MICROELECTRONIC ENGINEERING
ROCHESTER INSTITUTE OF TECHNOLOGY

A Review of IC Fabrication Technology

Dr. Lynn Fuller
Webpage: http://people.rit.edu/lffeee
Microelectronic Engineering
Rochester Institute of Technology
82 Lomb Memorial Drive
Rochester, NY 14623-5604
Tel (585) 475-2035
Email: Lynn.Fuller@rit.edu
Department webpage: http://www.microe.rit.edu

7-7-2014 Review.ppt

ADOBE PRESENTER

This PowerPoint module has been published using Adobe Presenter. Please click on the Notes tab in the left panel to read the instructors comments for each slide. Manually advance the slide by clicking on the play arrow or pressing the page down key.

OUTLINE

- Constants
- Periodic Table
- Material Properties
- Oxide Growth
- Diffusion
- Resistivity, Sheet Resistance, Resistance
- Mobility
- pn Junction
- MOSFET Vt
- Ion Implantation
- Conclusion

CONSTANTS

Electronic charge	q	1.602 E -19 Coulomb
Speed of light in vacuum	c	2.998E8 m/s
Permittivity of vacuum	εo	8.854 E -14 F/cm
Free electron Mass	m_o	9.11E-31 Kg
Planck constant	h	6.625E-34 J s
Boltzmann constant	k	1.38 E-23 J /°K = 8.625E-5 eV/°K
Avogadro’s number	A_o	6.022E23 molecules/gm- mole
Thermal voltage	kT/q	@ 300 °K = 0.02586

PLAY

PERIODIC TABLE OF THE ELEMENTS

Atomic Number

Density
g/cm3

Atomic Weight

Symbol

Name

14 20.086 Si 2.33 Silicon

1 1.0079 H 0.0899 Hydrogen																	2 4.0026 He 0.1787 Helium
3 6.914 Li 0.53 Lithium	4 9.01218 Be 1.85 Beryllium											5 10.81 B 2.34 Boron	6 12.011 C 2.62 Carbon	7 14.0067 N 1.251 Nitrogen	8 15.9994 O 1.429 Oxygen	9 18.9984 F 1.696 Fluorine	10 20.179 Ne 0.901 Neon
11 22.9898 Na 0.97 Sodium	12 24.305 Mg 1.74 Magnesium											13 26.9815 Al 2.70 Aluminum	14 20.086 Si 2.33 Silicon	15 30.97376 P 1.82 Phosphorous	16 32.06 S 2.07 Sulfur	17 35.453 Cl 3.17 Clorine	18 39.948 Ar 1.784 Argon
19 39.0983 K 0.86 Potassium	20 40.08 Ca 1.55 Calcium	21 44.9559 Sc 3.0 Scandium	22 47.90 Ti 4.50 Titanium	23 50.941 V 5.8 Vanadium	24 51.996 Cr 7.19 Chromium	25 54.938 Mn 7.43 Manganese	26 55.847 Fe 7.86 Iron	27 58.9332 Co 8.90 Selenium	28 58.70 Ni 8.90 Nickel	29 63.546 Cu 8.96 Copper	30 65.238 Zn 7.14 Zinc	31 69.72 Ga 5.98 Gallium	32 72.59 Ge 5.32 Germanium	33 74.9216 As 5.72 Arsenic	34 78.96 Se 4.80 Selenium	35 79.904 Br 3.12 Bromine	36 83.80 Kr 3.74 Krypton
37 85.468 Rb 1.53 Rubidium	38 87.62 Sr 2.8 Strontium	39 88.906 Y 4.5 Yttrium	40 91.22 Zr 6.49 Zirconium	41 92.906 Nb 8.55 Niobium	42 95.94 Mo 10.2 Molybdenum	43 98 Tc 11.5 Technetium	44 101.07 Ru 12.2 Rhodium	45 102.9055 Rh 12.4 Rhodium	46 106.4 Pd 12.0 Palladium	47 107.868 Ag 10.5 Silver	48 112.41 Cd 8.65 Cadmium	49 114.82 In 7.31 Indium	50 118.69 Sn 7.30 Tin	51 121.75 Sb 6.68 Antimony	26 55.847 Te 6.24 Tellurium	26 127.60 Fe 7.86 Tellurium	54 131.30 Xe 5.89 Xenon
55 132.90 Cs 1.87 Cesium	56 137.33 Ba 3.5 Barium	57 138.906 La 6.7 Lanthanum	58 178.49 Hf 13.1 Hafnium	59 180.95 Ta 16.6 Tantalum	60 183.85 W 19.3 Tungstem	61 186.207 Re 21.0 Rhenium	76 190.2 Os 22.4 Osmium	77 192.22 Ir 27.16 Iridium	78 195.09 Pt 21.4 IPlatinum	79 196.9665 Au 19.3 Gold	80 200.59 Hg 13.53 Mercury	81 204.37 Tl 11.85 Thallium	82 207.2 Pb 11.4 Lead	83 206.980 Bi 9.8 Bismuth	84 209 Po 9.4 Polonium	85 210 At ??? Astatine	86 222 Rn 9.91 Radon
87 223 Fr ??? Francium	88 226.02 Ra 5 Radium	89 227.02 Ac 10.07 Actinium	104 261 Unq ???? Unnilquadium	105 262 Unp Unnilpentium	106 263 Unh ???? Unnilhexium												

PLAY

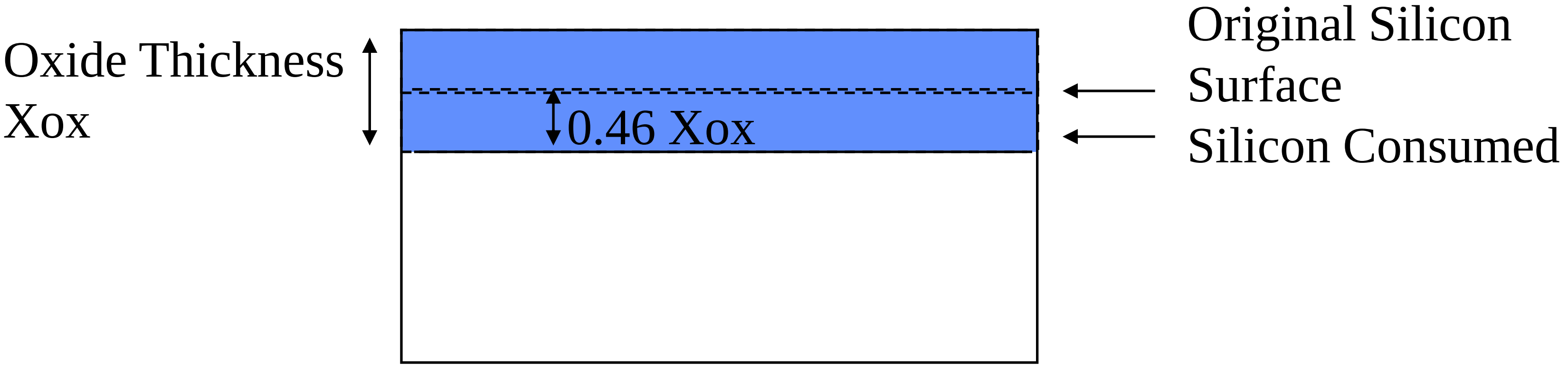
58 140.12 Ce 6.78 Cerium	59 140.91 Pr 6.77 Praseoymium	60 144.24 Nd 7.00 Neodymium	61 145 Pm 6.475 Promethium	62 150.4 Sm 7.54 Samarium	63 151.96 Eu 5.26 Europium	64 157.25 Gd 7.89 Gadolinium	65 158.92 Tb 8.27 Terbium	66 162.5 Dy 8.54 Dysprosium	67 164.93 Ho 8.90 Holmium	68 167.26 Er 9.06 Erbium	69 169.93 Tm 9.33 Thulium	70 173.04 Yb 6.98 Ytterbium	71 174.97 Lu 9.84 Lutetium
90 232.0 Th 11.7 Thorium	91 231 Pa 15.4 Protactinium	92 238.02 U 18.90 Uranium	93 237 Np 20.4 Neptunium	94 237 Pu 19.8 Plutonium	95 243 Am 13.6 Americium	96 247 Cm 13.511 Curium	97 247 Bk ???? Berkelium	98 251 Cf ???? Californium	99 252 Es ???? Einsteinium	100 257 Fm ???? Fermiumr	101 258 Md ???? Mendelevium	102 259 No ???? Nobelium	103 260 Lr ???? Lawrencium

