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Wednesday 8/26/2015

- [ ] Lab safety basics online (NDNF)
  - ↳ Send to Prof. by Monday
- [ ] NDNF Safety Overview (completed Fri. 8/26/2015)
- [ ] NDNF Safety Manual
  .edu/~ndnf/safety/index.html (turn into Prof.)

DON'T EVER BE LATE!!!

Office hours Fri: 3-4p
M, W: 3-4p

Cesar: T 11-12 (S.R. B20)

Sandhya: TH 1-2 (SR 228)

Book: Microchip Manufacturing

Sakai: Course Website

Monday — Aug. 31, 2015

Now Group 5

↳ Traing certificate & Agreement
Submitted 8/31/2015

Jun chi (Jun-chu^e)

Bases are worse burns than acids

Base = Caustic

Solvents => stainless steel tools

HMDS (Solvent in wrong hood)

Don't Put Metal in an oxidation Furnace!

Marie → STANDford "Silicon Run 1" (2nd ed.)

Ruth A. Carraz...?

Wednesday Sept. 2, 2015

☐ get book! (or access to it)

Make appointments (Snyder, Sandhya, Cesar)

1. Have water ready to push stepper (check fans)

2. " " (check alignment)

START Practice Lab ASAP; finish by early next week!

See cleanroom NOTEBOOK Guidelines

→ Create A picture NOTEBOOK (date each page)

↳ Do it as you go! ↳ submit in PDF

→ each person should write into notebook → add initials

Lab Procedure is up online!

↳ and in cleanroom!

(Etch vs develop?)

→ Write "Guidelines"

↳ must read Procedure <u>at least</u> twice & Understand <u>BEFORE</u> lab work.

↳ Cancelling or adjusting schedule <u>must</u> happen > 24 hrs. before lab work.

<u>Research writing!</u> (Most important)

1. When to stop!
2. What to leave out (just as important as what is put in!)

→

It is a mathematical fact that only two layers (of metal) are required to build any circuit.

The best technology can perform is just before it is about to be replaced

All calculations dissipate energy (counting on fingers, thinking, etc.)

Information is physical.
Manipulating information requires energy

Abacus → Pascalene → Babbage diff. engine
3000BC 1642 1832

Video: Babbage's D. Difference engine No. 2 //
(WIRED)

Elec. Engineers work with electrons (small & light →

Konrad Zuse → first Binary Digital Computer

(German, during ~~WWII~~, so winners never heard of him)

ENIAC (vacuum tubes instead of relays)

↳ 174 kW 17,500 Tubes

5,000 additions/sec.

Energy required to calculate trajectory

" " = to fire a projectile

Bug actually found (in relay!)

<u>Bill Schockley</u> → Nobel Prize Winner
Sperm Bank contributer

↳ started silicon valley b/c no-one wanted to work with him

Friday Sept. 4, 2015

→ 446 : Traing, Wednesday Tuesday
→ Finish practice lab by thursday

RIE => Greg's Baby

"Marketing people lie... get you to buy things you don't want, to impress people you dont like..."
↳ Dr. Greg

Small is good, but cheap is better

1935 : 1 logic gate/hr,
2015 : 10" " "/hr.
} Productivity is key

Core i7 → 8×10^{10} parts/in^3

Moore's law → "license to print money"
↳ exponentially more productivity

"women are more patient than men
you make a guy do this, and
he's gonna kill somebody..." → Dr. gred
#gradschool

"They got to the moon with 8K bits..."
↳ Dr. greg

More than 2K transistors on the chip were going to make

logic dissipates more energy than cache memory

Facebook → server farm in Norway
↳ sell waste heat!!!

Energy dissipation issue addressed by moving to many-cores, around year 2,000
↳ AMDEL'S Law
↳ saturation of performance @ high core #.

