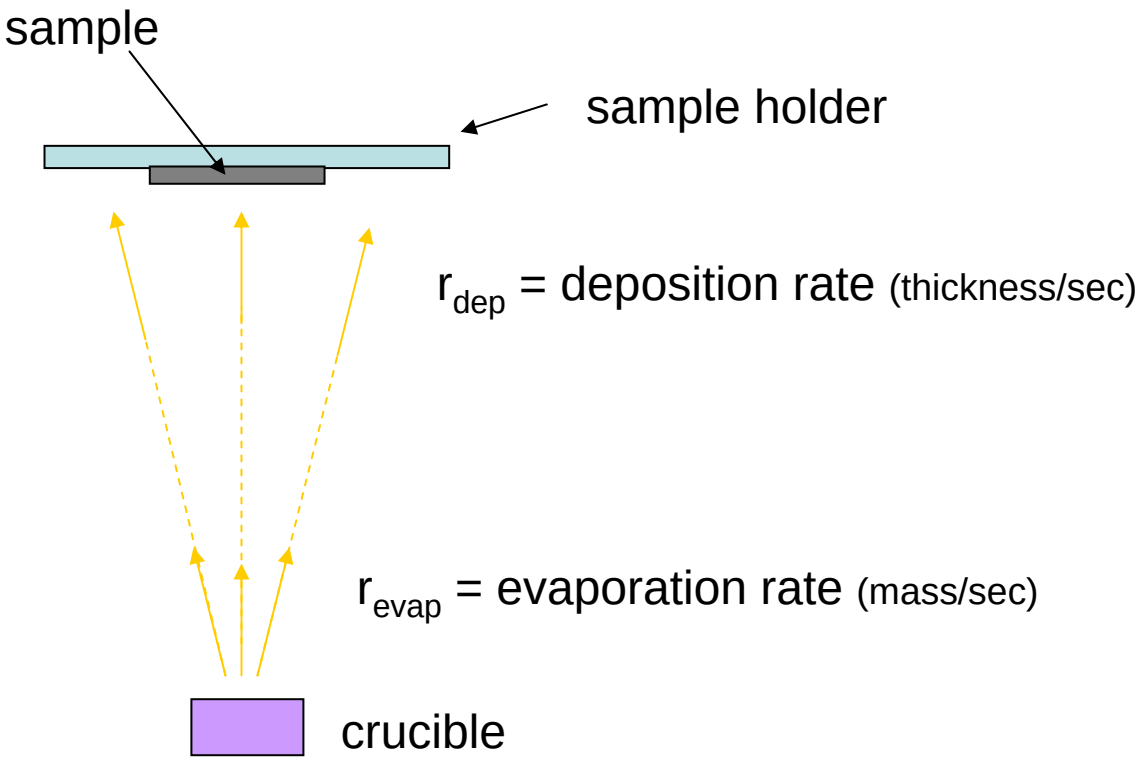
some things to think about when doing evaporation liftoff of nanometer scale patterns

1/30/09

review fundamentals


sample
sample holder
r_{dep} = deposition rate (thickness/sec)
r_{evap} = evaporation rate (mass/sec)
crucible

Evaporation Rate

$$r_{evap} = \sqrt{\frac{M}{2\pi kT}} P_e$$

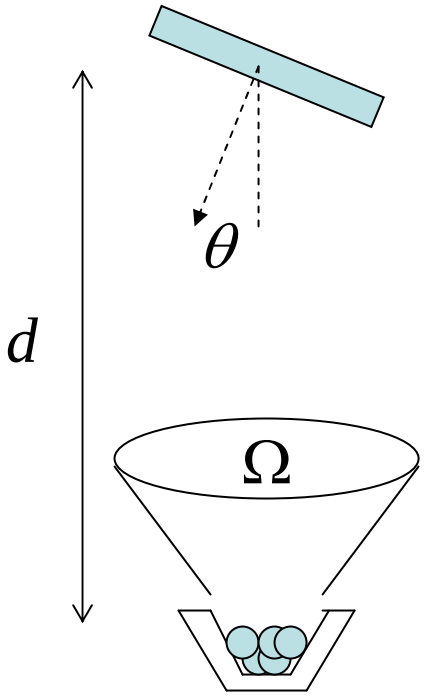
r_{evap} = evaporation rate
M = atomic mass
k = Boltzman's constant
T = temperature
P_e = vapor pressure

Deposition Rate

- deposition rate depends on the location and orientation of the wafer in the chamber

Deposition Rate

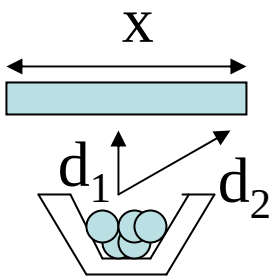
$$r_{dep} = \frac{r_{evap}}{\Omega d^2 \rho} \cos\theta$$



r_{dep} = deposition rate (thickness/sec)
r_{evap} = evaporation rate (mass/sec)
Ω = solid angle over which source emits (unit less steradians)
d = source to substrate distance
ρ = material density
θ = inclination of substrate away from direction to source

Uniformity

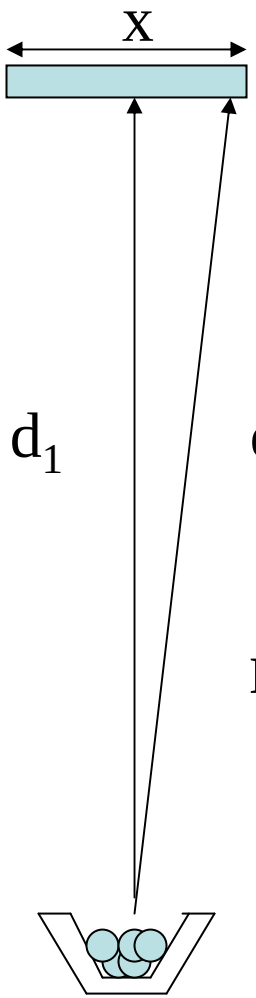
Case 1: d ≤ x



$d_1 < d_2$

$r_{dep}(d_1) > r_{dep}(d_2)$

Case 2: d >> x



$d_1 \approx d_2$

$r_{dep}(d_1) \approx r_{dep}(d_2)$

$$\Delta r_{dep} = \frac{1}{(\Delta d)^2}$$

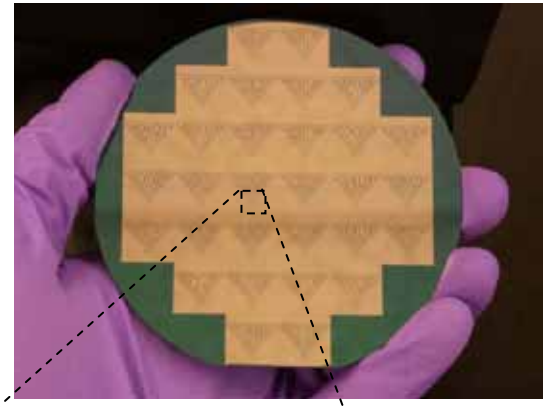
if $\Delta d = 2$, then $\Delta r_{dep} = \frac{1}{4}$

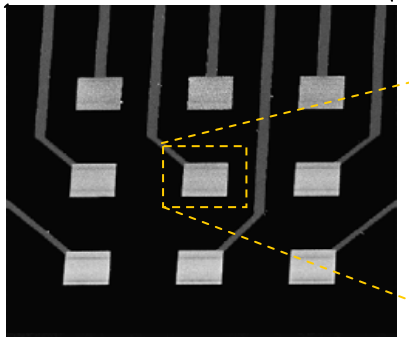
example

Detecting DNA with Carbon Nanotube Arrays

Prabhu Arumugam, NASA Ames Research Center
Devin Brown, Georgia Tech Nanotechnology Research Center
Bruce Gale, University of Utah
Neil Gordon, Early Warning Inc.

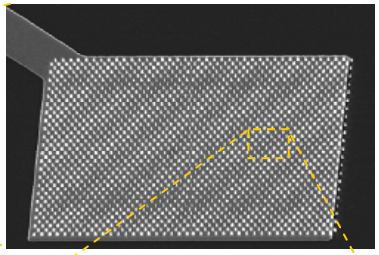
Below is a 4 inch wafer with 30 chips.