MATERIAL PROPERTIES

	Symbol	Units	Si	Ge	GaAs	GaP	SiO$_2$	Si$_3$N$_4$
Atoms per unit cell			8	8	8	8		
Atomic Number	Z		14	32	31/33	31/15	14/8	14/7
Atomic weight	MW	g/g-mole	28.09	72.59	144.64	100.70	60.08	140.28
Lattice constant	ao	nm	0.54307	0.56575	0.56532	0.54505		0.775
Atomic density	No	cm^{-3}	5.00E22	4.42E22	2.21E22	2.47E22	2.20E22	1.48E22
Density	d	g cm^{-3}	2.328	5.323	5.316	4.13	2.19	3.44
Energy Gap 300°K	Eg	eV	1.124	0.67	1.42	2.24	8~9	4.7
Relative permittivity	εr		11.7	16.0	13.1	10.2	3.9	7.5
Index of refraction	n		3.44	3.97	3.3	3.3	1.46	2.0
Melting point	Tm	°C	1412	937	1237	1467	1700	
Specific heat	Cp	J (gK)$^{-1}$	0.70	0.32	0.35		1.4	0.17
Thermal diffusivity	K	w(cmK)$^{-1}$	0.87	0.36	0.44	0.004	0.32	
Coefficient expansion	Dth	K^{-1}	2.5E-6	5.7E-6	5.9E-6	5.3E-6	5E-6	2.8E-6
Intrinsic carrier conc	ni	cm^{-3}	1.45E10	2.4E13	9.0E6			
Electron Mobility	µn	cm^2/Vs	1417	3900	8800	300	20	
Hole Mobility	µp	cm^2/Vs	471	1900	400	100	10E-8	
Density of States conduction	Nc	cm^{-3}	2.8E19	1.04E19	4.7E17			
Density of States valance	Nv	cm^{-3}	1.04E19	6.0E18	7.0E18			
Breakdown Electric Field	E	V/cm	3E5	8E4	3.5E5		6~9E6	
Effective mass electron	mn*/mo		1.08	0.55	0.068	0.5		
Effective mass hole	mp*/mo		0.81	0.3	0.5	0.5		
Electron affinity	qX	eV	4.05	4.00	4.07	4.3	1.0	

From Muller and Kamins

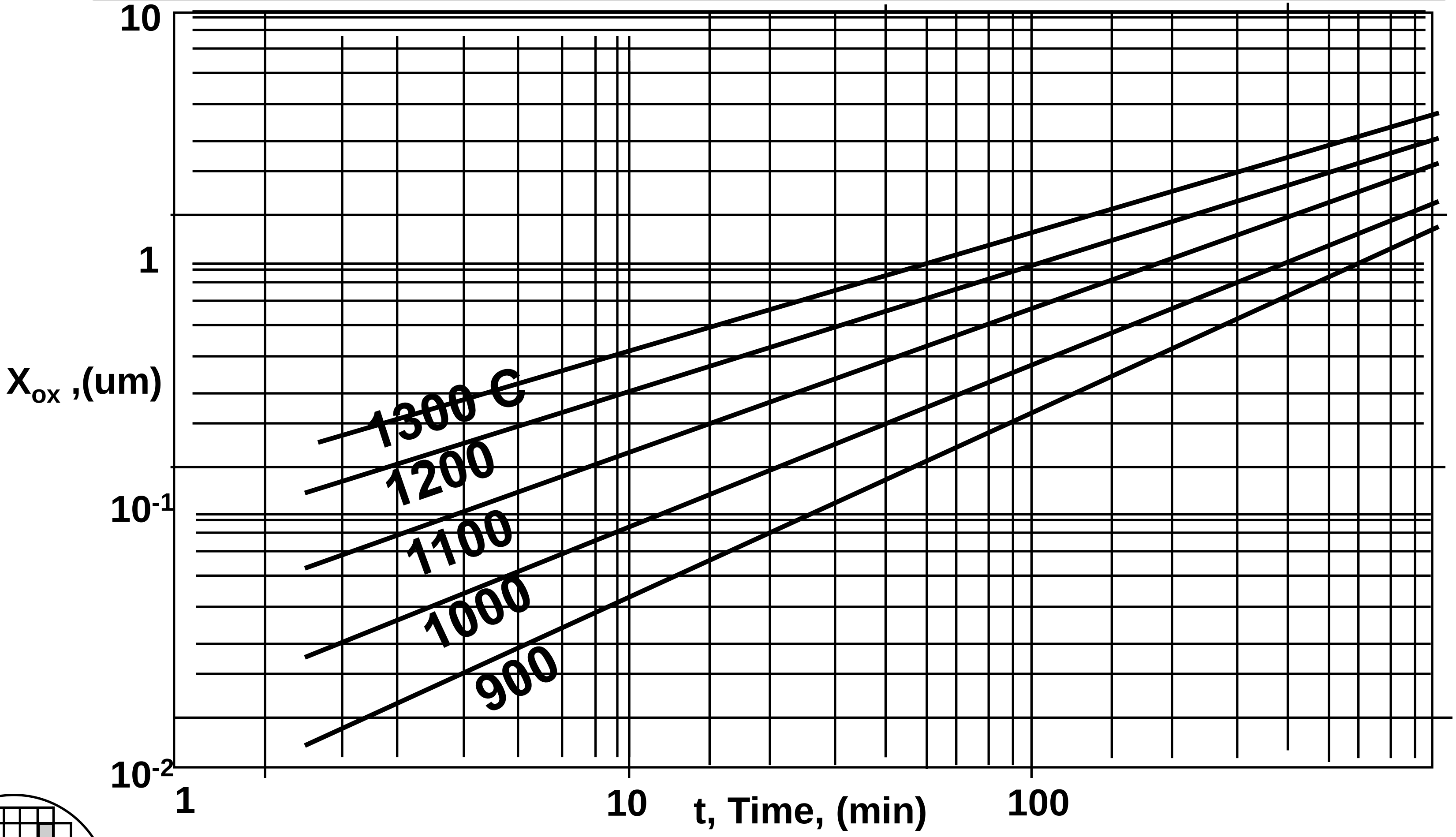
OXIDE GROWTH



Dry oxide O2 only
Wet oxide O2 bubbled through water
Steam burn H2 in O2 to make H20 (steam)