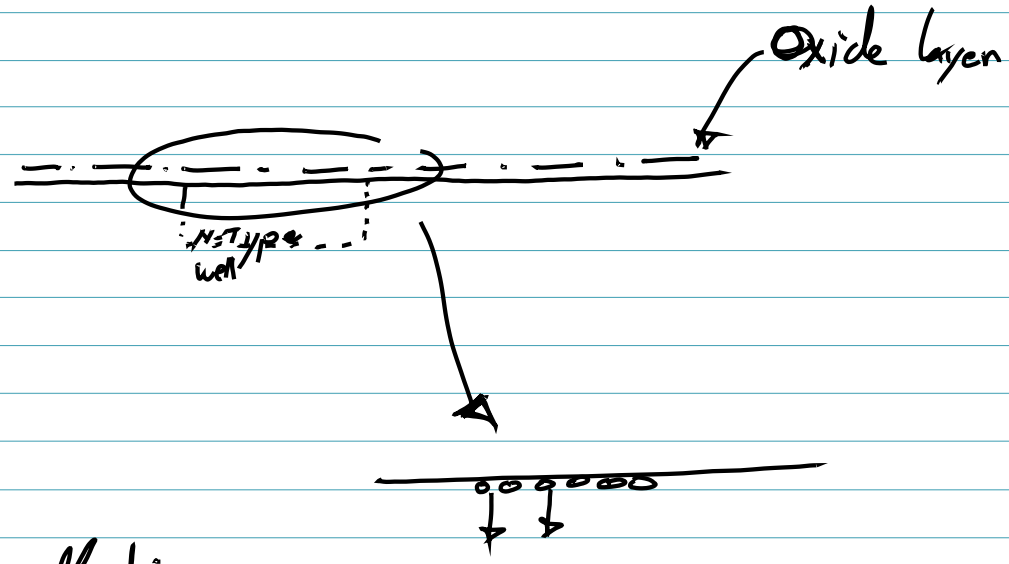
Apple switched from IBM to Intel to reduce heat exchanger size

How much is 300mm water worth? (~50% yeild)

"My wife is Italian, and she has scary cousins which will make you dissapear for much less [$] than that..."
↳ Dr. Greg

END OF HISTORY

CMOS Process Flow:



we'll drive dopents into silicon

Step 1: 1000 Å deep notch into Silicon

Layer 0 → □

(we'll make 1,200 Sand chips)

You can program your own song

64 notes // → Excel file

0.75 μ rign oscillator (Goal is to make work)

Monday Sept. 7, 2015

☐ Finish Practice lab by Thursday

4/6: 3p Tuesday

☐ → Tell groupmates to get remote coral

☐ Skim Ch. 2-4 → We'll probably work on Wednesday

Half of the world's transistors were made in the last 3-4 years.

Moore → double ~~transistors~~ or chip

Sand → SiO_2 → ... → Water

Quartzite

Carbon payback on Silicon Solar cells ~3yrs.

MGS → Metal Grade Silicon

EGS → Electronics Grade Silicon

~~Bad~~

Kilo-gram: 1. it's gaining weight (we think)

Physical object 2. Not attainable from scratch somewhere else

3. It's in France

~~Boot~~ Boule → big thing of single crystal Silicon

What is an internal diameter blade?

(RMS) Surface Roughness of our waters; about 1 nm.

A

Wednesday Sept. 9

S. Wolf → Microchip Manufacturing

Skim Chapters 2-4 & Ch. 13

START "Real" wafers tomorrow (Thursday, sept. 10)

"Best way to get fired from Intel is to touch a wafer with tweezers."

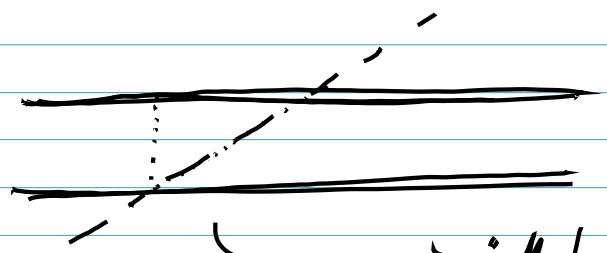
↳ [Intel wafer manufacturing is completely automated.]

Q1: What is the "end of scaling?"