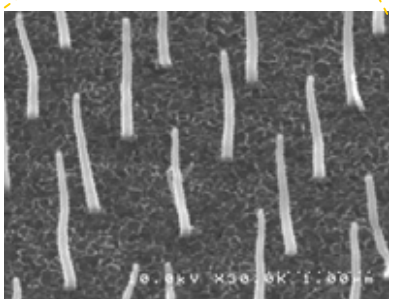




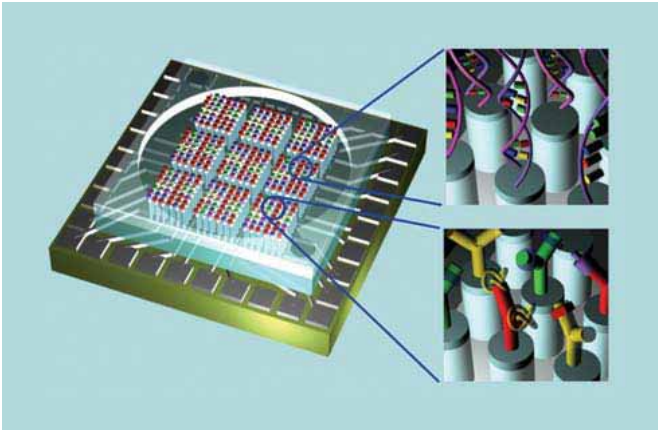
Each chip has a 3 x 3 array of 200 micron pads shown above.

Each pad has 100nm nickel dots spaced at 1 micron, shown below.





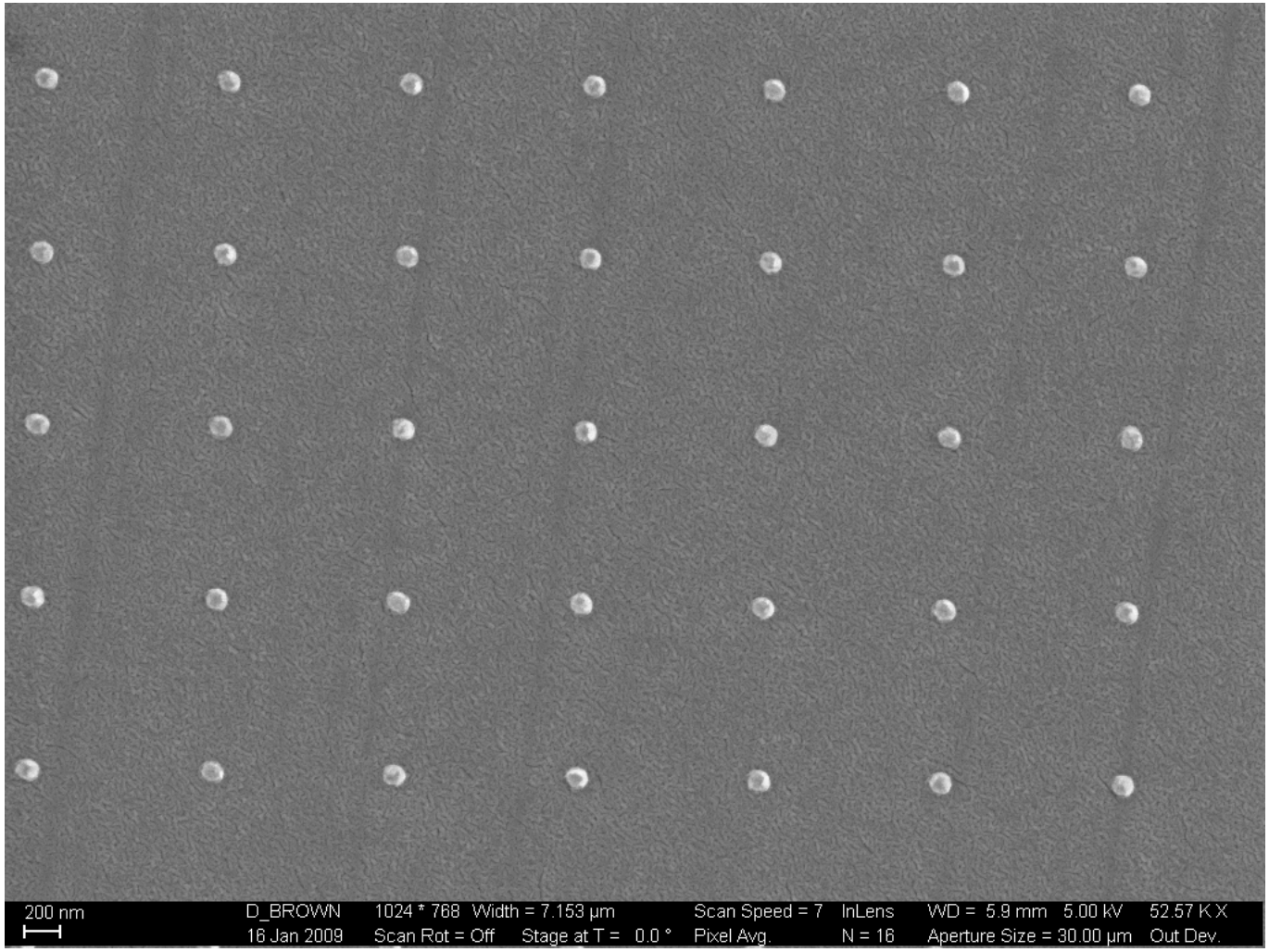
Multi-walled carbon nanotubes are grown on each nickel dot.



At left is an artist's conception of an ultrasensitive multiplex electronics biosensor based on a carbon nanotube nanoelectrode array. The insets on the right represent applications in DNA (top) and antigen detection (bottom).

Carbon nanotubes offer a wide electrochemical window, flexible surface chemistry, and biocompatibility. By placing a thousand nanotube probes in the space of one of today's metal electrodes, DNA sequences can be detected from less than a thousand strands. This is sensitive enough to directly measure mRNAs in a drop of blood or a piece of tiny tissue sample. It matches the upper limit of sensitivity of conventional laser-based fluorescence techniques, but doesn't require time-consuming sample preparation and expensive and bulky analytical equipment.