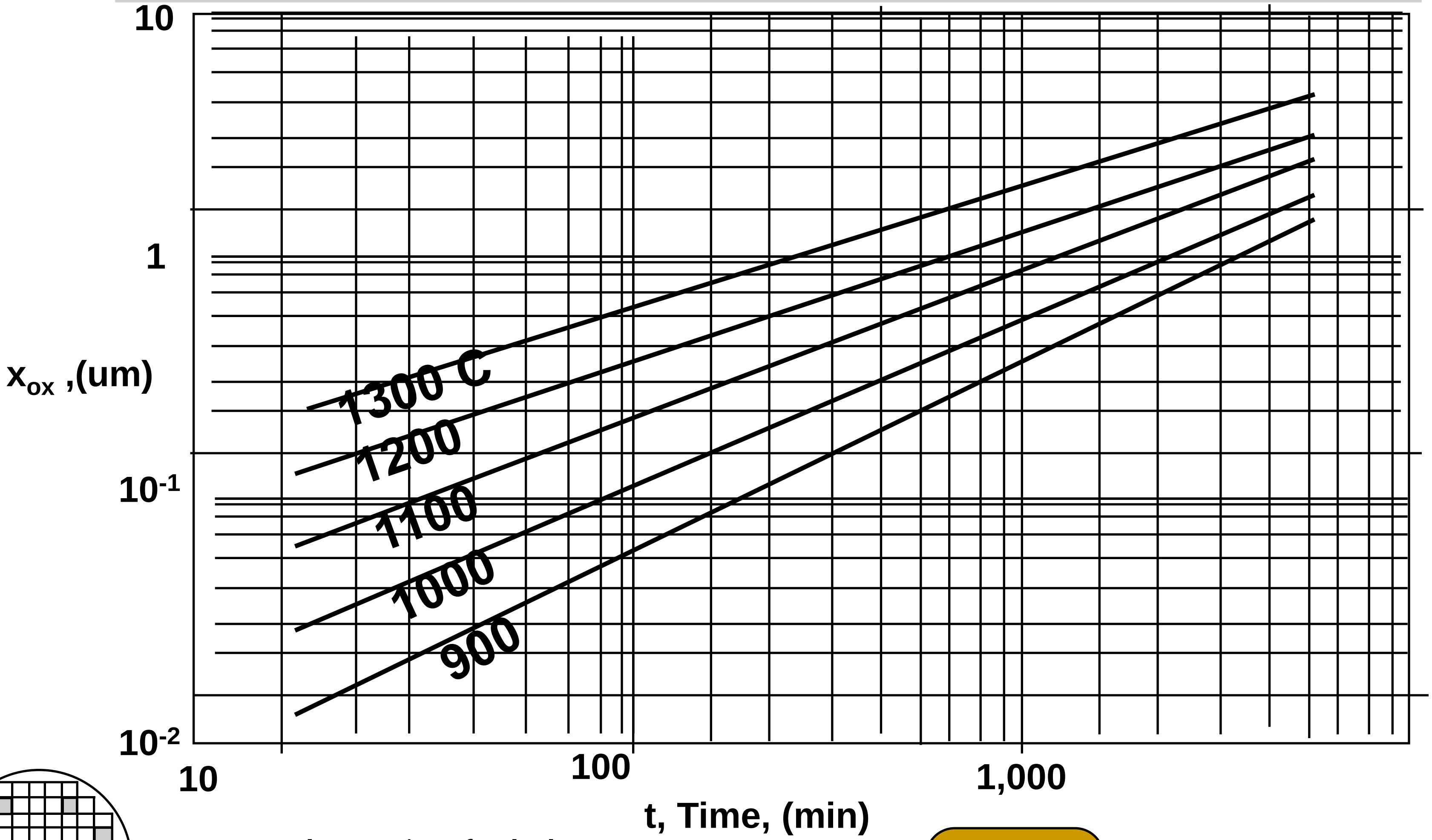
PLAY

WET OXIDE GROWTH CHART



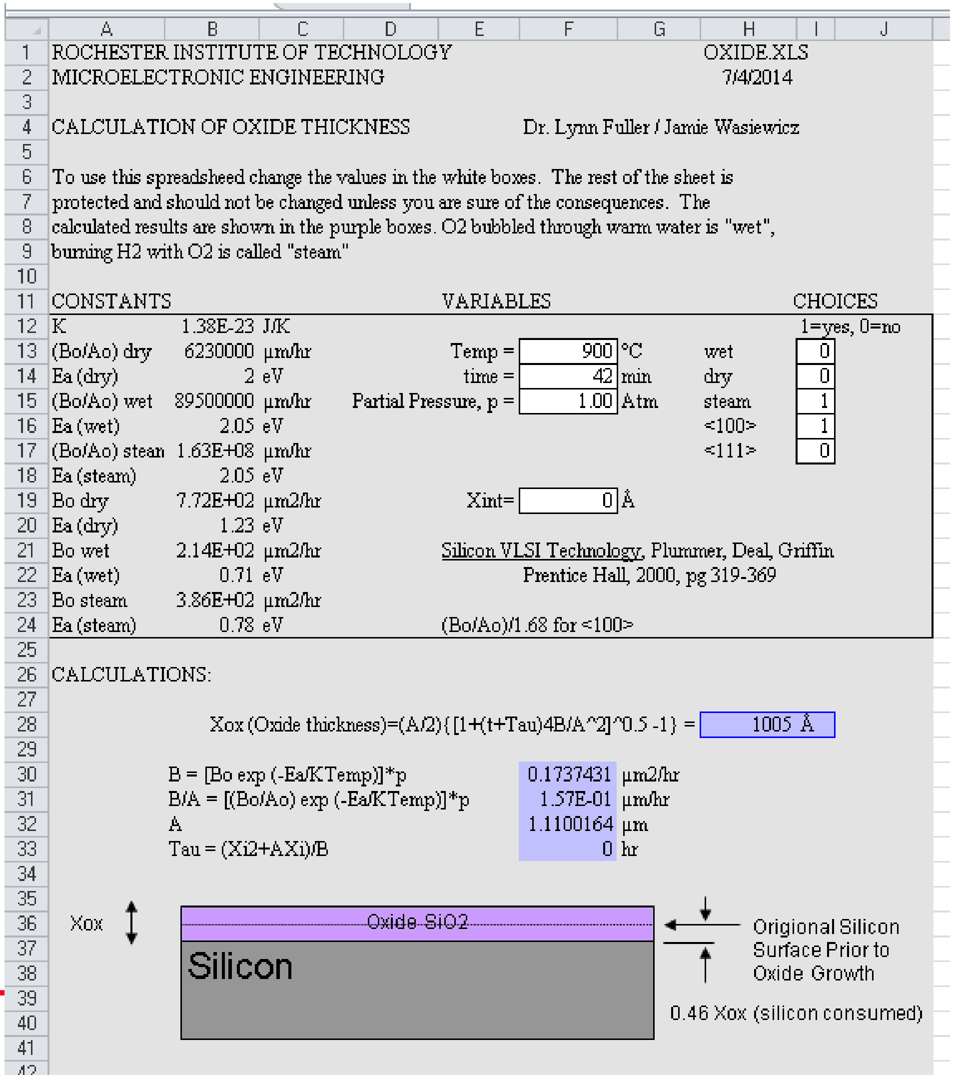
PLAY

DRY OXIDE GROWTH CHART



PLAY

OXIDE GROWTH CALCULATOR



ROCHESTER INSTITUTE OF TECHNOLOGY — OXIDE.XLS
MICROELECTRONIC ENGINEERING — 7/4/2014

CALCULATION OF OXIDE THICKNESS — Dr. Lynn Fuller / Jamie Wasiewicz

To use this spreadsheed change the values in the white boxes. The rest of the sheet is protected and should not be changed unless you are sure of the consequences. The calculated results are shown in the purple boxes. O2 bubbled through warm water is "wet", burning H2 with O2 is called "steam"

CONSTANTS			VARIABLES			CHOICES	
K	1.38E-23	J/K					1=yes, 0=no
(Bo/Ao) dry	6230000	µm/hr	Temp =	900	°C	wet	0
Ea (dry)	2	eV	time =	42	min	dry	0
(Bo/Ao) wet	89500000	µm/hr	Partial Pressure, p =	1.00	Atm	steam	1
Ea (wet)	2.05	eV				<100>	1
(Bo/Ao) stean	1.63E+08	µm/hr				<111>	0
Ea (steam)	2.05	eV					
Bo dry	7.72E+02	µm2/hr	Xint=	0	Å		
Ea (dry)	1.23	eV					
Bo wet	2.14E+02	µm2/hr	Silicon VLSI Technology, Plummer, Deal, Griffin				
Ea (wet)	0.71	eV	Prentice Hall, 2000, pg 319-369				
Bo steam	3.86E+02	µm2/hr					
Ea (steam)	0.78	eV	(Bo/Ao)/1.68 for <100>				

CALCULATIONS:

Xox (Oxide thickness)=(A/2){[1+(t+Tau)4B/A^2]^0.5 -1} = 1005 Å

B = [Bo exp (-Ea/KTemp)]*p	0.1737431	µm2/hr
B/A = [(Bo/Ao) exp (-Ea/KTemp)]*p	1.57E-01	µm/hr
A	1.1100164	µm
Tau = (Xi2+AXi)/B	0	hr

OXIDE.XLS

EXAMPLES

1. Estimate the oxide thickness resulting from 50 min. soak at 1100 °C in wet oxygen.

2. If 1000 Å of oxide exists to start with, what is resulting oxide thickness after an additional 50 min. soak at 1100 °C in dry oxygen.

OXIDE THICKNESS COLOR CHART

Thickness	Color
500Å	Tan
700	Brown
1000	Dark Violet - Red Violet
1200	Royal Blue Blue
1500	Light Blue - Metallic Blue
1700	Metallic - very light Yellow Green
2000	LIght Gold or Yellow - Slightly Metallic
2200	Gold with slight Yellow Orange
2500	Orange - Melon
2700	Red Violet
3000	Blue - Violet Blue
3100	Blue Blue
3200	Blue - Blue Green
3400	Light Green
3500	Green - Yellow Green
3600	Yellow Green
3700	Yellow
3900	Light Orange
4100	Carnation Pink
4200	Violet Red
4400	Red Violet
4600	Violet
4700	Blue Violet

Thickness	Color
4900	Blue Blue
5000	Blue Green
5200	Green
5400	Yellow Green
5600	GreenYellow
5700	Yellow -"Yellowish"(at times appears to be Lt gray or matel
5800	Light Orange or Yellow - Pink
6000	Carnation Pink
6300	Violet Red
6800	"Bluish"(appears violet red, Blue Green, looks Blue
7200	Blue Green - Green
7700	"Yellowish"
8000	Orange
8200	Salmon
8500	Dull, LIght Red Violet
8600	Violet
8700	Blue Violet
8900	Blue Blue
9200	Blue Green
9500	Dull Yellow Green
9700	Yellow - "Yellowish"
9900	Orange
10000	Carnation Pink

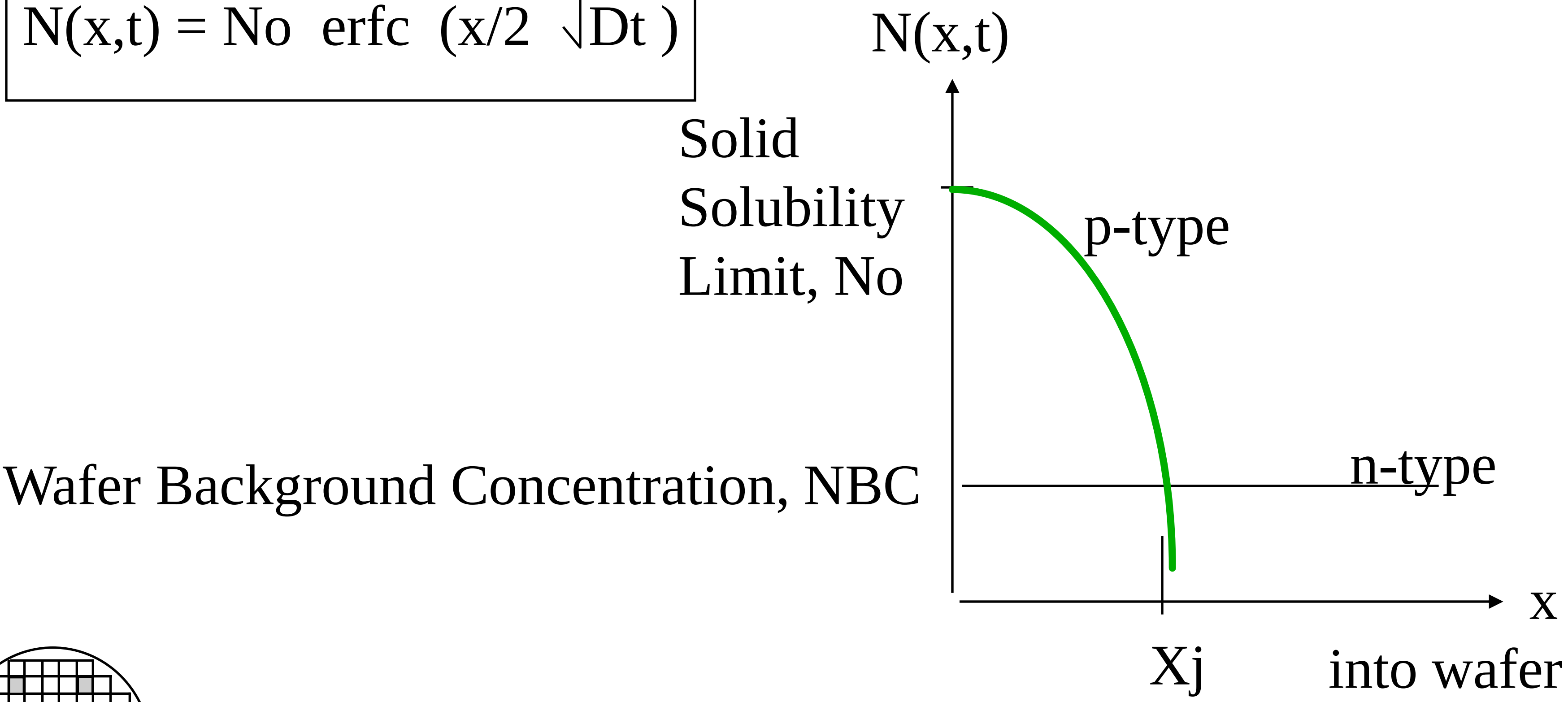
Nitride Thickness = (Oxide Thickness)(Oxide Index/Nitride Index)
Eg. Yellow Nitride Thickness = (2000)(1.46/2.00) = 1460