300mm wafers are 2mm thick

OXIDATION: "Silicon oxide is God's gift to humanity!"

cut



"Mechanically amplify distance to examine profile"

[cut on an angle instead of perpendicular]

Friday Sept. 11.

∴ Take wafers out of SPD and they go directly into the furnace

446: Goal: N-well done by next Friday

"Professors are all sidistic bastards..."
→ Dr. Greg

1. Alignment & etch → Sat (no later than 8:30a)
2. First oxidation (Tuesday morning)
3. Spin. N-well Litho.

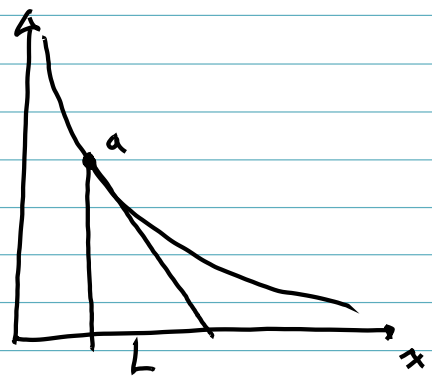
(Photo-notebook → PDF → Su Kai (two-weeks))

Things that happen with $\sqrt{t}$ means there is probably diffusion happening

Oxidation is a thermally activated process.

$$D = D_0 \exp\left(\frac{-E_A}{kT}\right)$$ Arrhenius Relationship

"I call the exponential function the Sarah Palin/Trump equation, because no matter what you do, it never goes away."
↳ Dr. Greg



where 'a' is a point, the line is a tangent, and 'L' is the characteristic length

$e^3 = 20$

"If you put a man and a woman in a room @ opposite walls, & they cover half the distance between them each start, when will they meet?"

mathematician → never
engineer → they'll get close enough

SiO_2 density is essentially the same
(oxide layer) (except right @ interface)

Hydrogen diffuses very easily (hence hydrogen cars are difficult to produce)

"You are a walking bag of sodium." ↳ Pr. 6

You can't get sodium off a water
↳ Picture of Threshold in color preserved hand-print

Wolf is wrong on pg. 219
Oxide loves water!!!
SiO_2 is hydrophilic.

Wet Oxide → thicker
Dry Oxide → Better surface Quality
So, typically Dry → wet → Dry

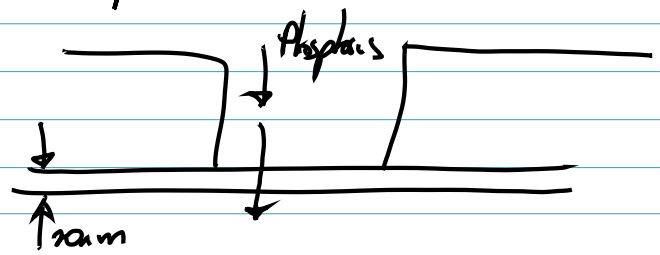
Monday Sept. 14, 2015

GOAL: N-well done by Friday

Be Ready by 8:30a (Tuesday)

we'll grow ~20nm oxidation layer

ion implantation



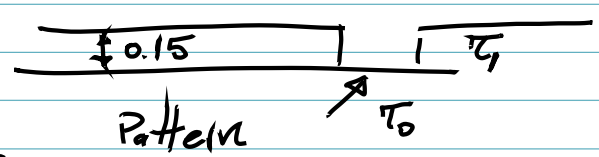
Dry Oxidation is slightly more dense (than wet)

Lets say: we do the following oxidation procedure

1100°C
Pattern → Dry → 2 hr,
→ Wet → 2 hr.