Carbon nanotube catalyst pattern
130nm diameter on 1um pitch
100A Cr + 300A Ni

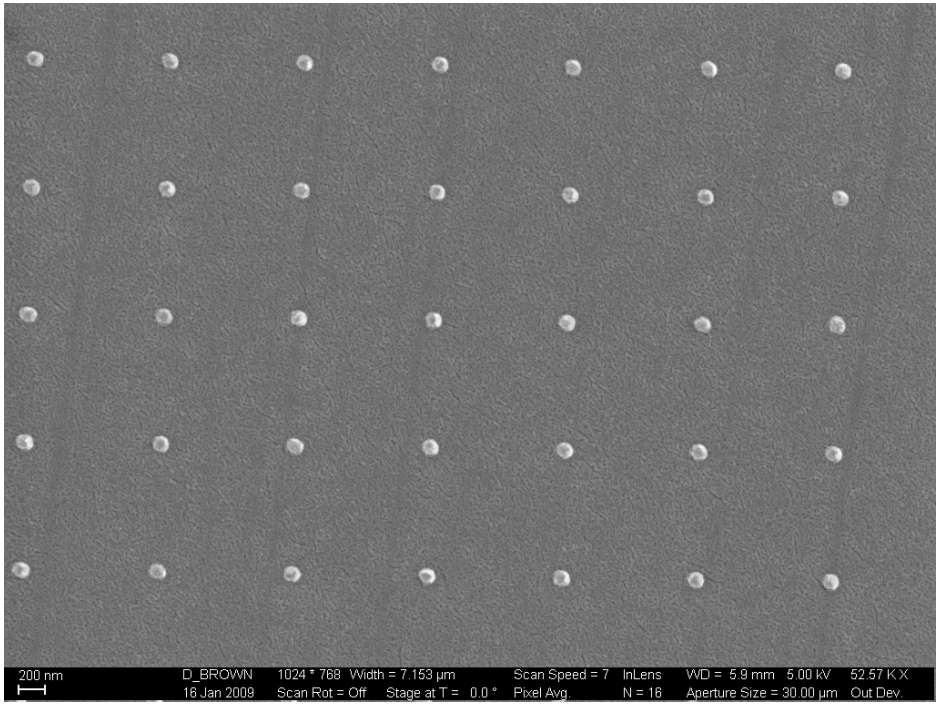


Process Flow

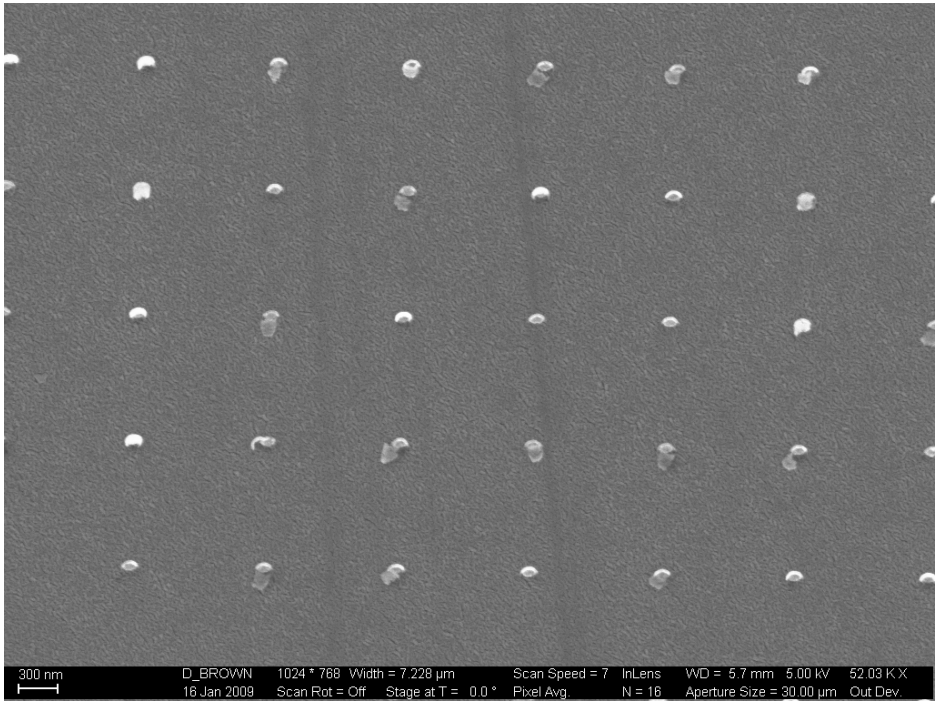
step	description	equipment
1	spincoat PMMA A4 at 2000RPM, 1000RPM/s, 60sec	CEE Brewer 100CB spincoater
2	hotplate bake 180C, 90sec	CEE Brewer 100CB spincoater
3	resist thickness measurement	Woolam ellipsometer (180nm), Tencor P15 profilometer (230nm)
3	EBL expose requires prealignment 100kV, 2nA, 1950uC/cm2, shot pitch = 4nm	JEOL JBX-9300FS EBL system
4	develop 1:1 MIBK:IPA 2min immersion, IPA immersion 30sec	wet bench
5	optical microscope inspection	Leitz Ergolux
6	e-beam evaporate 10nm Cr @ 1A/s, 30nm Ni @ 2A/s	CVC E-beam evaporator
7	acetone liftoff (2 to 3 hrs)	wet bench
8	SEM inspection (Hitachi full die inspection)	Zeiss Ultra 60 FESEM, or Hitachi 3500 Thermionic SEM