PLAY

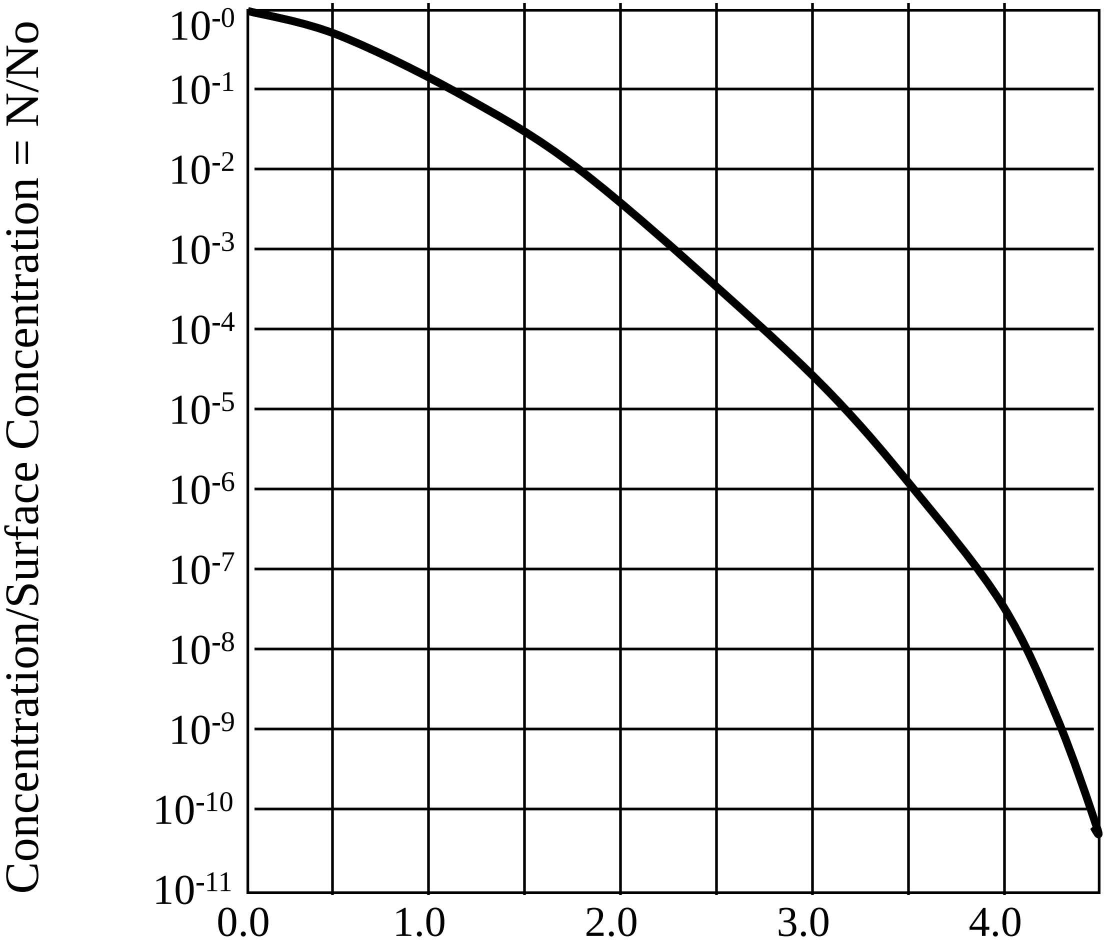
DIFFUSION FROM A CONSTANT SOURCE

PLAY **STOP**

$$N(x,t) = No \ \ \text{erfc} \ \ (x/2\sqrt{Dt})$$



ERFC FUNCTION



$\alpha = x / \sqrt{4Dt}$

PLAY

DIFFUSION CONSTANTS AND SOLID SOLUBILITY

	DIFFUSION CONSTANTS				
TEMP	BORON DRIVE-IN	PHOSPHOROUS PRE	PHOSPHOROUS DRIVE-IN	BORON SOLID SOLUBILITY NOB	PHOSPHOROUS SOLID SOLUBILITY NOP
900 °C	1.07E-15 cm2/s	2.09e-14 cm2/s	7.49E-16 cm2/s	4.75E20 cm-3	6.75E20 cm-3
950	4.32E-15	6.11E-14	3.29E-15	4.65E20	7.97E20
1000	1.57E-14	1.65E-13	1.28E-14	4.825E20	9.200E20
1050	5.15E-14	4.11E-13	4.52E-14	5.000E20	1.043E21
1100	1.55E-13	9.61E-13	1.46E-13	5.175E20	1.165E21
1150	4.34E-13	2.12E-12	4.31E-13	5.350E20	1.288E21
1200	1.13E-12	4.42E-12	1.19E-12	5.525E20	1.410E21
1250	2.76E-12	8.78E-12	3.65E-12	5.700E20	1.533E21

PLAY

TEMPERATURE DEPENDENCE OF DIFFUSION CONSTANTS

Temperature Dependence:

PLAY

$D = D_0 \, \mathrm{Exp}\,(-E_A/kT)$ cm^2/sec k = 8.625E-5 eV/°K T in Kelvins

Boron	$D_0 = 0.76$	Phosphorous	$D_0 = 3.85$
	$E_A = 3.46$		$E_A = 3.66$

Temperature Dependence of the Solid Solubility of Boron and Phosphorous in Silicon

$NOB = 3.5E17T + 1.325E20$ cm^{-3} T in Celsius
$NOP = 2.45E18T - 1.53E21$ cm^{-3} T in Celsius

DIFFUSION FROM A LIMITED SOURCE

$$N(x,t) = \frac{Q'_A(tp)\ \mathrm{Exp}\ (-\,x^2/4Dt)}{\sqrt{\pi\,Dt}}$$

PLAY

for erfc predeposit

$$Q'_A\,(tp) = Q_A(tp)/\mathrm{Area} = 2\ \mathrm{No}\ \sqrt{(Dptp)\,/\,\pi}\ \ = \mathrm{Dose}$$

PLAY

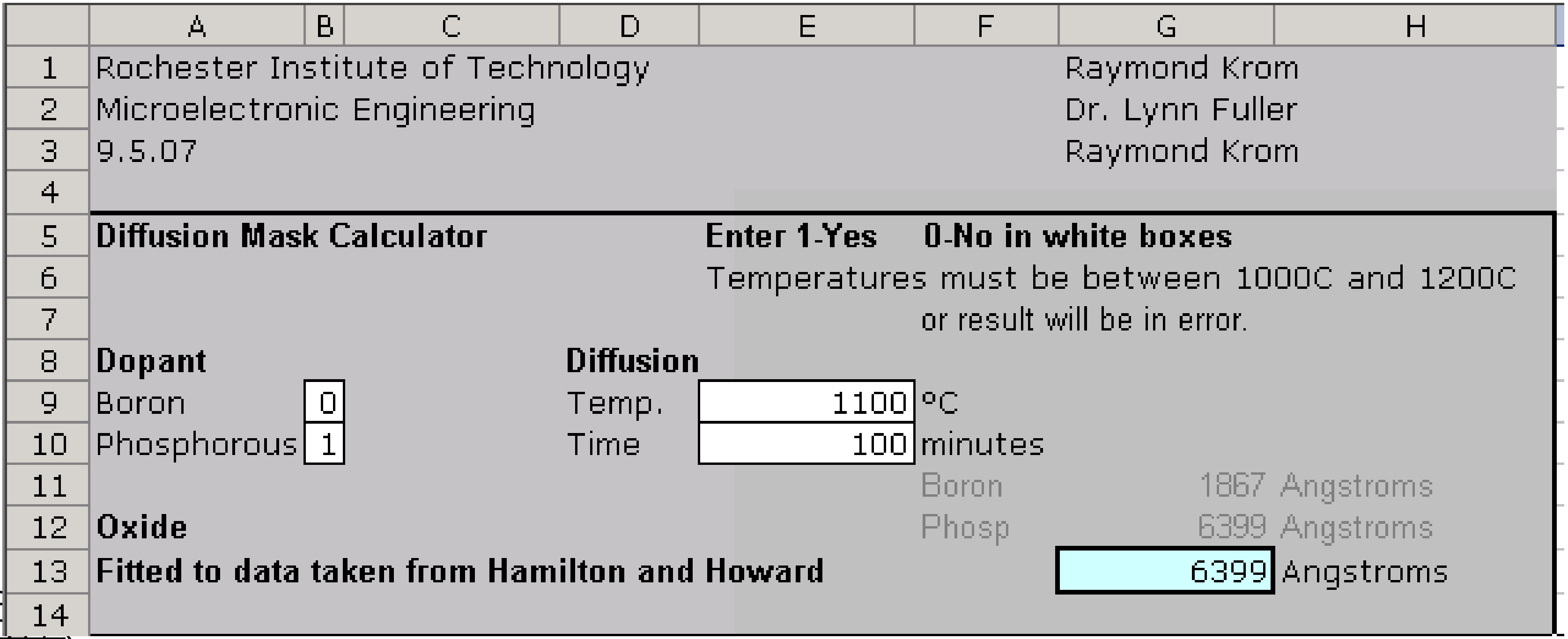
for ion implant predeposit

$$Q'_A(tp) = \mathrm{Dose}$$

Where D is the diffusion constant at the drive in temperature and t is the drive in diffusion time, Dp is the diffusion constant at the predeposit temperature and tp is the predeposit time

