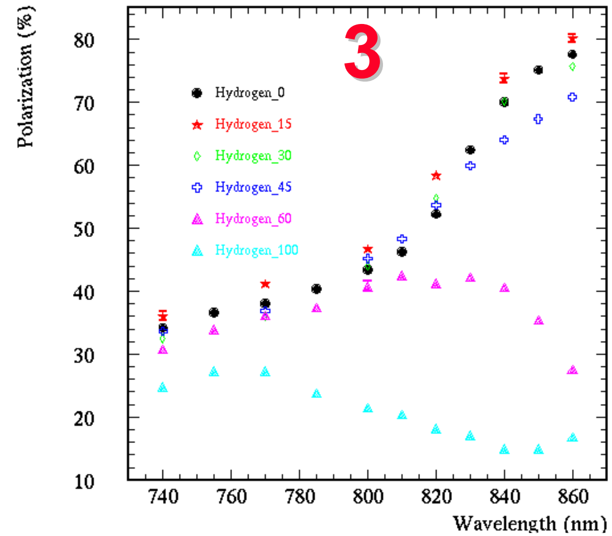


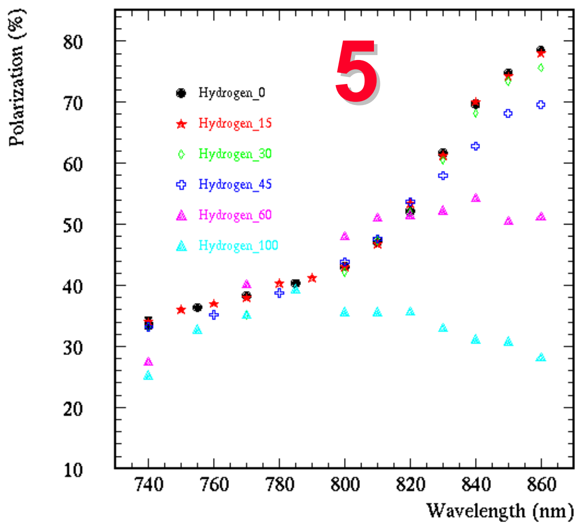
Depolarization:

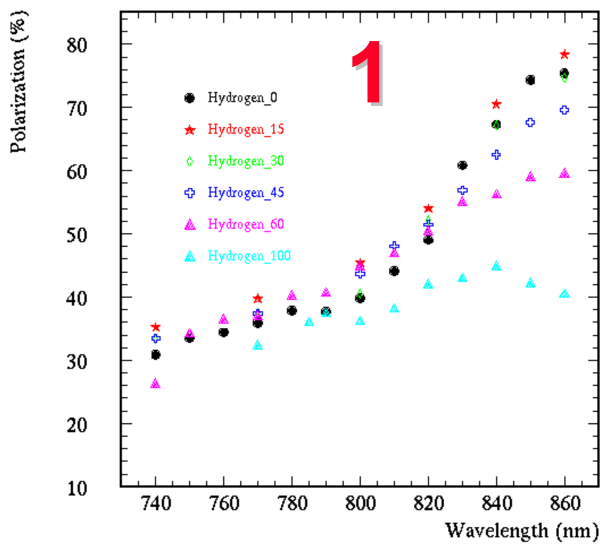
- λ-dependent
- strongest @ high λ

Polarization vs. H across wafer

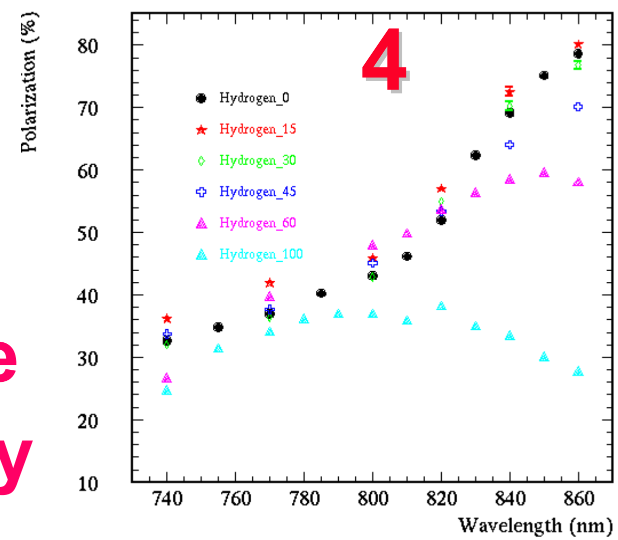




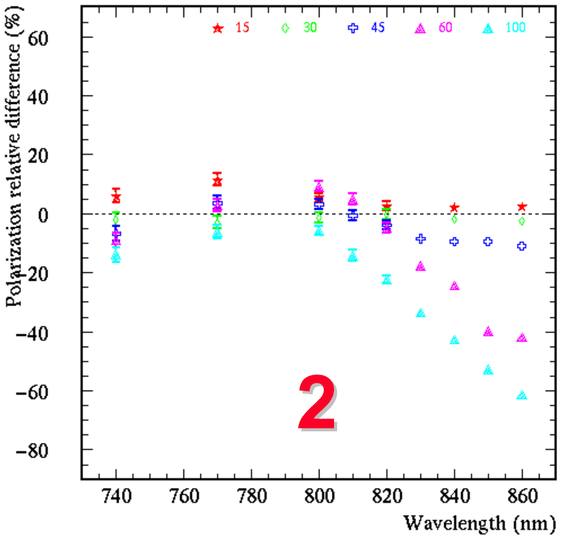


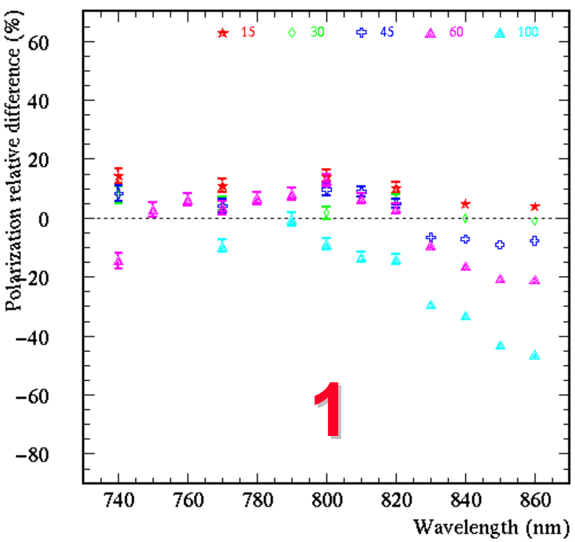


- Low dose