Problem

want this

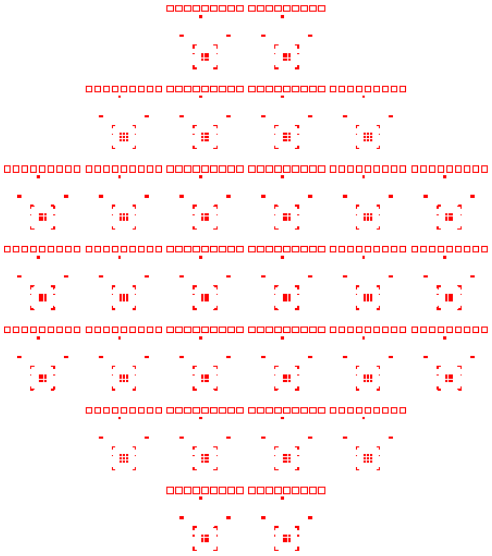


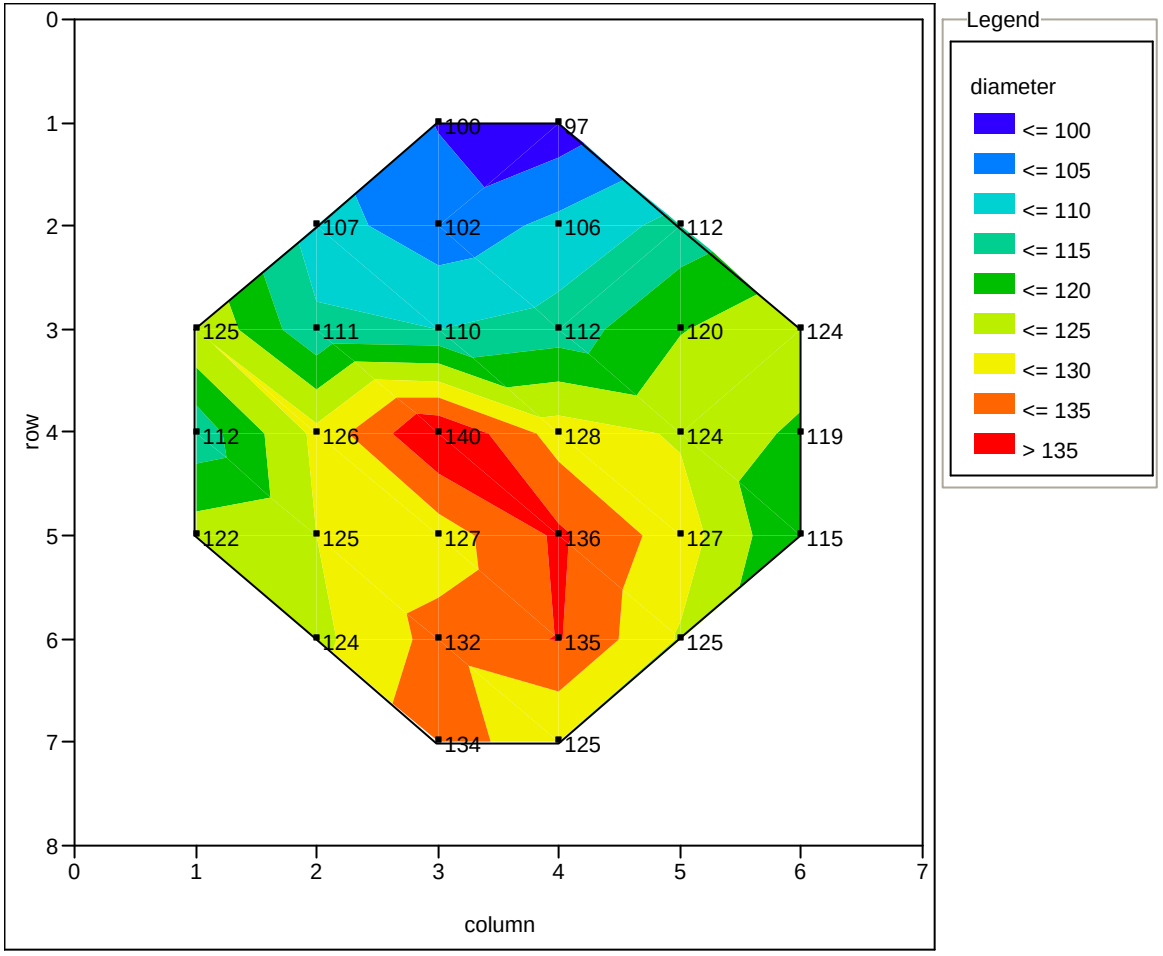
but often get this



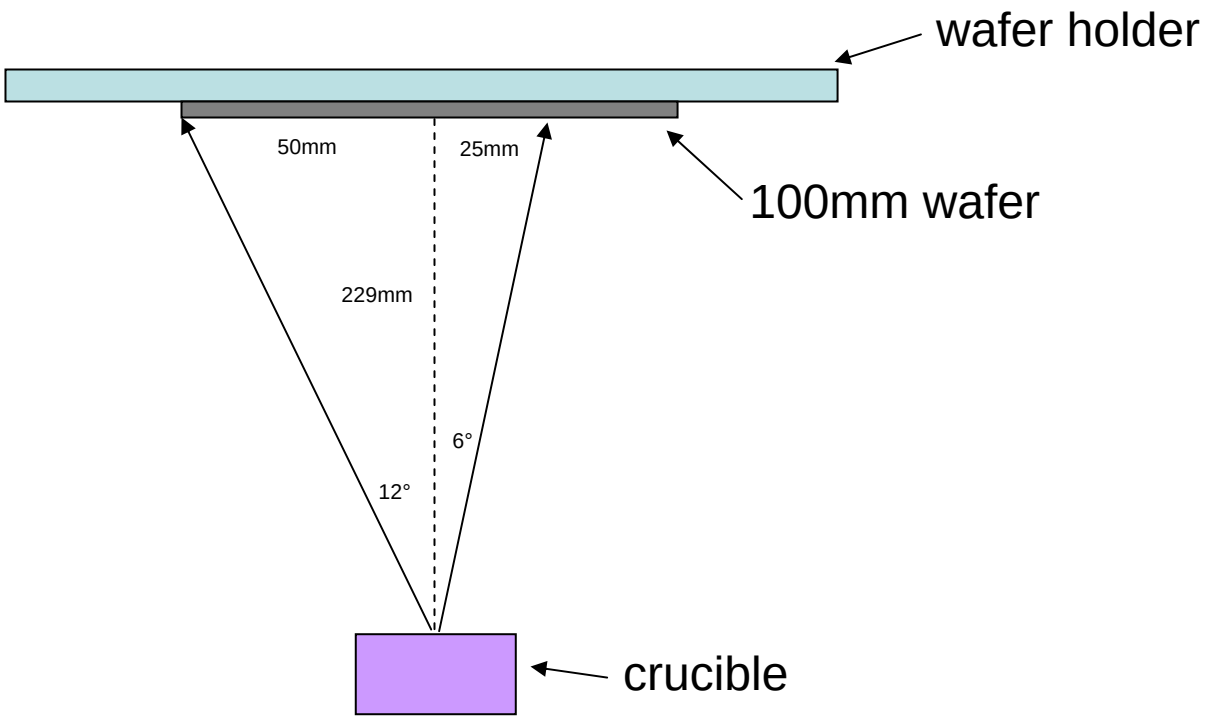
nanodot diameters for uu27 / slot 8

all die measured

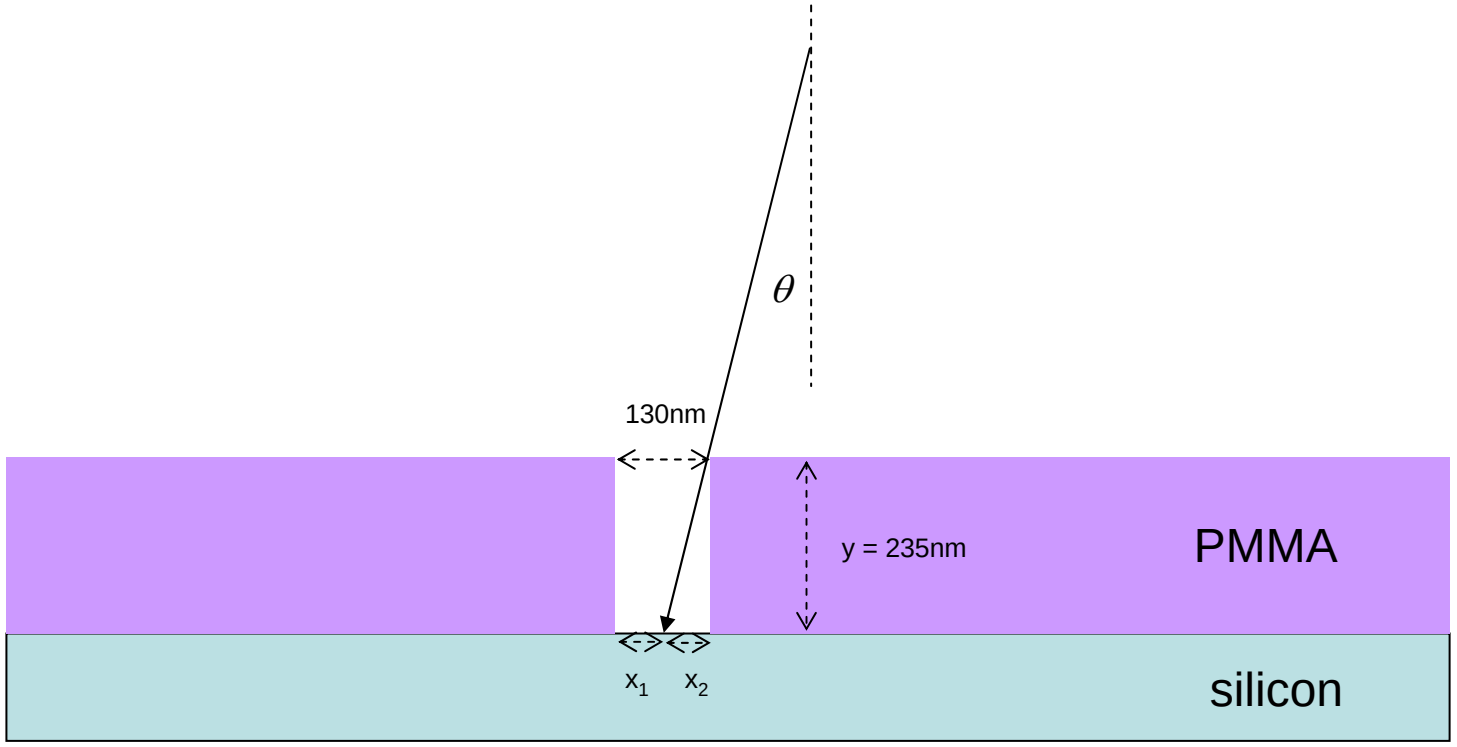




evaporator geometry



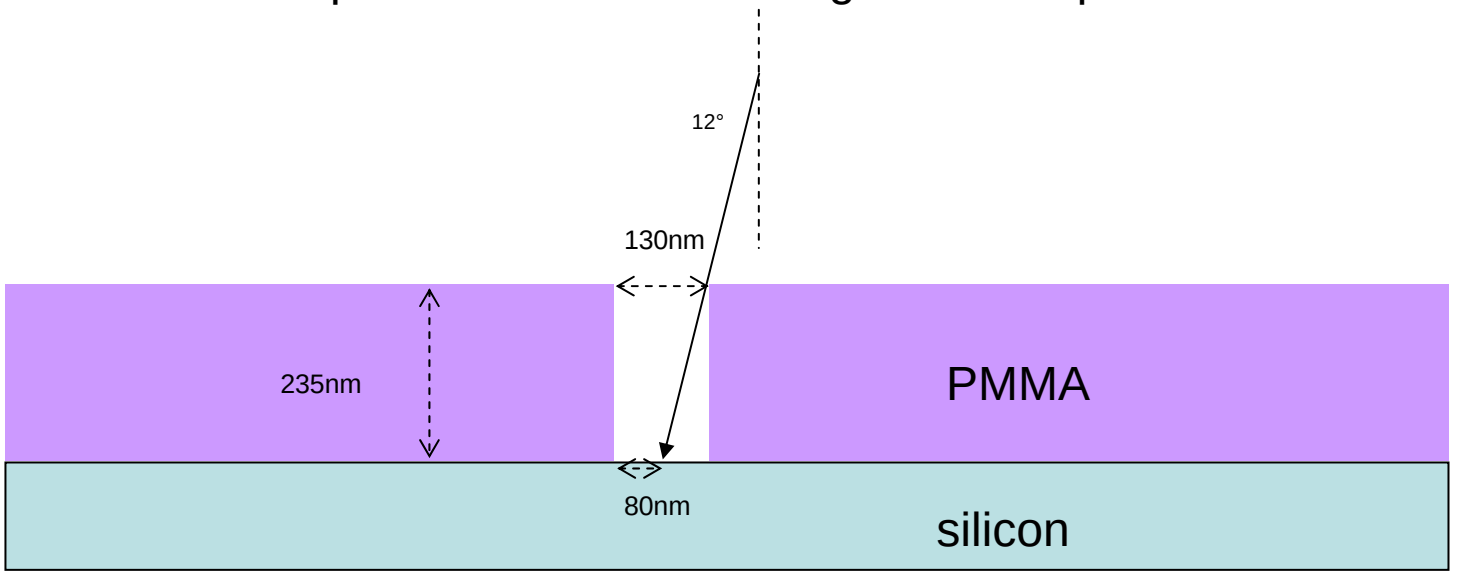
wafer point of view to incoming metal evaporation