for first step $\tau = 0$, (initial oxide is negligable)

after first oxidation



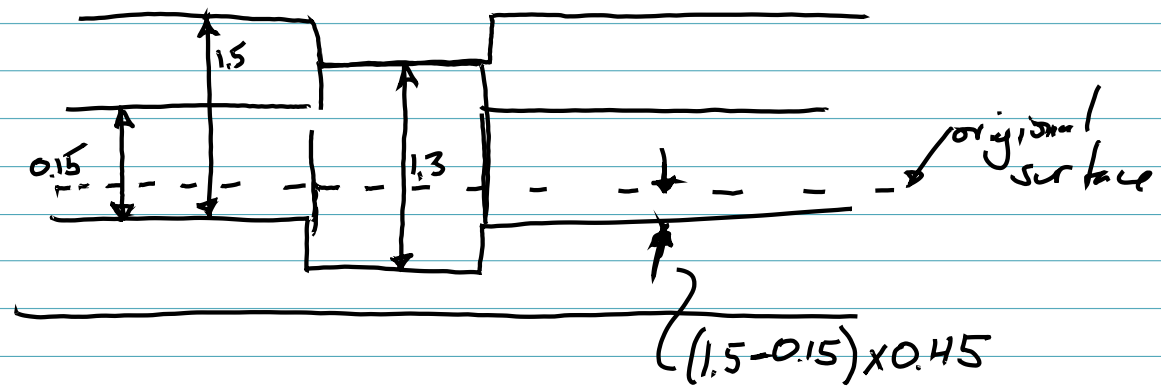
So we have two τ for step 2.

$x_i \rightarrow$ layer thickness

Which will yeild the new oxide layers

X_{o_0} and X_{o_1}

So, it will look something like



Test Question: Given a desired step height, design the process to accomplish it

---

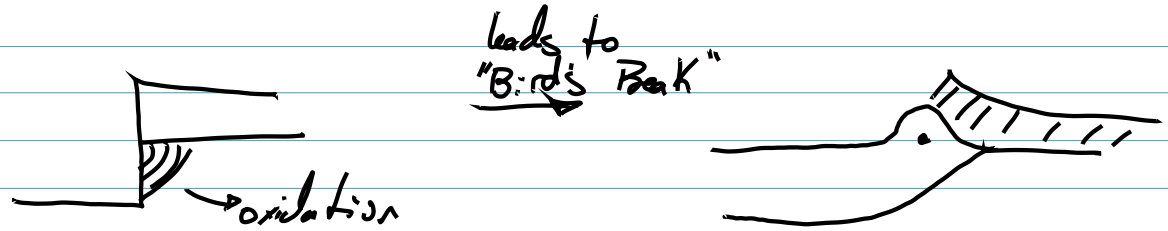
XX Be careful when using oxide as a diffusion mask, finding/using graphs to check minimum thickness