  $\Rightarrow$ light increase
- Non-uniformity

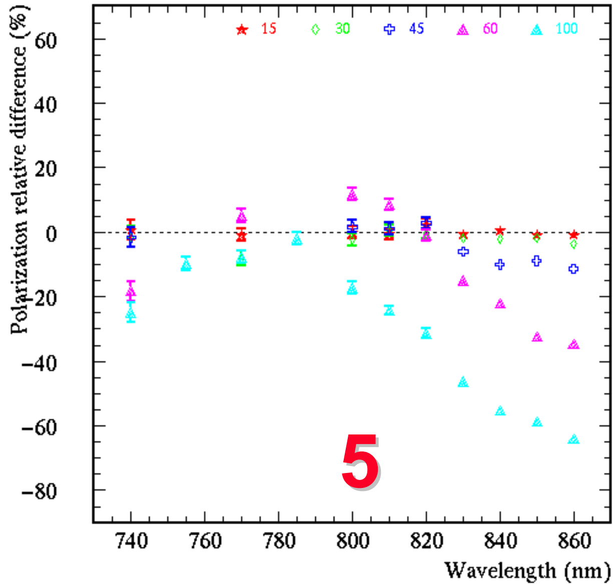


Relative polarization vs. H

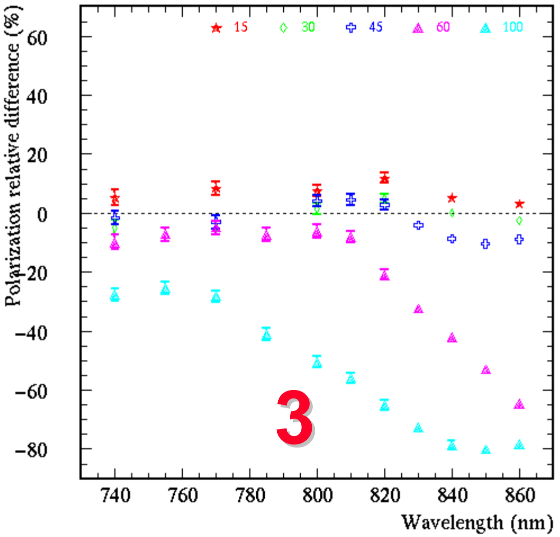


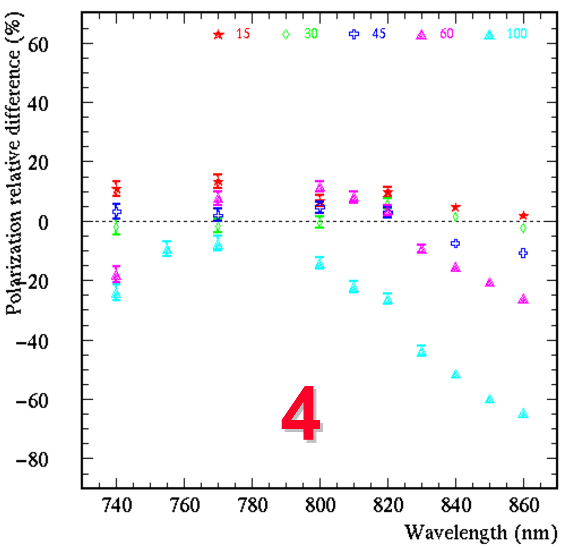


$$\frac{P_e(t) - P_e(0)}{P_e(0)}$$

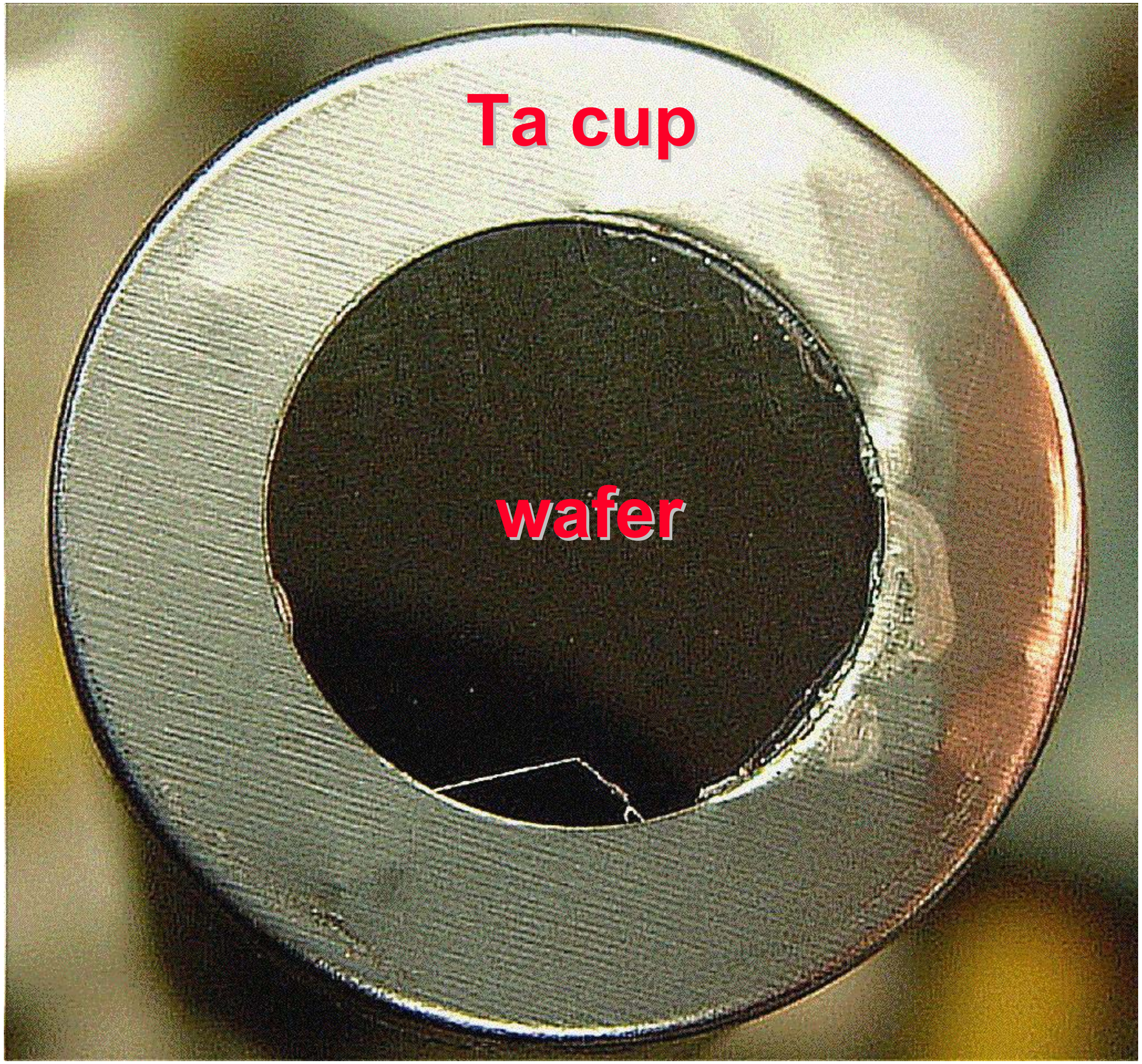