$$\tan\theta = \frac{x_2}{y}$$

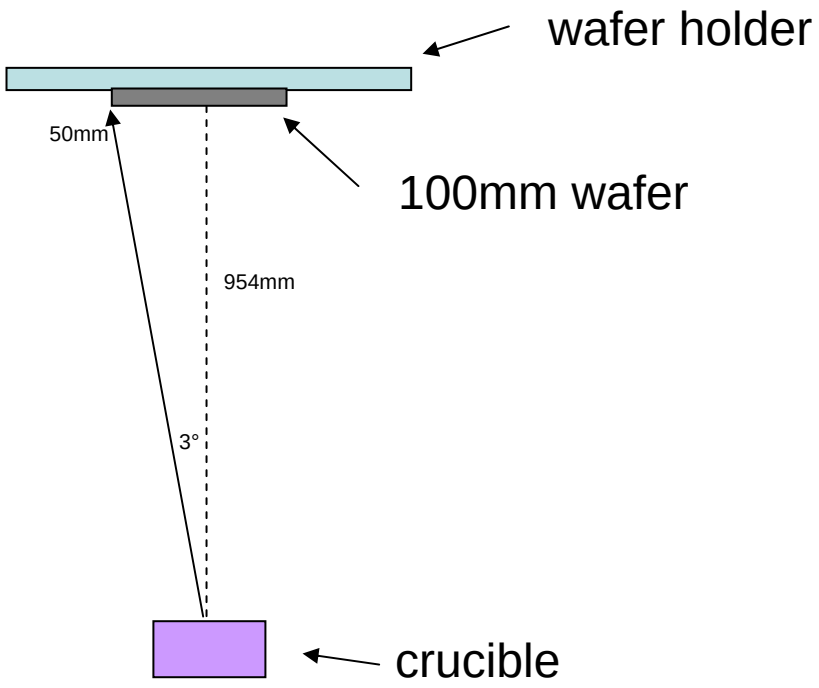
$$x_2 = \tan\theta \times y$$

wafer point of view to incoming metal evaporation



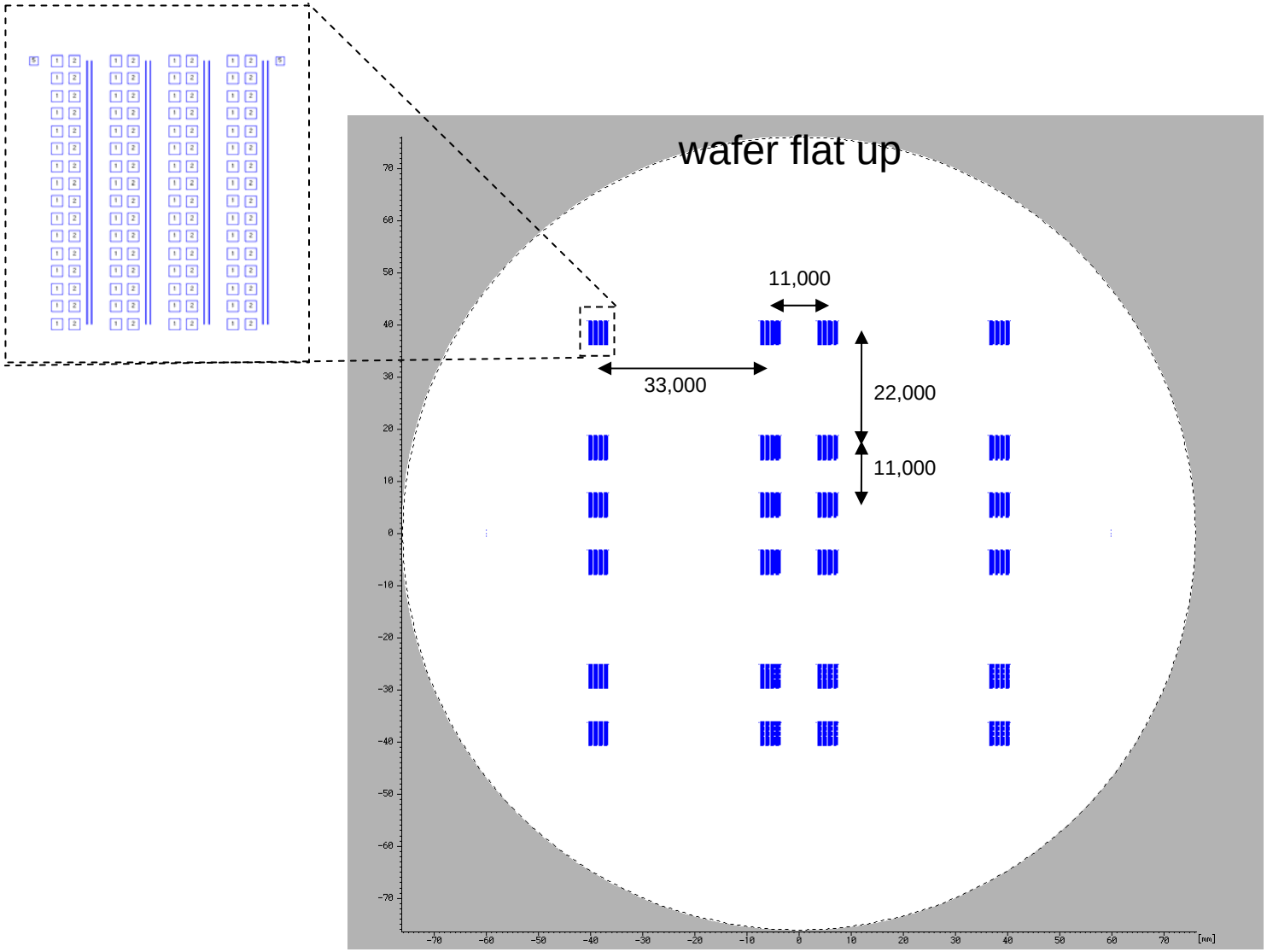
angle (degrees)	nanodot size (nm)	top down shape	side view shape
0	130		
1	128		
3	123		
6	116		
9	109		
12	80		