Wednesday Sept. 16, 2015

Patterning Oxide: grow it, then etch it

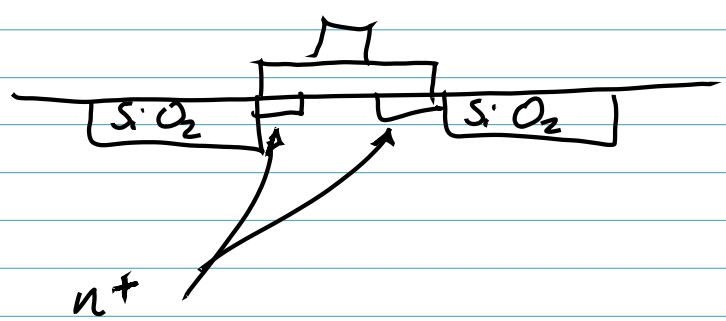
OR oxidize only where you want it

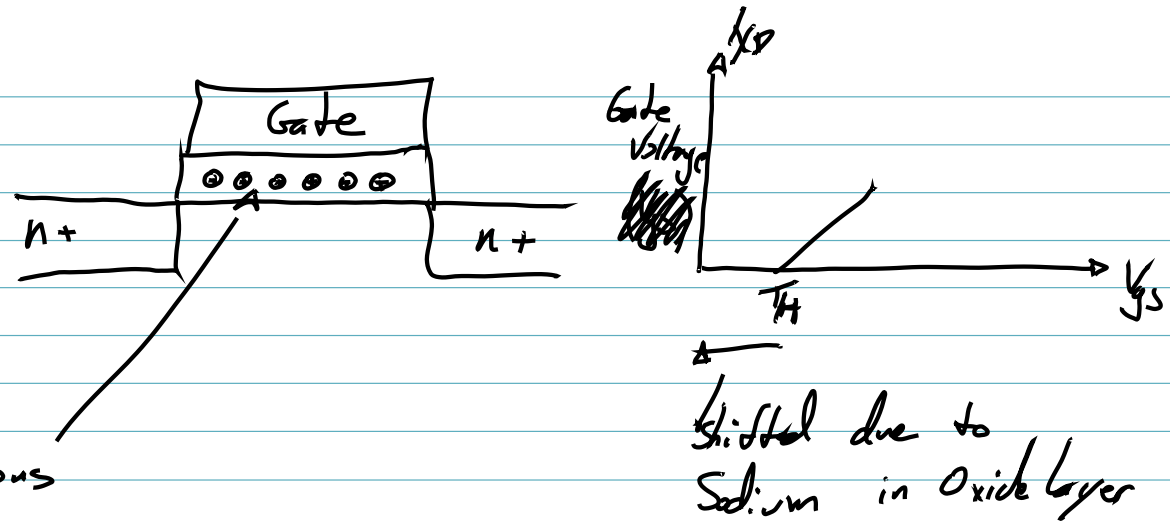
Si_3N_4 → is really Si_xN_x



∴ Locos has been replaced by shallow trench isolation

So we want:





So, not only will the threshold shift, but it will change due to changing location of ions

Trans LC (chlorine containing solvent) dichloral ethane

TCE (tri-chloral, ethelyene) great solvent, but carcinogenec

"Indiana is the upper-penninsula of Alabama"
"Indiana tries to be as backward as it can in lots of ways."
Dr. Greg

Sodium very easily gives up an electron, but then doesn't want to bond to anything near by.

Photolithography

Reading Ch. 18-20

Piranha ($H_2SO_4 : H_2O_2$) (3:1)

Friday Sept. 18, 2015

- ☐ Submit photo lab notebook Sakai.
- ☐ ↳ lab notebooks will be collected
- ☐ Upload Text Problems

"I'm mean for a Reason..." Dr. Greg → Lies My Teacher told Me

You can etch SiO_2

ME: microfluidics
EE: IC Fab

[Blog: Two Perspectives on a Water

Light reflects anywhere two different indices of refraction meet

"Spin-casting"
↳ This is how glass was made ∴ thickest @ edges
↳ which you would naturally put at the bottom (stronger)

∴ Glass will flow, but over really long time periods

Thickness

$$t \approx \frac{ks^2}{\sqrt{rpm}}$$

k → Sensitation coefficients (ignorance constant)

s → % solids in PR

rpm → spin speed

"I love the smell of photoresist..." → Dr. Greg

Name of P.R.
↳ what thickness you get @ 4,000 RPM

controlling thickness is <u>not</u> good with rpm, varies as the square root

What you want in P.R. → Cheap
Sensitive
High Res.
Tough
Stable

SU8 is essentially a photo-sensitive epoxy

<u>Positive PR</u>
Expensive
High Res.
Aqueous Developers
Easy to Remove
Fairly tough

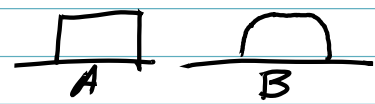
Typical

<u>Negative PR</u>
Cheap
Resolution limited by Swelling
Solvent Developers
Hard to Remove
Very tough

exposed areas develop away

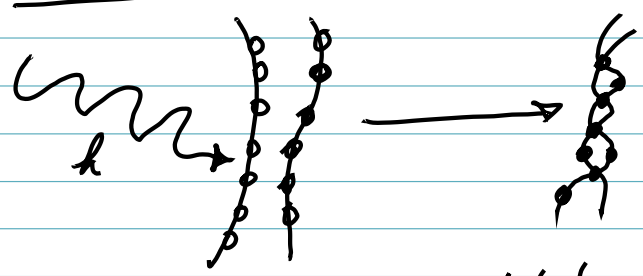
areas exposed stay

Q1: if you created a square feature with both Pos & Neg., which would be sharper?