DIFFUSION MASKING CALCULATOR

Select
  Boron or Phosphorous
Enter
  Temperature and Time



	A	B	C	D	E	F	G	H
1	Rochester Institute of Technology						Raymond Krom	
2	Microelectronic Engineering						Dr. Lynn Fuller	
3	9.5.07						Raymond Krom	
4								
5	**Diffusion Mask Calculator**				**Enter 1-Yes**	**0-No in white boxes**		
6					Temperatures must be between 1000C and 1200C			
7						or result will be in error.		
8	**Dopant**			**Diffusion**				
9	Boron	0		Temp.	1100	°C		
10	Phosphorous	1		Time	100	minutes		
11						Boron	1867	Angstroms
12	**Oxide**					Phosp	6399	Angstroms
13	**Fitted to data taken from Hamilton and Howard**						6399	Angstroms
14								

From: Hamilton and Howard

DIFFUSION MASKING

Phosphorous Masking

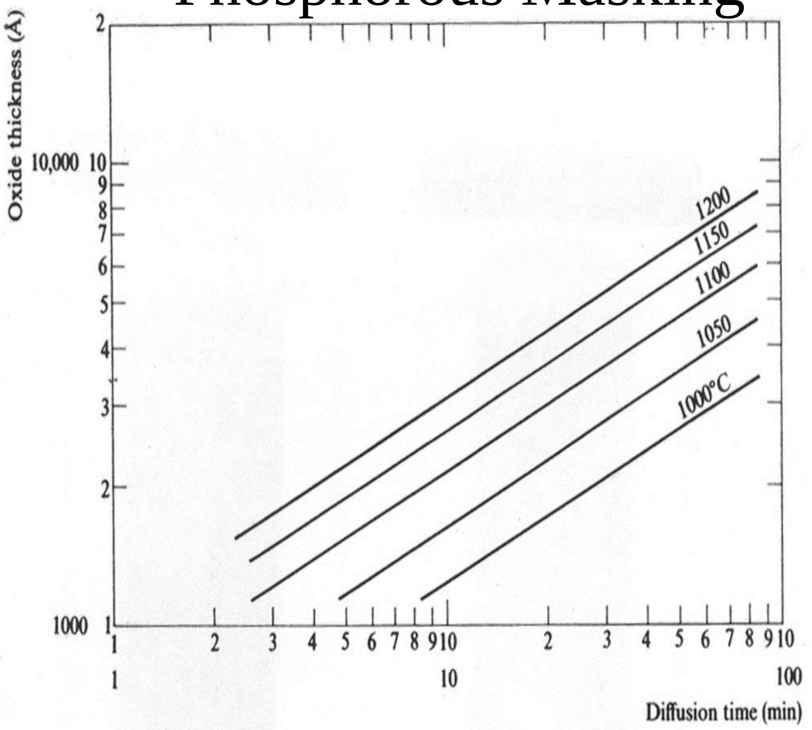


FIGURE 2-28
Minimum oxide thickness required for phosphorus diffusion masking as a function of time (after Burger and Donovan[4]).

Boron Masking

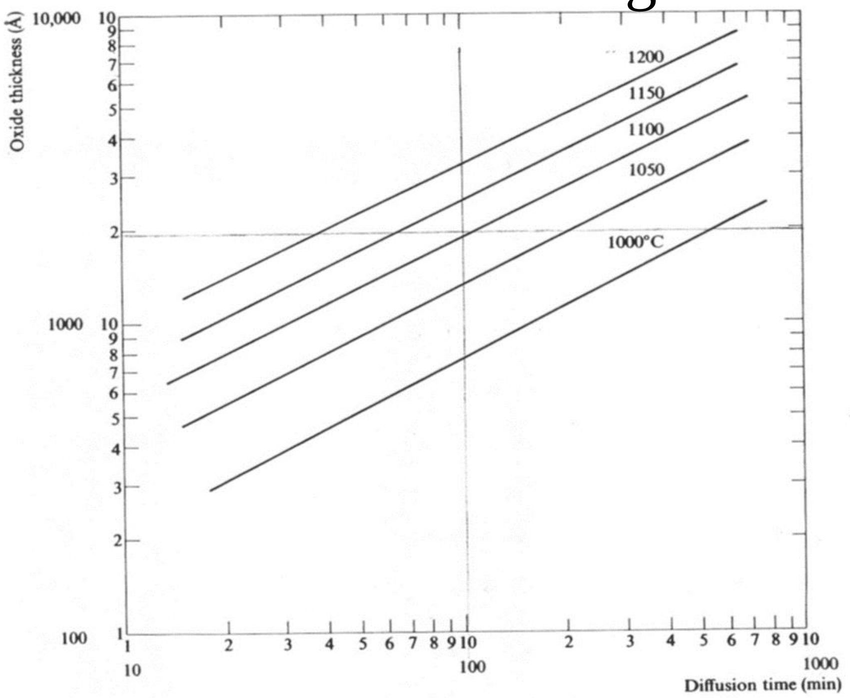
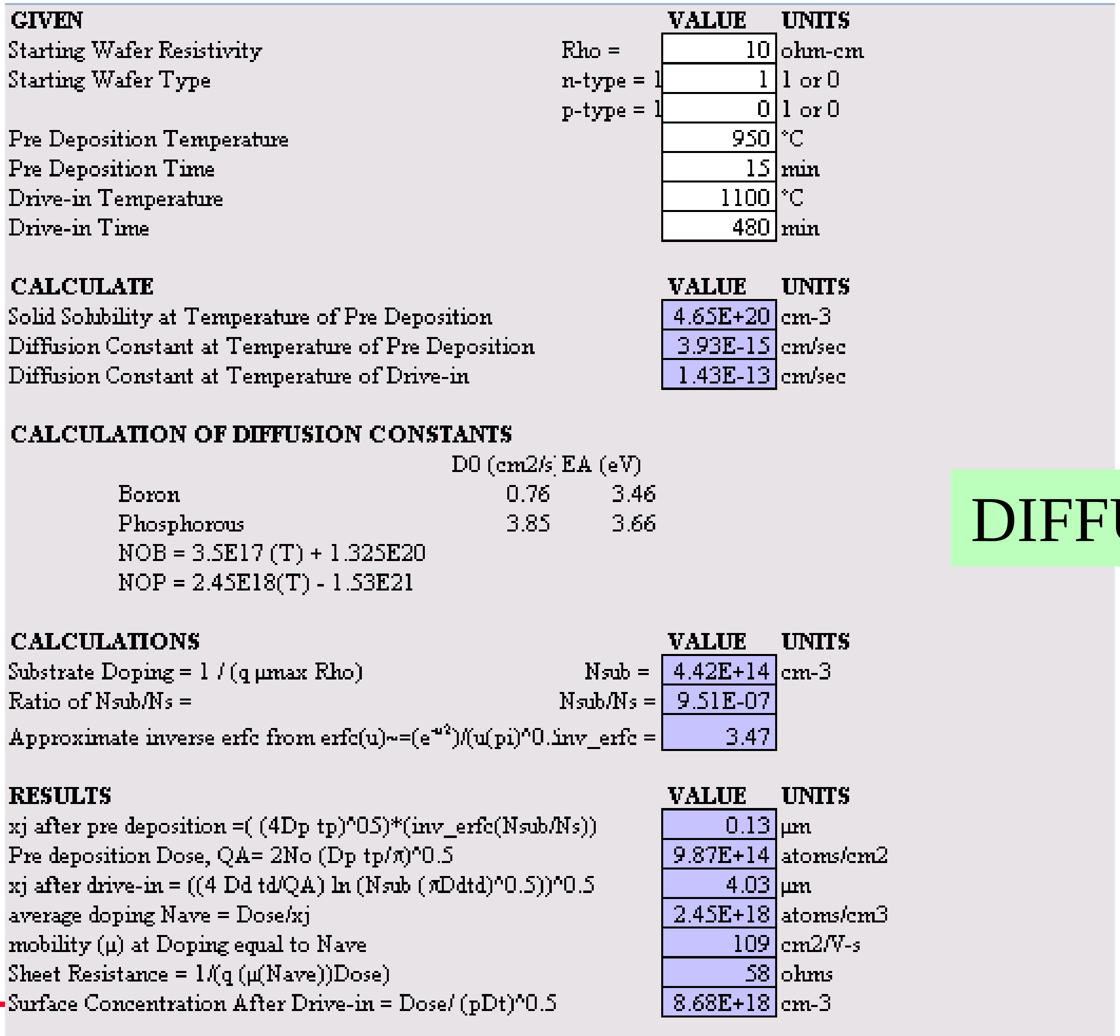


FIGURE 2-27
Minimum oxide thickness required to mask boron at various temperatures (after Burger and Donovan[4]).