effect of increasing sample distance from crucible

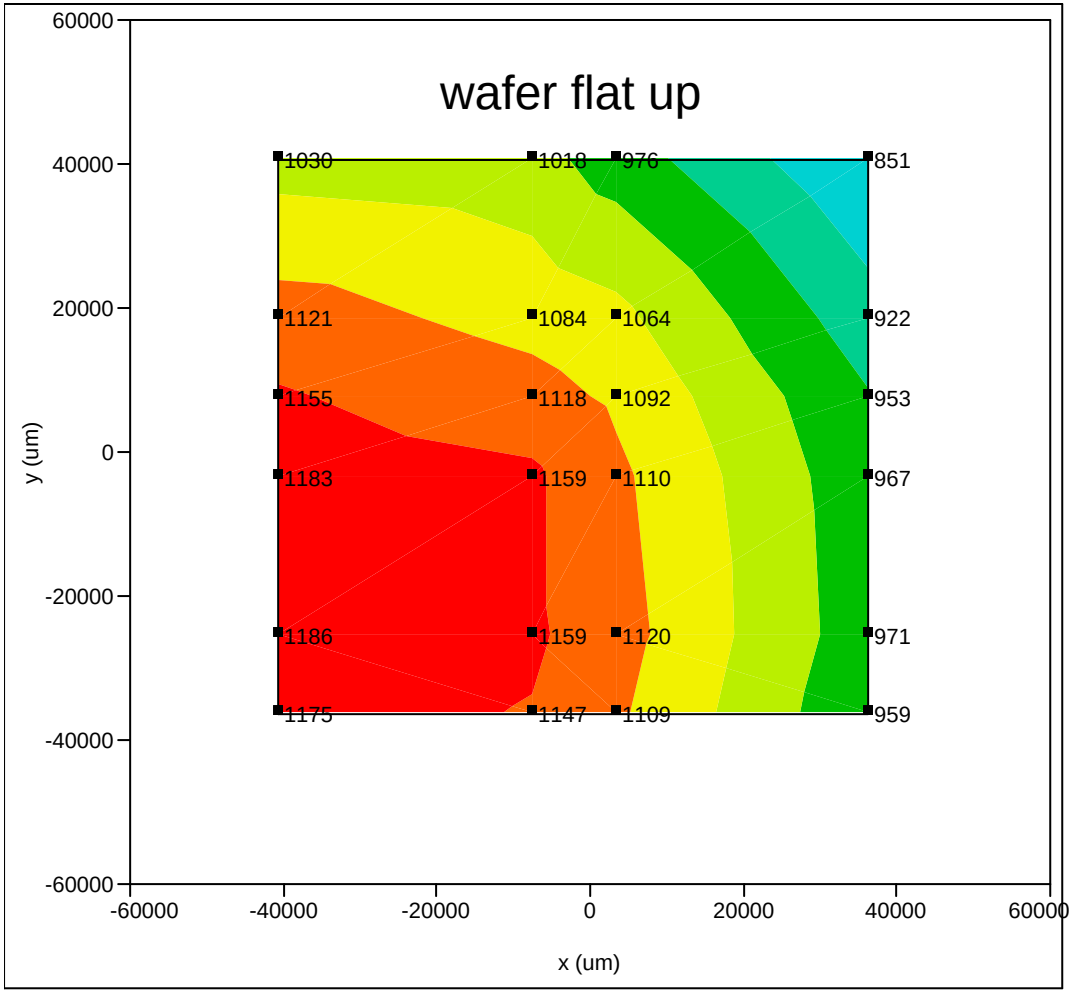


in order to limit incoming angle to 3 degrees or less across entire wafer, the sample would have to be placed almost 1m away from crucible, however this would decrease evaporation rate by 1/16.

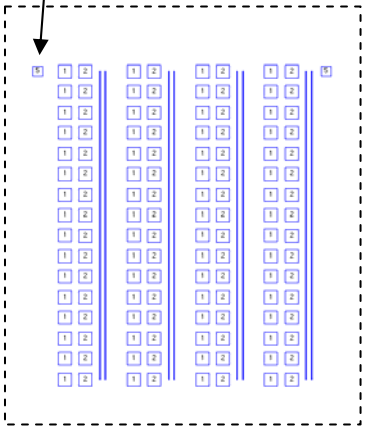
6” wafer



Cr + Ni thickness

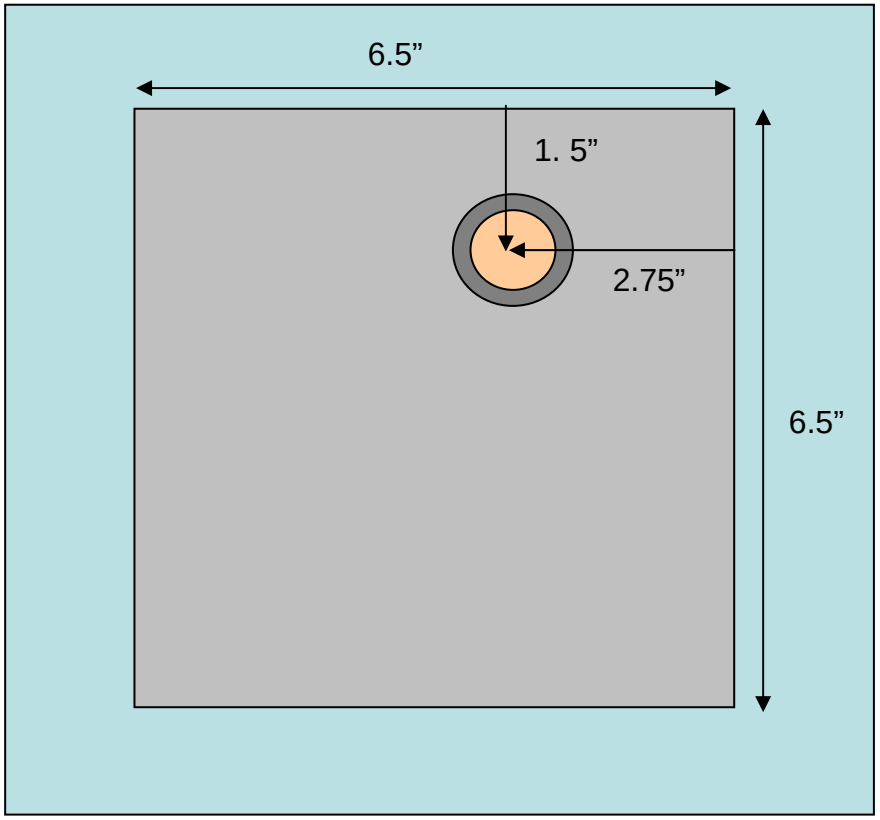


Cr+Ni thickness measured on this mark of each chip



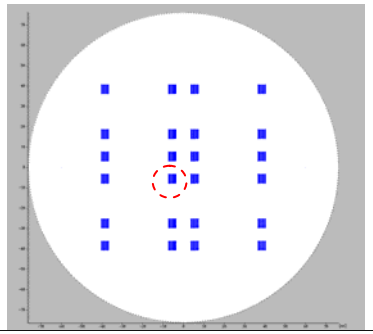
measured by contact profilometry on the left alignment mark for each chip