(Negative Resist)

Crosslinking:



increases Molecular Weight

Dalton (Mass of Carbon-12 atom)

(Positive Resist)
1. Low molecular weight alkali-soluable resin
2. Photoactive dissolution inhibitor ($$$)
3. Solvent

(Wolf) Fig. 19-1

Contrast is <u>the</u> most important factor!!!

"If you worked at Intel you would throw your grandmother under a bus to get better contrast."
↳ Dr. Greg

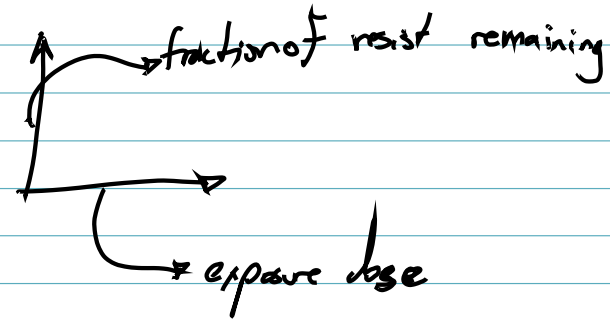
$$\gamma = \frac{1}{\log_{10}(D_{100}/D_0)}$$

D_0 → all resist stays

D_{100} → All resist gone

} Positive resist

contrast is slope on



Rabbitholes →

"I got to program in my first programming class on punchcards." → Dr. G

Q2:
Who is Sam Spade?

Monday Sept. 21, 2015

"If it doesn't come up, we'll have to call the trolls at OIT." → Dr. Greg

"Modified Demarcy, I ask your opinion, and I do whatever the hell I want..." → Dr. G

You want your layout to require as few flashes as possible.

"That's our workaround for buying emulsion plates from those pirates in South Korea." ↳ Dr. G

A Mask is 1-to-1.

A Reticle is used in a reduction system

E-beam is about 2 to 3 nm wide (lithography)

Exposure Methods:

NOTE: Edge Bead will prevent mask from perfectly contacting PR on wafer.

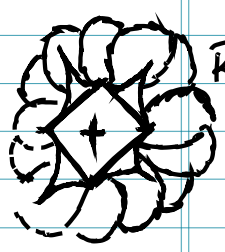
NOTE: You can develop edge bead away!!!

Carl Zeus ⇒ tech. 0.35 μm resolution

Downside to Contact Lithography is damage to mask and substrate.

∴ Proximity Exposure
↳ however you give up a lot of resolution

∴ Projection Exposure
industry standard, but expensive



Rayleigh

$$\sigma = \frac{\lambda k}{NA}$$

wavelength, constant, aperature

$$= \frac{(0.61)(365\text{ nm})}{0.4} = 556\text{nm}$$

quoted as 600nm (0.6μm)

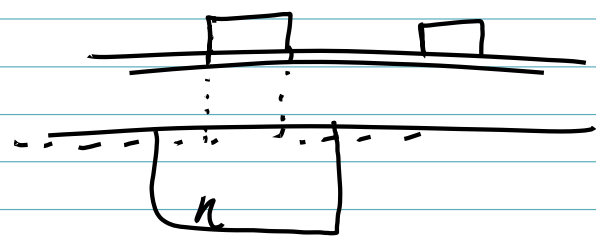
Wednesday Sept. 23, 2015

Next Monday Morning in Cleanroom

↳ Active Litho

Si_xN_x 100nm

Etch

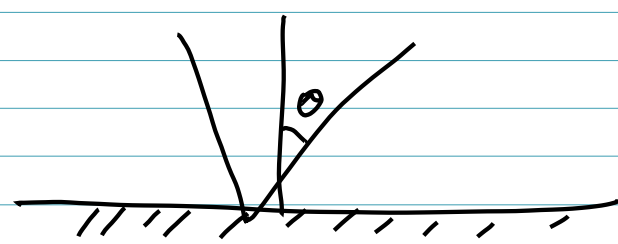


By Next Wednesday!!!