From: Hamilton and Howard

DIFFUSION AND DRIVE IN CALCULATIONS



GIVEN		VALUE	UNITS
Starting Wafer Resistivity	Rho =	10	ohm-cm
Starting Wafer Type	n-type = 1	1	1 or 0
	p-type = 1	0	1 or 0
Pre Deposition Temperature		950	°C
Pre Deposition Time		15	min
Drive-in Temperature		1100	°C
Drive-in Time		480	min

CALCULATE	VALUE	UNITS
Solid Solubility at Temperature of Pre Deposition	4.65E+20	cm-3
Diffusion Constant at Temperature of Pre Deposition	3.93E-15	cm/sec
Diffusion Constant at Temperature of Drive-in	1.43E-13	cm/sec

CALCULATION OF DIFFUSION CONSTANTS

	D0 (cm2/s)	EA (eV)
Boron	0.76	3.46
Phosphorous	3.85	3.66

NOB = 3.5E17 (T) + 1.325E20

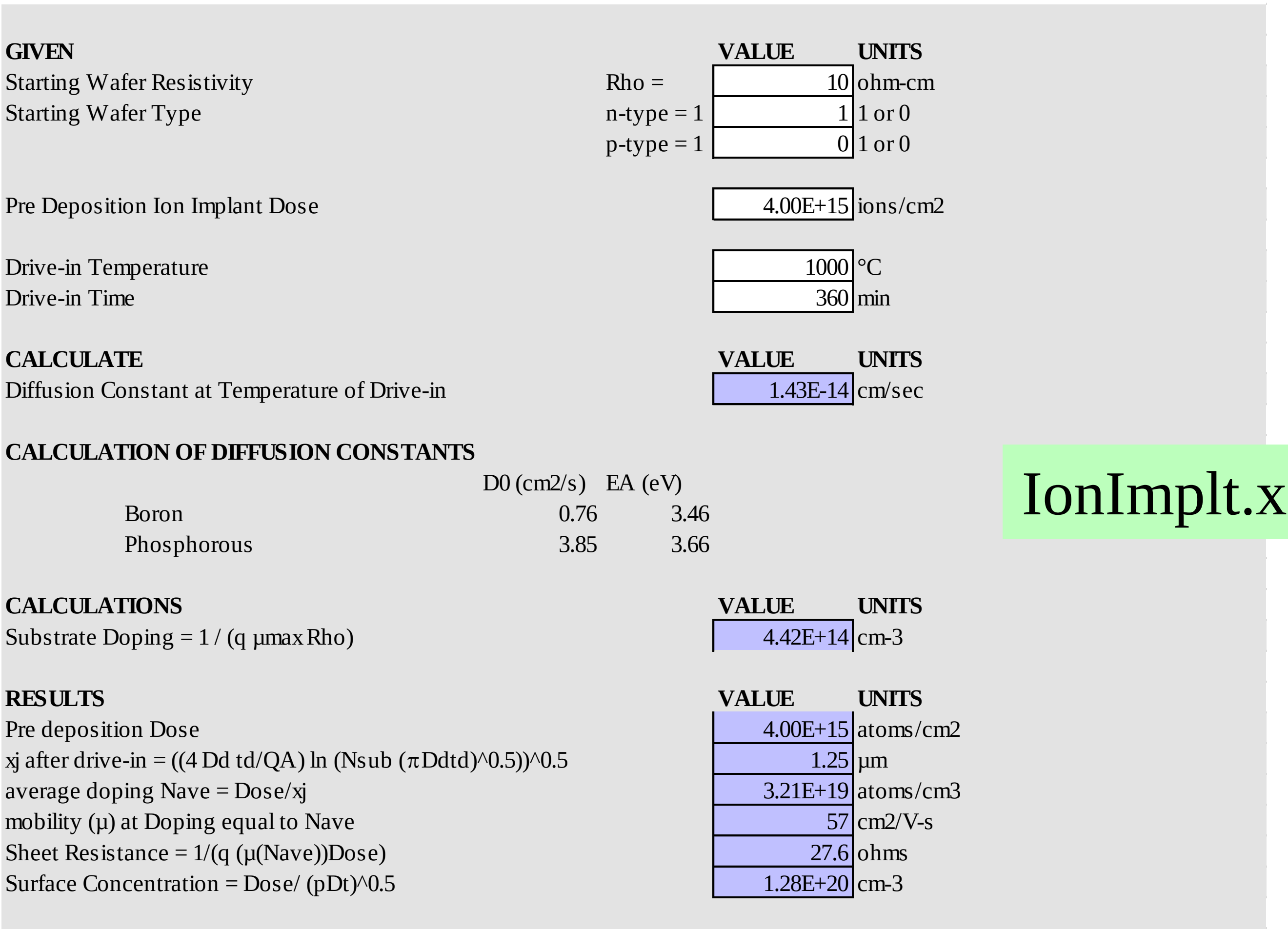
NOP = 2.45E18(T) - 1.53E21

CALCULATIONS		VALUE	UNITS
Substrate Doping = 1 / (q µmax Rho)	Nsub =	4.42E+14	cm-3
Ratio of Nsub/Ns =	Nsub/Ns =	9.51E-07	
Approximate inverse erfc from erfc(u)~=(e$^{-u^2}$)/(u(pi)^0.	inv_erfc =	3.47	

RESULTS	VALUE	UNITS
xj after pre deposition =((4Dp tp)^05)*(inv_erfc(Nsub/Ns))	0.13	µm
Pre deposition Dose, QA= 2No (Dp tp/π)^0.5	9.87E+14	atoms/cm2
xj after drive-in = ((4 Dd td/QA) ln (Nsub (πDdtd)^0.5))^0.5	4.03	µm
average doping Nave = Dose/xj	2.45E+18	atoms/cm3
mobility (µ) at Doping equal to Nave	109	cm2/V-s
Sheet Resistance = 1/(q (µ(Nave))Dose)	58	ohms
Surface Concentration After Drive-in = Dose/ (pDt)^0.5	8.68E+18	cm-3

DIFFUSION.XLS

DIFFUSION FROM A LIMITED SOURCE



GIVEN		**VALUE**	**UNITS**
Starting Wafer Resistivity	Rho =	10	ohm-cm
Starting Wafer Type	n-type = 1	1	1 or 0
	p-type = 1	0	1 or 0
Pre Deposition Ion Implant Dose		4.00E+15	ions/cm2
Drive-in Temperature		1000	°C
Drive-in Time		360	min

CALCULATE	**VALUE**	**UNITS**
Diffusion Constant at Temperature of Drive-in	1.43E-14	cm/sec

CALCULATION OF DIFFUSION CONSTANTS

	D0 (cm2/s)	EA (eV)
Boron	0.76	3.46
Phosphorous	3.85	3.66

CALCULATIONS	**VALUE**	**UNITS**
Substrate Doping = 1 / (q µmax Rho)	4.42E+14	cm-3

RESULTS	**VALUE**	**UNITS**
Pre deposition Dose	4.00E+15	atoms/cm2
xj after drive-in = ((4 Dd td/QA) ln (Nsub (π Ddtd)^0.5))^0.5	1.25	µm
average doping Nave = Dose/xj	3.21E+19	atoms/cm3
mobility (µ) at Doping equal to Nave	57	cm2/V-s
Sheet Resistance = 1/(q (µ(Nave))Dose)	27.6	ohms
Surface Concentration = Dose/ (pDt)^0.5	1.28E+20	cm-3

IonImplt.xls

EXAMPLE

1. A predeposit from a p-type spin-on dopant into a 1E15 cm-3 wafer is done at 1100°C for 10 min. Calculate the resulting junction depth and dose.

2. The spin-on dopant is removed and the Boron is driven in for 2 hours at 1100 °C. What is the new junction depth?

RESISTANCE, RESISTIVITY, SHEET RESISTANCE

Resistance = R = ρ L/Area = ρ_s L/w ohms

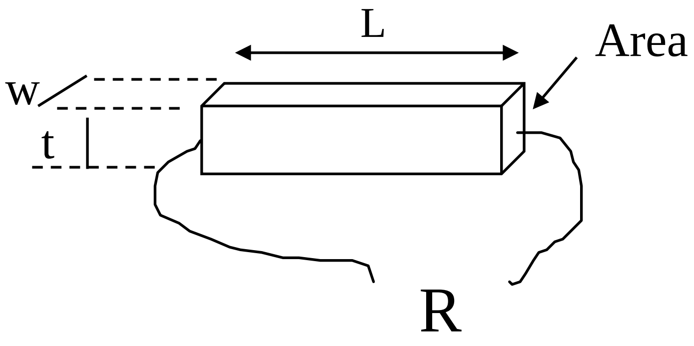
Resistivity = ρ = $1/(q\mu_n n + q\mu_p p)$ **PLAY** ohm-cm

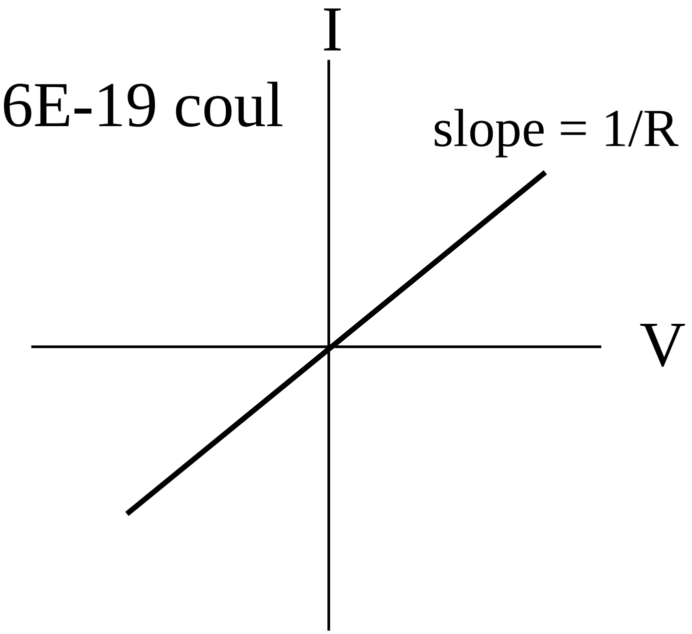
Sheet Resistance = $\rho_s = 1/(\int q\,\mu(N)\,N(x)\,dx) \sim 1/(q\mu\ \mathrm{Dose})$ ohms/square