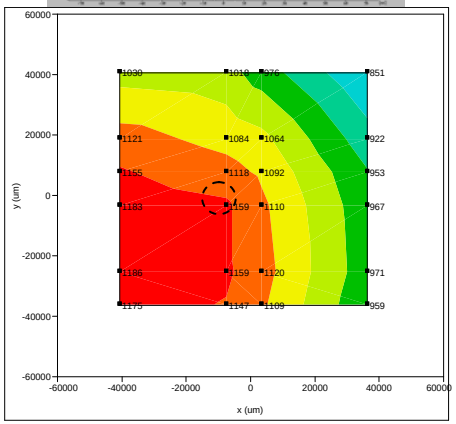
CVC1 evaporator

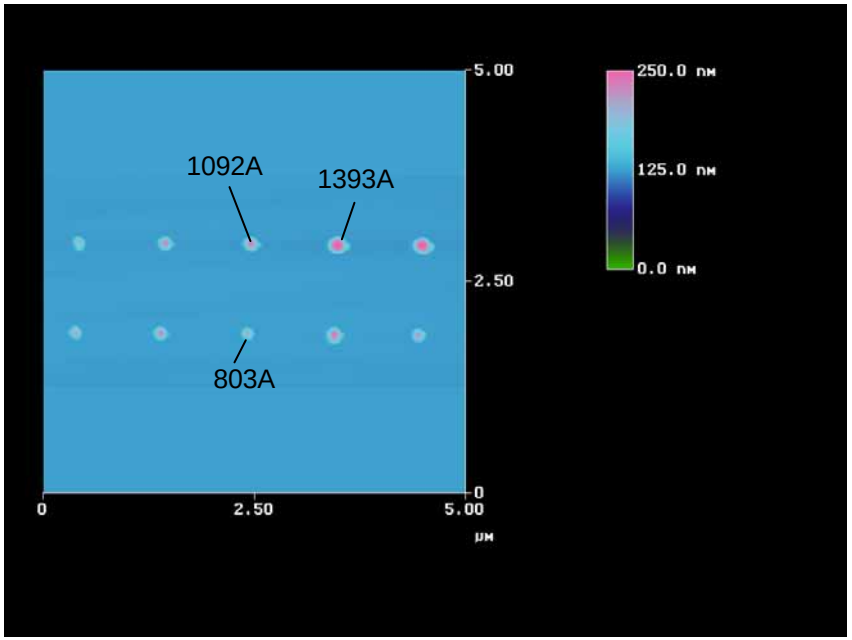


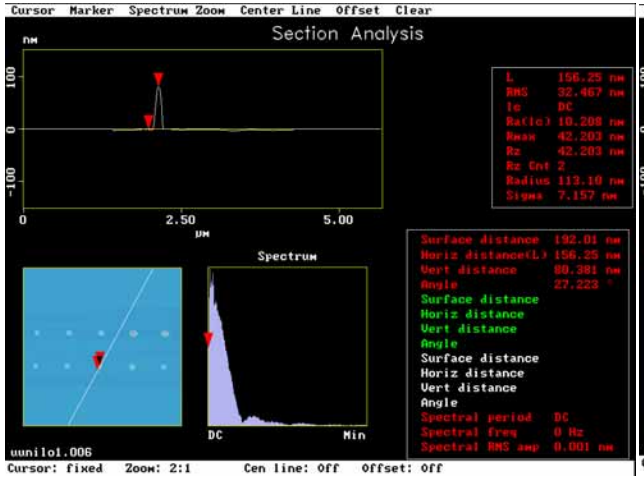
crucible not centered relative to sample holder

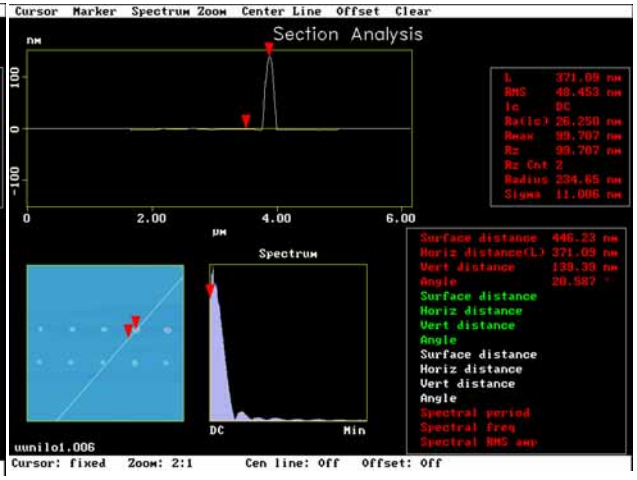
AFM measurement of nanodots

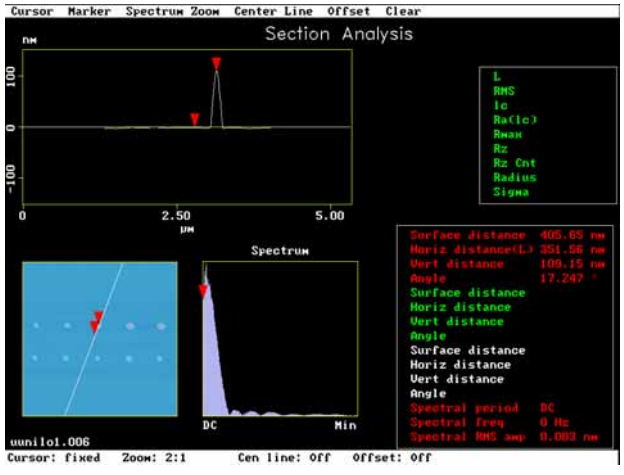


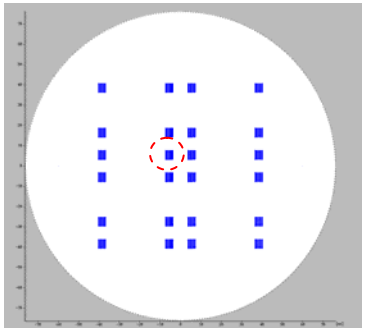










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5 Jan 2009
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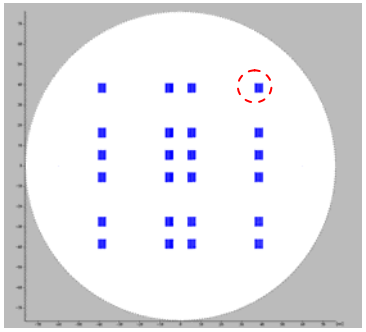
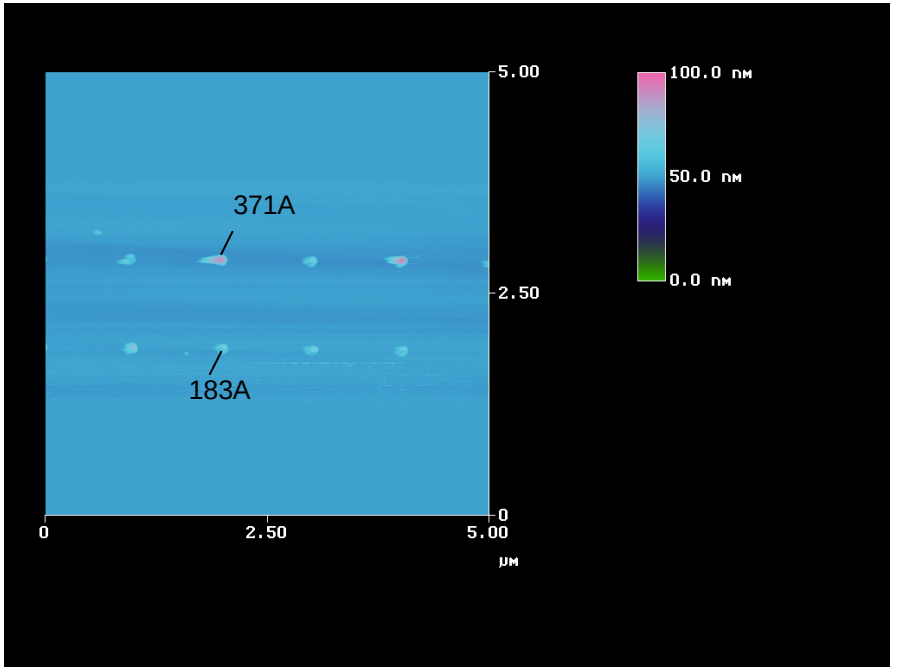
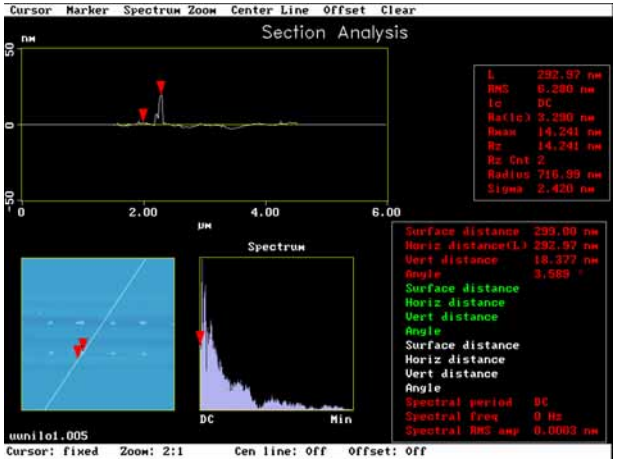
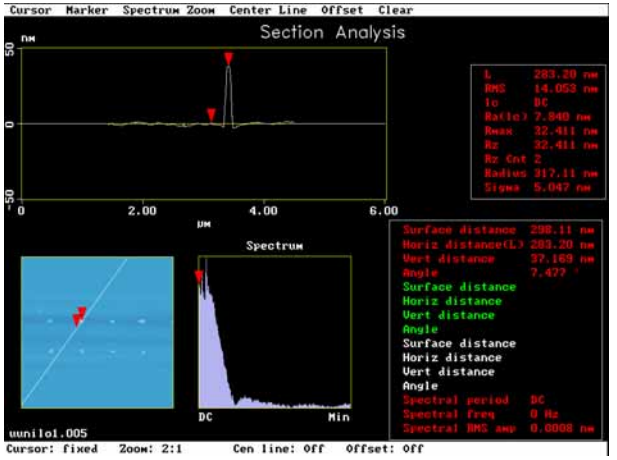
Stage at T = 0.0 °
Scan Speed = 7
Line Avg
InLens
N = 2
WD = 6.9 mm 5.00 kV 184.01 K X
Aperture Size = 30.00 µm Out Dev.