CcI : P goes down at band-gap w/ H exposure

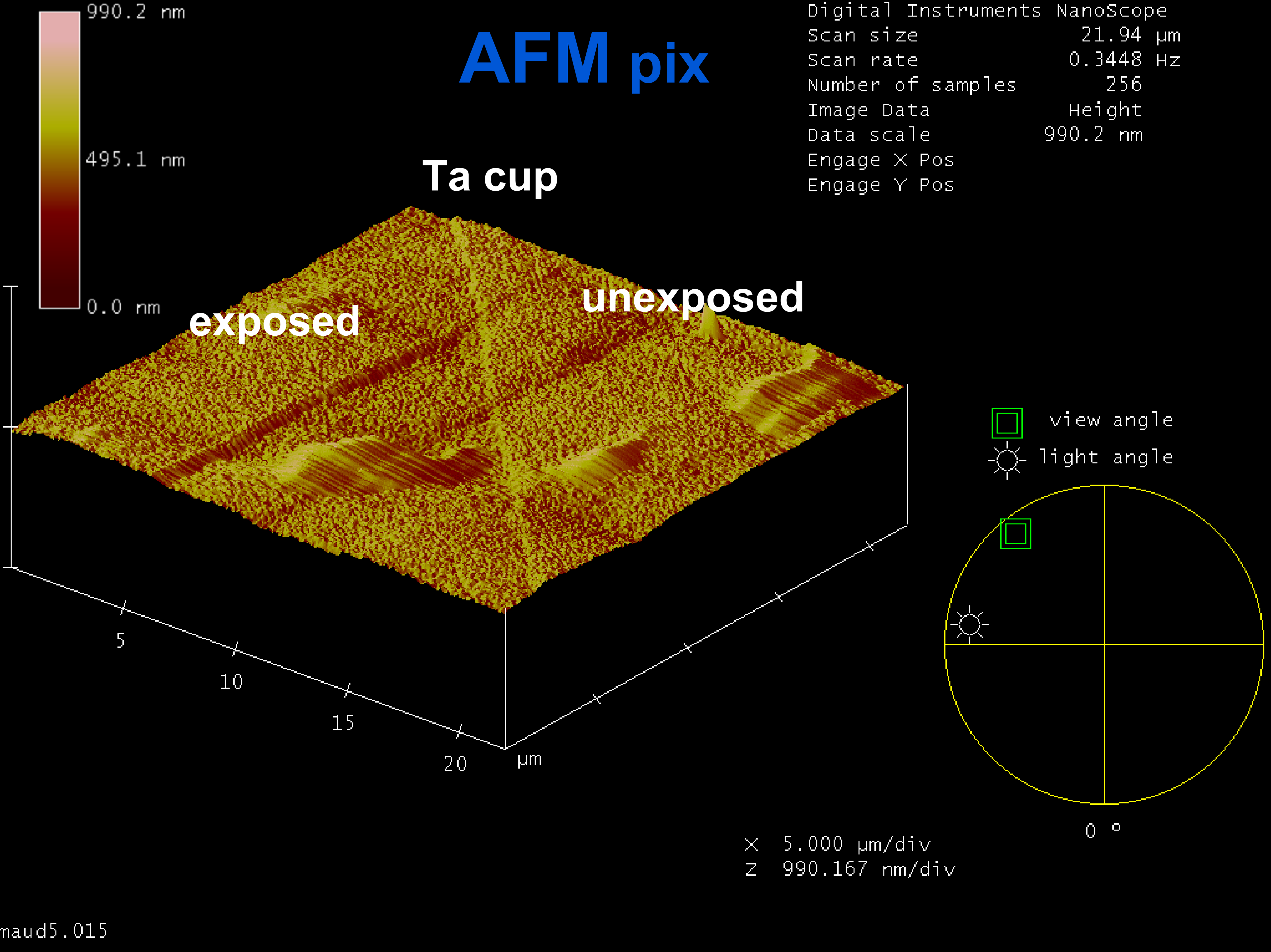




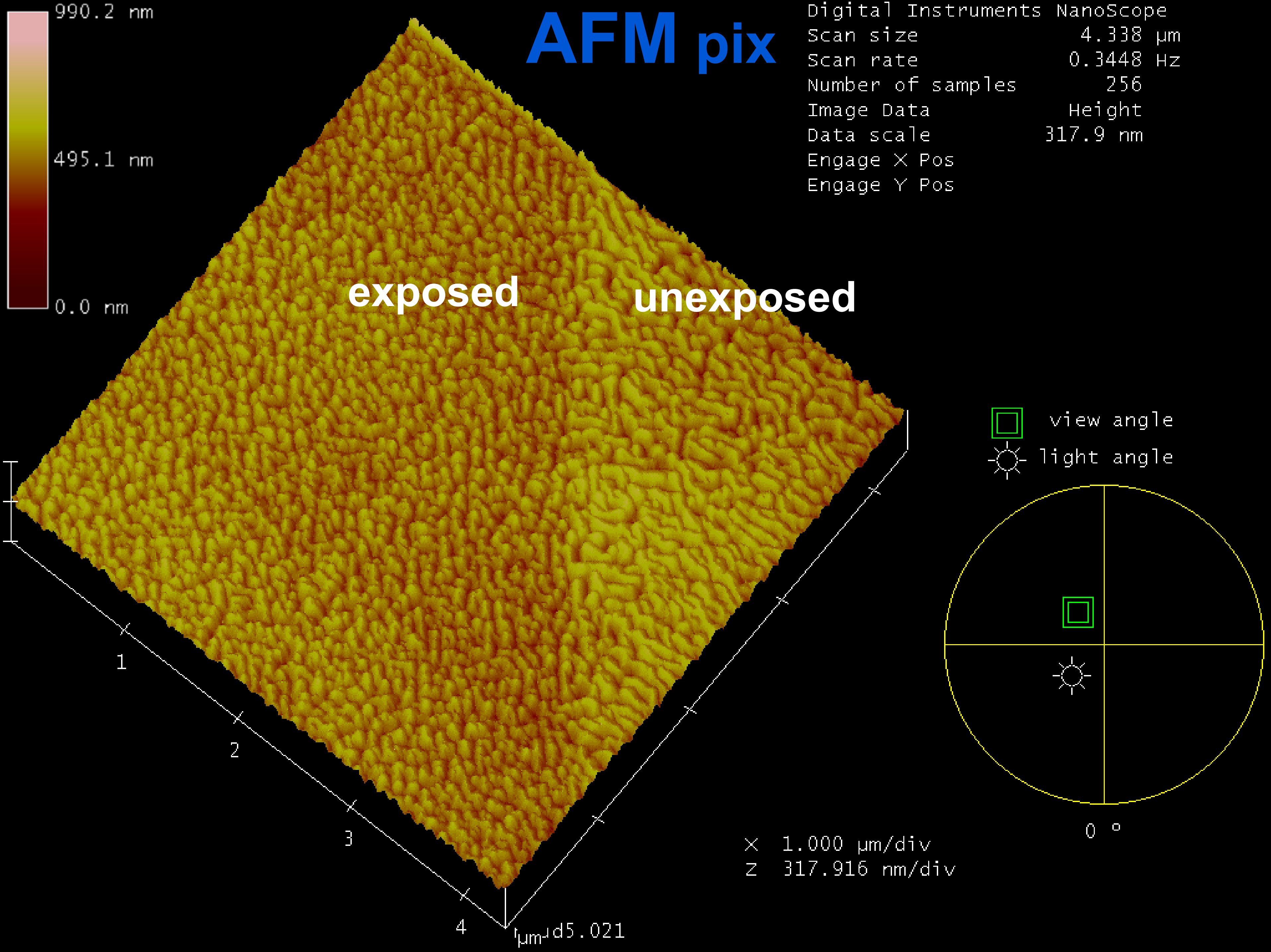
Wafer after H exposure



AFM pix

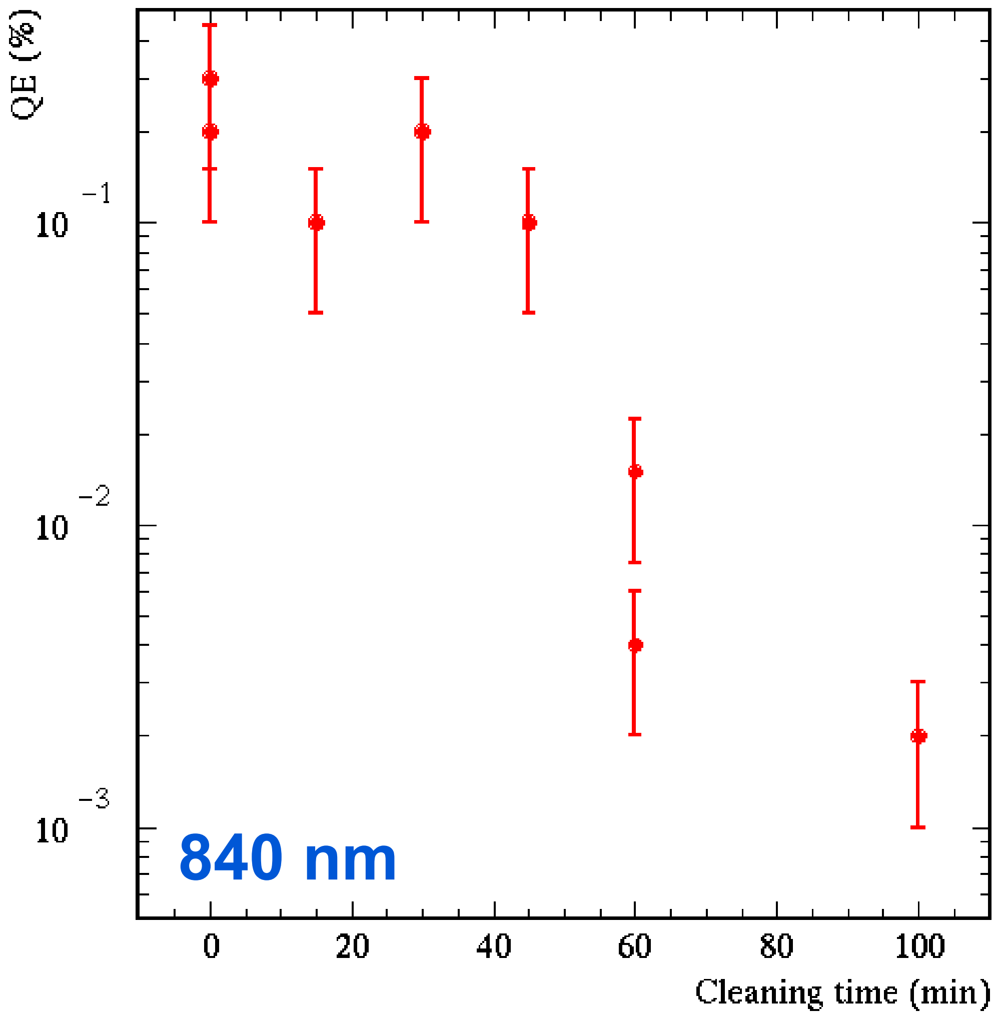


990.2 nm
495.1 nm
0.0 nm
Digital Instruments NanoScope
Scan size 21.94 µm
Scan rate 0.3448 Hz
Number of samples 256
Image Data Height
Data scale 990.2 nm
Engage X Pos
Engage Y Pos
Ta cup
exposed
unexposed
view angle
light angle
5
10
15
20
µm
0 °
X 5.000 µm/div
Z 990.167 nm/div
maud5.015



AFM pix
990.2 nm
495.1 nm
0.0 nm
Digital Instruments NanoScope
Scan size 4.338 µm
Scan rate 0.3448 Hz
Number of samples 256
Image Data Height
Data scale 317.9 nm
Engage X Pos
Engage Y Pos
exposed
unexposed
view angle
light angle
0 °
1
2
3
4
µm
d5.021
X 1.000 µm/div
Z 317.916 nm/div