PLAY

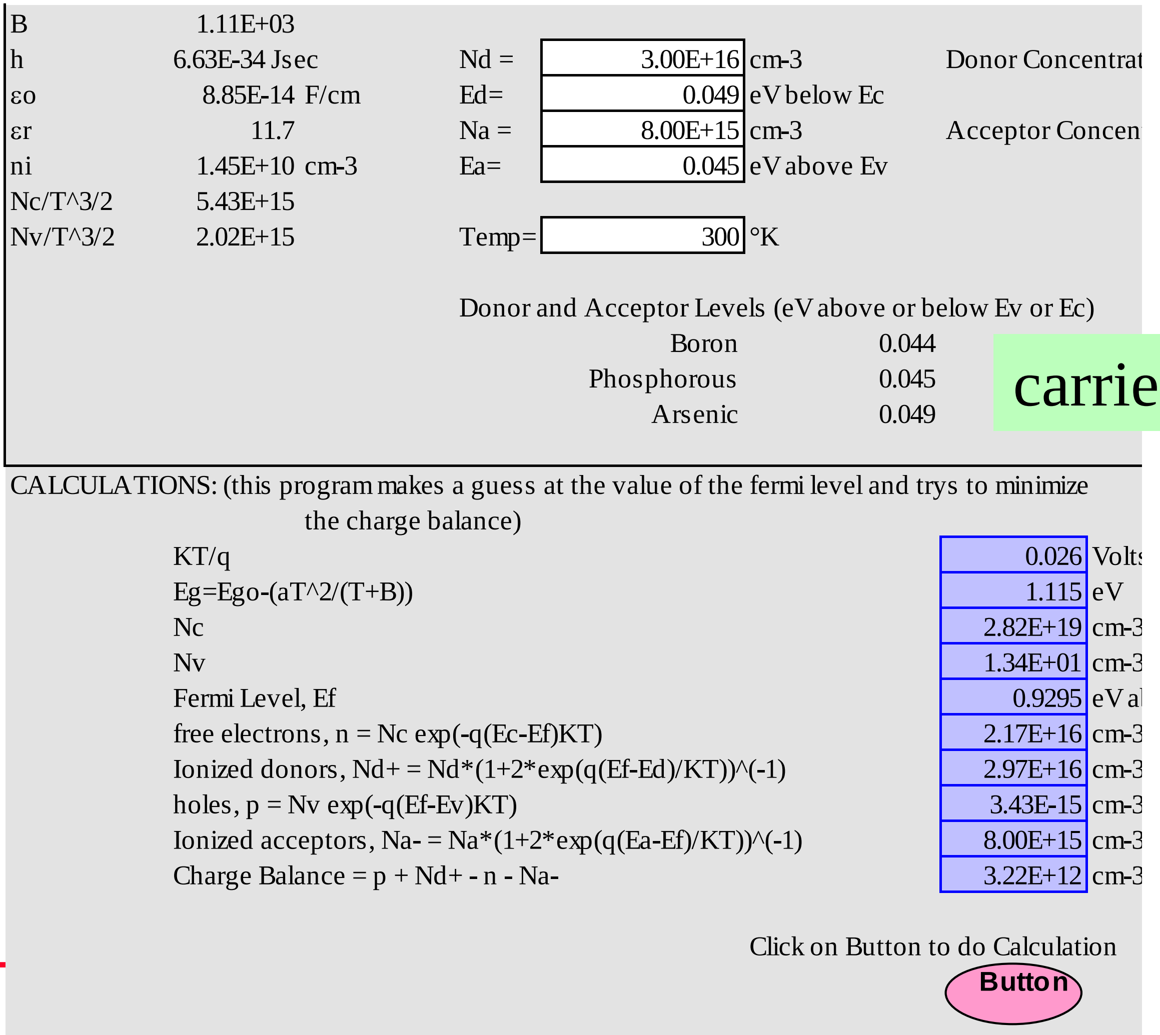
$\rho_s = \rho / t$

q = 1.6E-19 coul





CALCULATION OF CARRIER CONCENTRATIONS



B	1.11E+03				
h	6.63E-34 Jsec	Nd =	3.00E+16	cm-3	Donor Concentrat
εo	8.85E-14 F/cm	Ed=	0.049	eV below Ec	
εr	11.7	Na =	8.00E+15	cm-3	Acceptor Concen
ni	1.45E+10 cm-3	Ea=	0.045	eV above Ev	
Nc/T^3/2	5.43E+15				
Nv/T^3/2	2.02E+15	Temp=	300	°K	

Donor and Acceptor Levels (eV above or below Ev or Ec)

Boron	0.044
Phosphorous	0.045
Arsenic	0.049

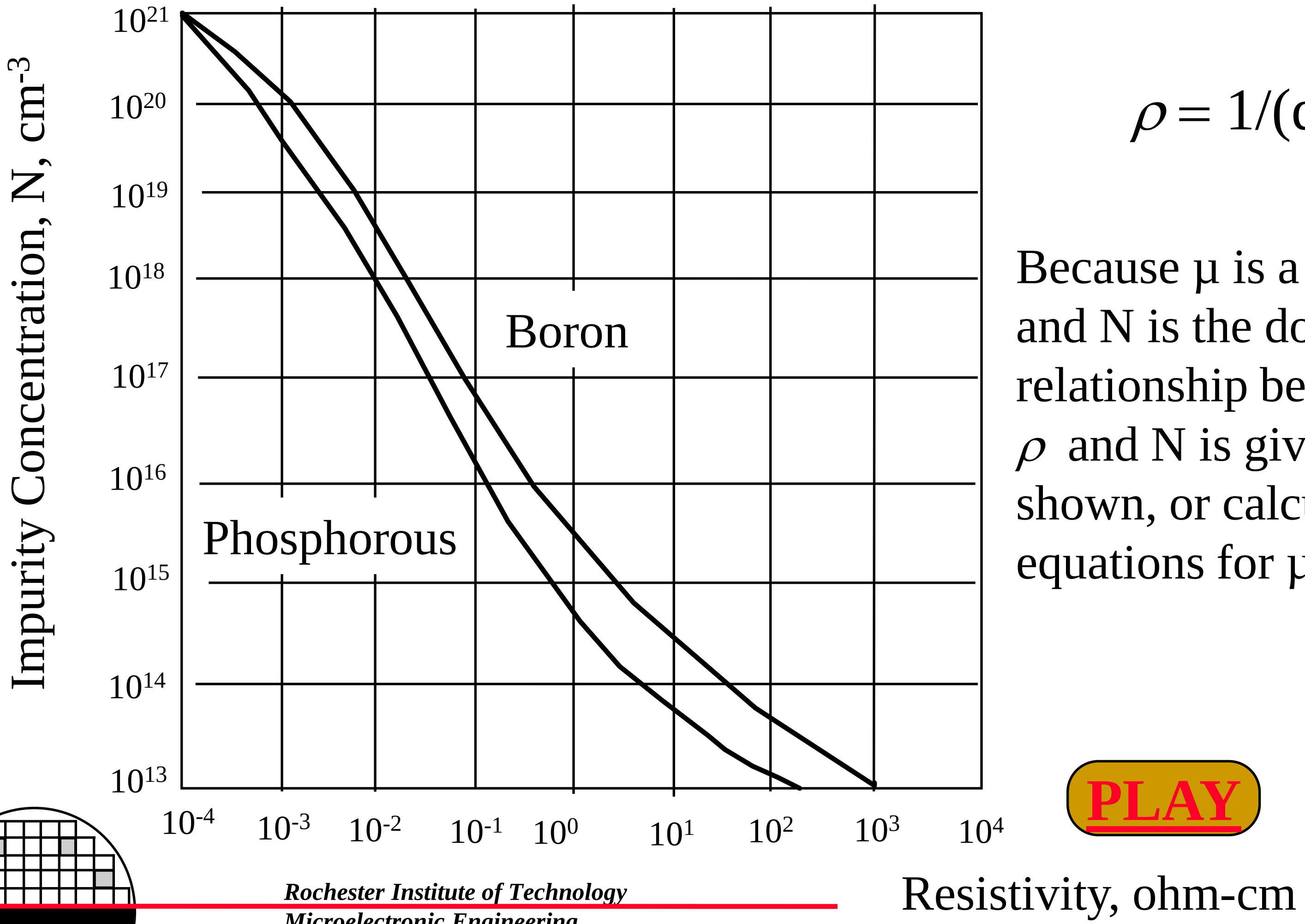
carrier_conc.xls

CALCULATIONS: (this program makes a guess at the value of the fermi level and trys to minimize the charge balance)