(Tuesday and/or Monday 3-6p)

$NA = \sin\theta$

"angle of acceptance"



Modern Steppers ~ NA ~ 0.7-0.8

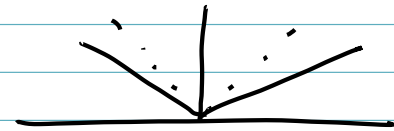
Practical limit 0.9

$$d = \frac{k_2 \lambda}{(NA)^2} \quad k_2 = 0.5$$

"Solid angle of light acceptance"

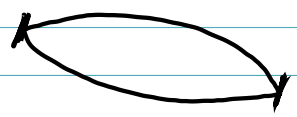
A high NA means lens passes high spatial frequency components $\longrightarrow$ leads to high res.

$0.8 = \sin\theta$ Then $\theta = 53°$



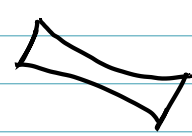
$\therefore$ Big lens

Huge lm refracting lens
$\hookrightarrow$ become too heavy



lens can only be supported @ edges

<u>But</u> a mirror (reflecting telescope) can be supported from its back.



High NA means large & expensive lens <u>and</u> small depth of focus.

<u>But</u> for wafer processing we want larger depth of focus

for example $d = \frac{0.5 \ (365\,nm)}{(0.4)^2}$

depth of focus $= 1.1\ \mu m$ //

Actually: $NA = n \sin\theta$

DI water ~1.3
Fluorthicks ~1.4

c we want $n > 1$

(put a thick between lens & substrate)

"How quickly the transition between redicuks and necessary can happen when billions of dollars are at stake."

Water does not diffuse through silicon nitride.

Water/liquids pull particles from the air.

Resolution @ ND 5 nm

(using e-beam lithography)

↳ used by IBM on "custom circuits"

~~wafers~~ made 95%, last

metal layer custom directly

written onto top layer of wafer

Friday Sept. 25, 2015

446 Use PECVD ICsinx 6min.

Nitride Nominal etch time is 3:30.

Active Litho and etch done by Next Wednesday.

Gamma-Rays → will kill you

X-Rays → " " more slowly

Eduard Teller → Father of Hydrogen Bomb

To a hammer every problem is a nail,

to Eduard Teller every solution is a hydrogen Bomb.

Lenses are difficult for X-Rays (they just blast through everything)
impossible

Really <u>Good</u>

IF you can make the mask

Intel is not a tech. creator,
it is a tech. exploiter.

IBM however does spend big bucks into developing technology.

$\lambda = 10\text{-}14\,nm$ Intel & IBM

Extreme Ultra-violet (EUV)

a better name one that "fools the business majors"

No refractive optics @ this wavelength (Ref. index $\cong 1$)

Keep in mind reduction (factor of 2) makes masks easier to fabricate,

Numerical Aperture is the number or order of waves (light modes?) that can pass through.

Recall $\Rightarrow$ $\sigma = \frac{k_1 \lambda}{NA}$

$k_1 \sim 0.6$ (Rayleigh refraction)

7:00a Monday!

Monday Sept. 28, 2015

"... That's why the Good Lord invented undergrads..."
↳ Dr. Greg

Me: Ask yourself what was the best & worst part of your old:
- job
- life
- house
- city
- relationship
- ⋮
- ... ?

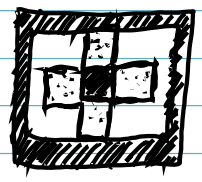
$(0.95)^{10}$ → yeild # of layers

This is why 95% yeild is ~~not~~ considered garbage at Intel

Alignment is Key!!!

Computers can only do two things:
→ add and compare two numbers (which is greater?)

Dr. Snyder's favorite alignment mark



You will typically align your most critical layers to one another.

Contact Lithography → Alignment Marks are simply religious convictions

Vernier

New Homework on Wednesday!

<u>Epitaxial Growth</u>: 446: Read Ch. 17

↳ Substrate used as template to grow more single-crystal material

In autoepitaxy (homoepitaxy), we grow the same material on top.