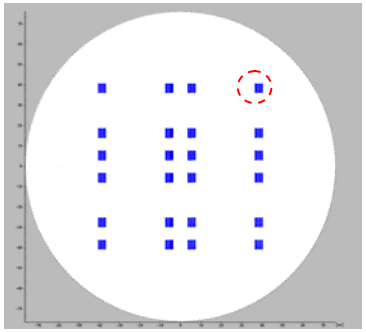
AFM measurement of nanodots

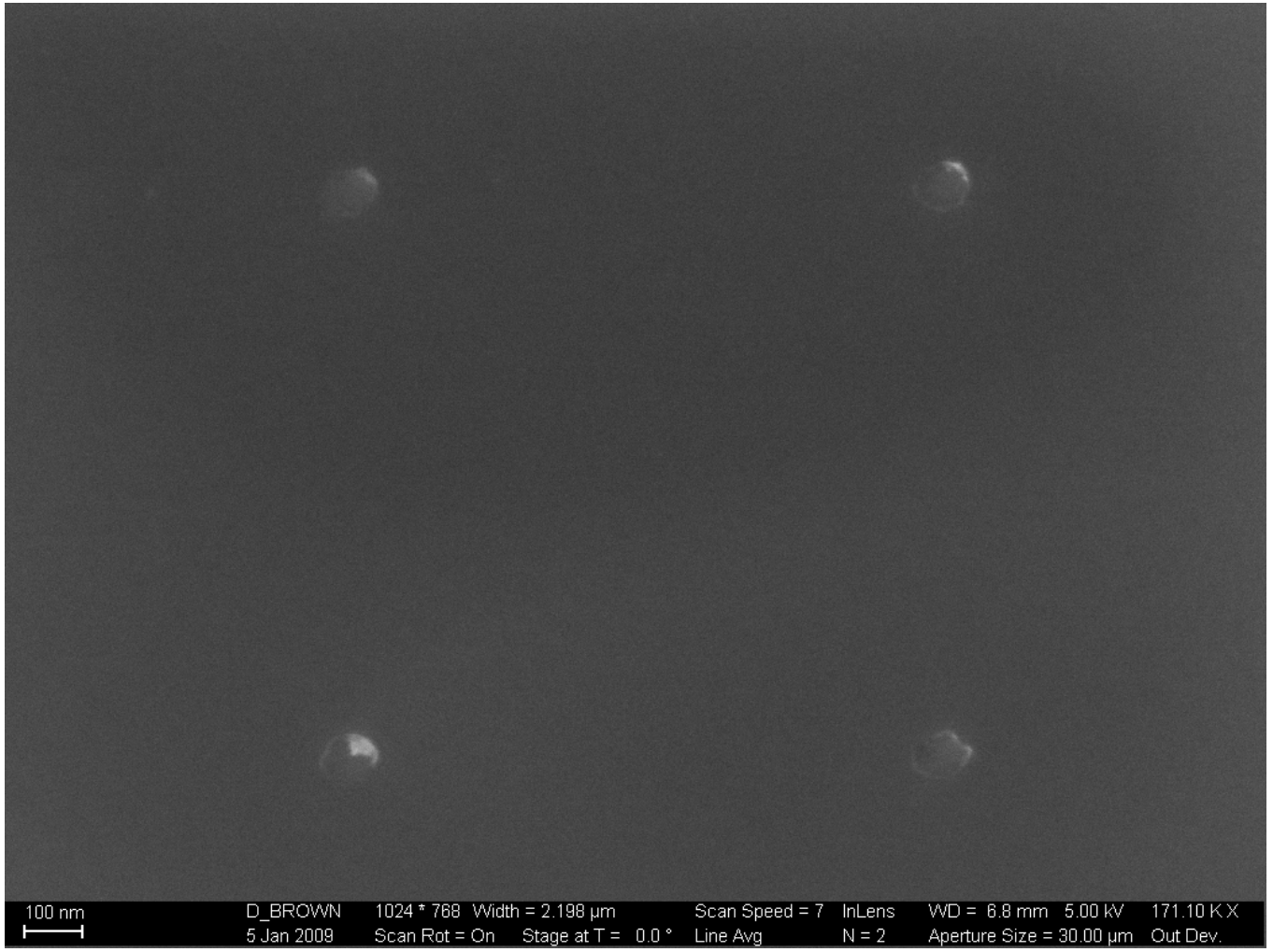








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5 Jan 2009
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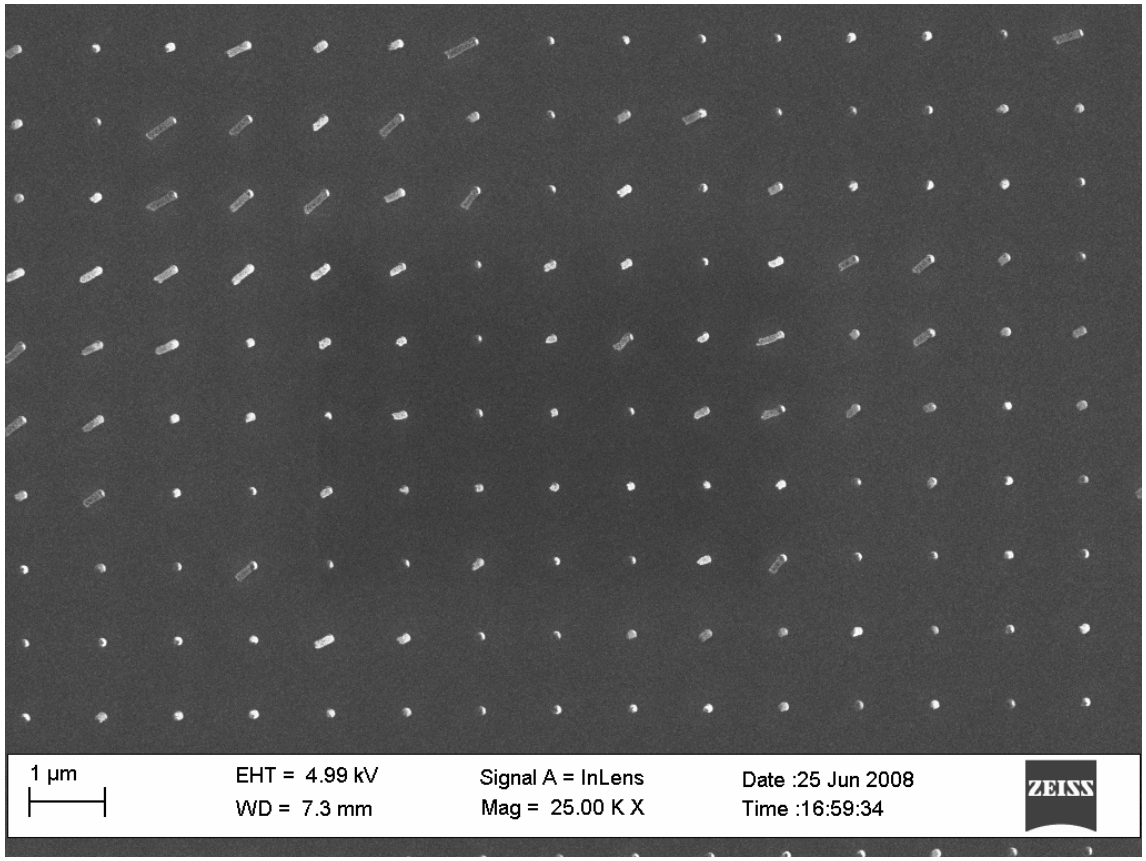
InLens
N = 2
WD = 6.8 mm 5.00 kV 171.10 K X
Aperture Size = 30.00 µm Out Dev.

follow up points for next time

thicker resist is worse



characterize your resist (dose vs. feature size)