QE at band-gap vs. Hydrogen exposure

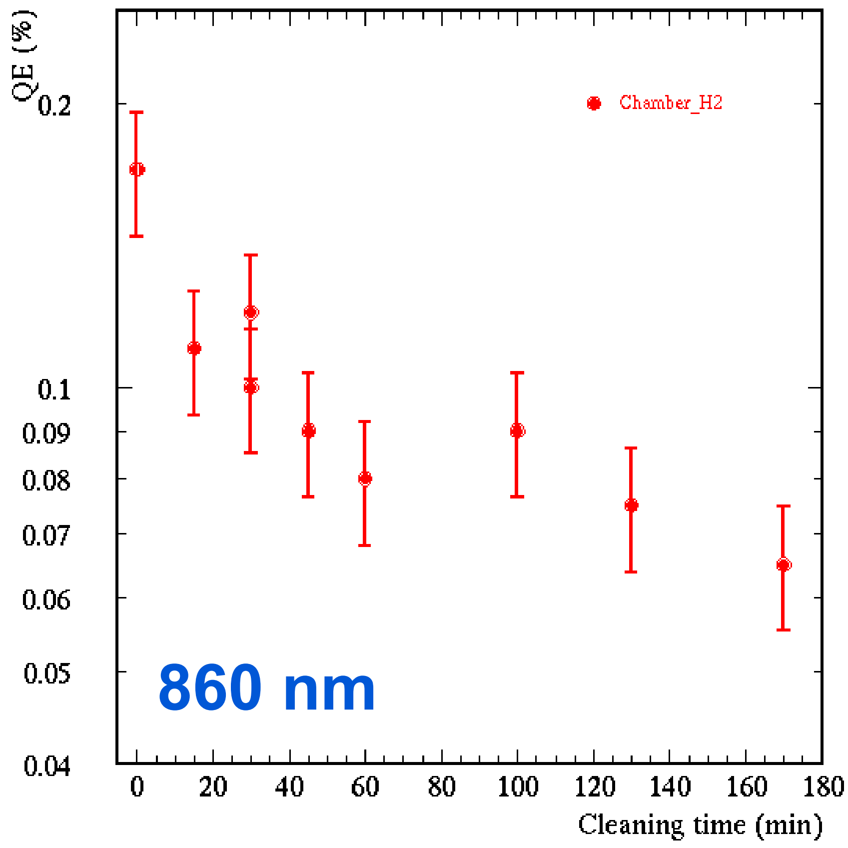


Significant drop in QE vs. H cleaning

Real effect or procedure?

QE drop confirmed

- Repeated tests in another chamber w/o breaking vacuum between hydrogen exposures
- Same trend of decrease of QE measured



Polarization vs. Hydrogen exposure : preliminary results

- **Small dose slightly increases P_e,**

  high dose kills P_e at band-gap

- Below band-gap, effects are not so pronounced

- Surface analysis shows:

  some structure change, but no conclusive observation

- **QE seems to be only lowered by hydrogen dose!!!**

Polarization results

- Real benefit in hydrogen cleaning?
  - H cleaning not as important at JLab anymore
  - Wafers are clean right “out of the box”
  - Eliminated a prep. step which can “dirty” a wafer on path to installation
- Much of the poor performances of early SPIRE wafers at JLab can be attributed to overexposure to H
- Users now get the highest possible P_e :

  all wafers used for production running are H cleaned

  for 15 minutes: **P_e ~ 76 to 78 % (5 MeV Mott)**

What's next?

- Since then:

  install hydrogen dissociator on test gun
  wavelength range broader: 765 to 935 nm
  improve Mott electronics: charge asymmetry (dead time)

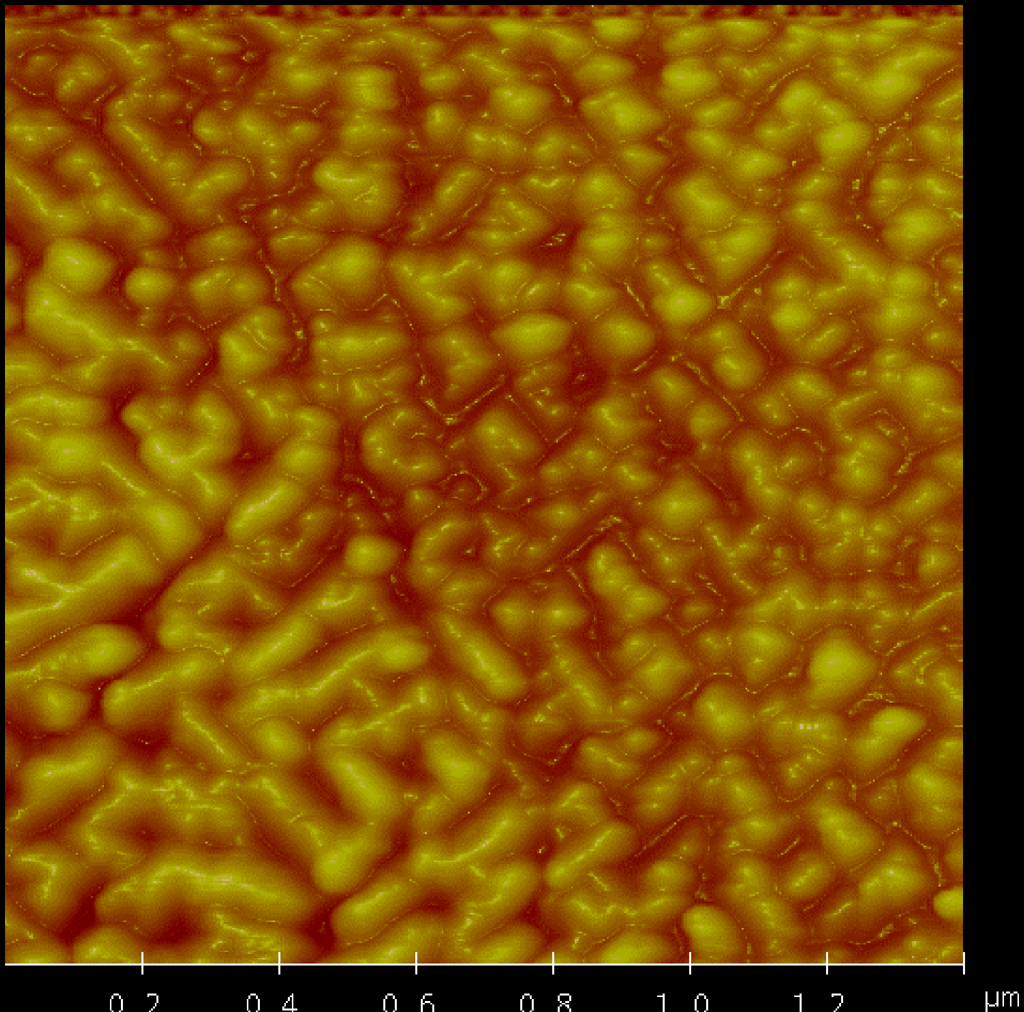
- Study continues:

  repeat with strained wafer: verify data
  study bulk GaAs wafer: surface effect or something associated w/ strained layer
  check QE, P_e vs. heat clean only: artifact of procedure?
  Hydrogen source geometry dependent?
  model effect: collaborators welcome

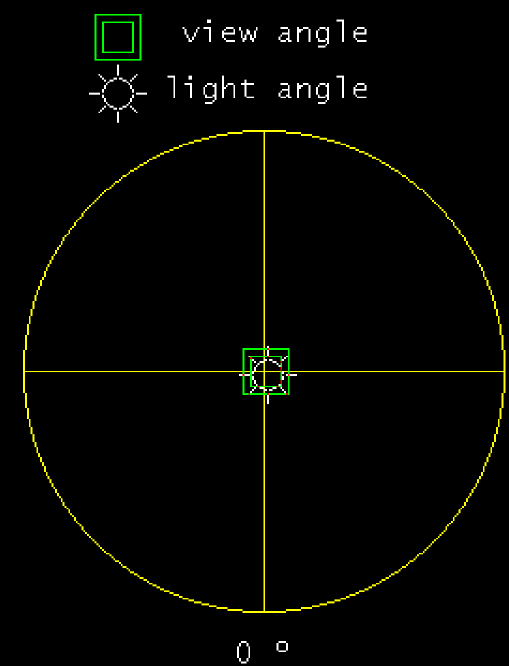
⇒ goal : $P_e \gtrsim 85$ %

AFM pix

Digital Instruments NanoScope	
Scan size	1.392 µm
Scan rate	0.3448 Hz
Number of samples	256
Image Data	Height
Data scale	1.013 um
Engage X Pos	
Engage Y Pos	



X 0.200 µm/div



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