KT/q	0.026	Volts
Eg=Ego-(aT^2/(T+B))	1.115	eV
Nc	2.82E+19	cm-3
Nv	1.34E+01	cm-3
Fermi Level, Ef	0.9295	eV al
free electrons, n = Nc exp(-q(Ec-Ef)KT)	2.17E+16	cm-3
Ionized donors, Nd+ = Nd*(1+2*exp(q(Ef-Ed)/KT))^(-1)	2.97E+16	cm-3
holes, p = Nv exp(-q(Ef-Ev)KT)	3.43E-15	cm-3
Ionized acceptors, Na- = Na*(1+2*exp(q(Ea-Ef)/KT))^(-1)	8.00E+15	cm-3
Charge Balance = p + Nd+ - n - Na-	3.22E+12	cm-3

Click on Button to do Calculation

RESISTIVITY OF SILICON VS DOPING

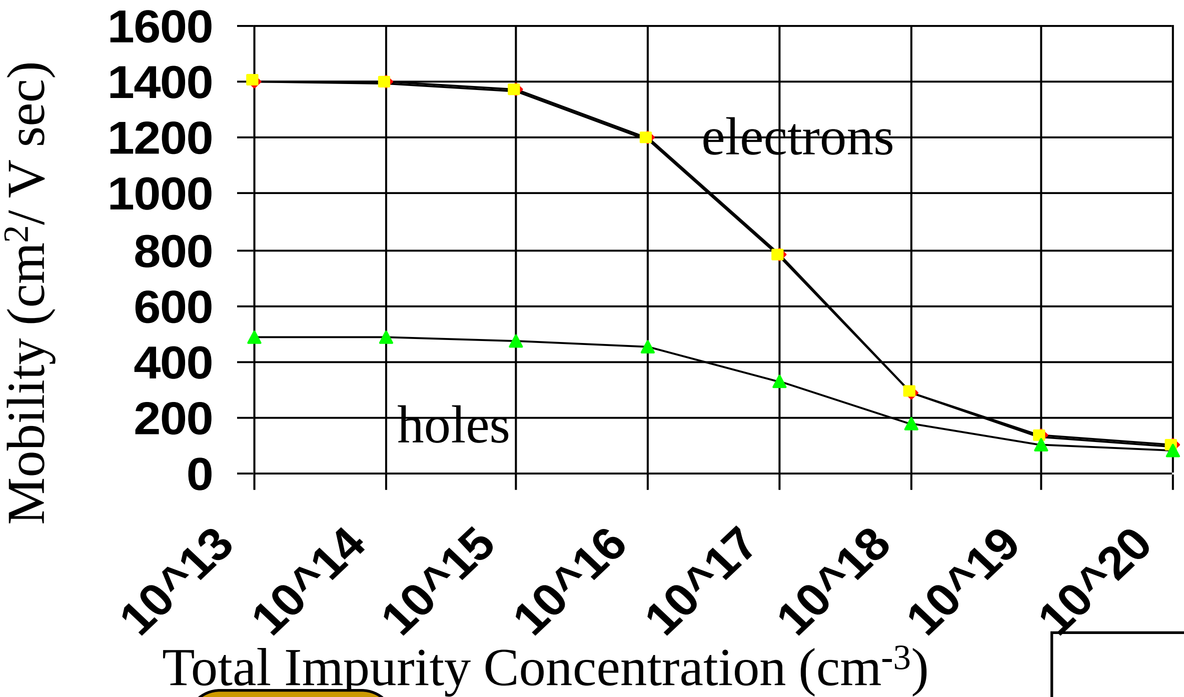


$$\rho = 1/(q\mu(N)N)$$

Because μ is a function of N and N is the doping, the relationship between resistivity ρ and N is given in the figure shown, or calculated from equations for μ(N)

PLAY

ELECTRON AND HOLE MOBILITY



PLAY

PLAY

Electron and hole mobilities in silicon at 300 K as functions of the total dopant concentration (N). The values plotted are the results of the curve fitting measurements from several sources. The mobility curves can be generated using the equation below with the parameters shown:

$$\mu(N) = \mu_{mi} + \frac{(\mu_{max}-\mu_{min})}{\{1 + (N/N_{ref})^{\alpha}\}}$$

Parameter	Arsenic	Phosphorous	Boron
μ_{min}	52.2	68.5	44.9
μ_{max}	1417	1414	470.5
N_{ref}	9.68X10^16	9.20X10^16	2.23X10^17
α	0.680	0.711	0.719

From Muller and Kamins, 3rd Ed., pg 33

TEMPERATURE EFFECTS ON MOBILITY

Derived empirically for silicon for T in K between 250 and 500 °K and for N (total dopant concentration) up to 1 E20 cm-3

$$\mu n\ (T,N) = 88\ Tn^{-0.57} + \frac{1250\ Tn^{-2.33}}{1 + [\ N\ /\ (1.26E17\ Tn^{\ 2.4})]\ \hat{}0.88\ Tn^{\ -0.146}}$$

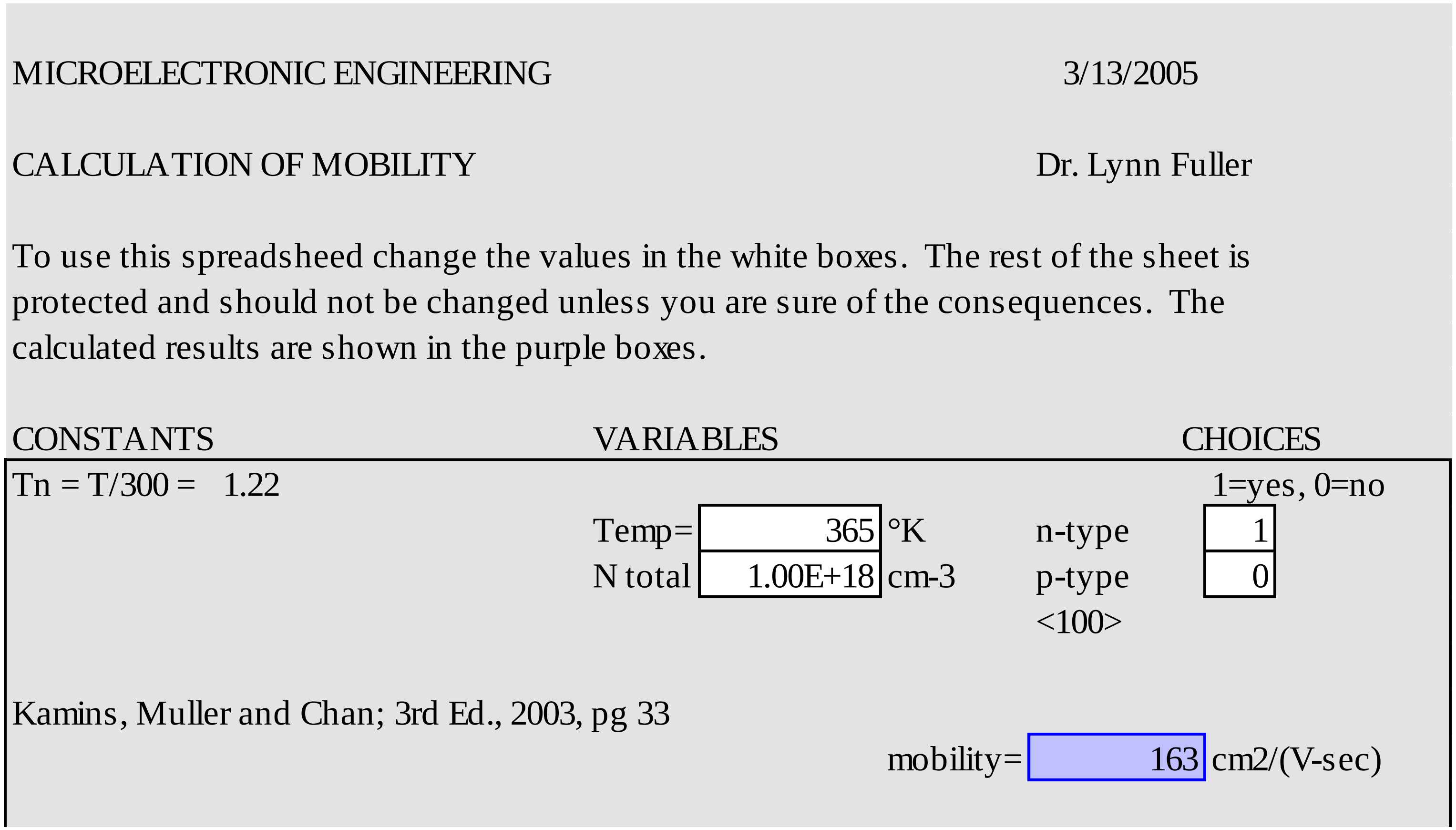
PLAY

$$\mu p\ (T,N) = 54.3\ Tn^{-0.57} + \frac{407\ Tn^{-2.33}}{1 + [\ N\ /\ (2.35E17\ Tn^{\ 2.4})]\hat{}\ 0.88\ Tn^{\ -0.146}}$$

Where Tn = T/300

From Muller and Kamins, 3rd Ed., pg 33

EXCELL WORKSHEET TO CALCULATE MOBILITY



MICROELECTRONIC ENGINEERING 3/13/2005

CALCULATION OF MOBILITY Dr. Lynn Fuller

To use this spreadsheed change the values in the white boxes. The rest of the sheet is protected and should not be changed unless you are sure of the consequences. The calculated results are shown in the purple boxes.

CONSTANTS	VARIABLES				CHOICES
Tn = T/300 = 1.22					1=yes, 0=no
	Temp=	365	°K	n-type	1
	N total	1.00E+18	cm-3	p-type	0
				<100>	

Kamins, Muller and Chan; 3rd Ed., 2003, pg 33

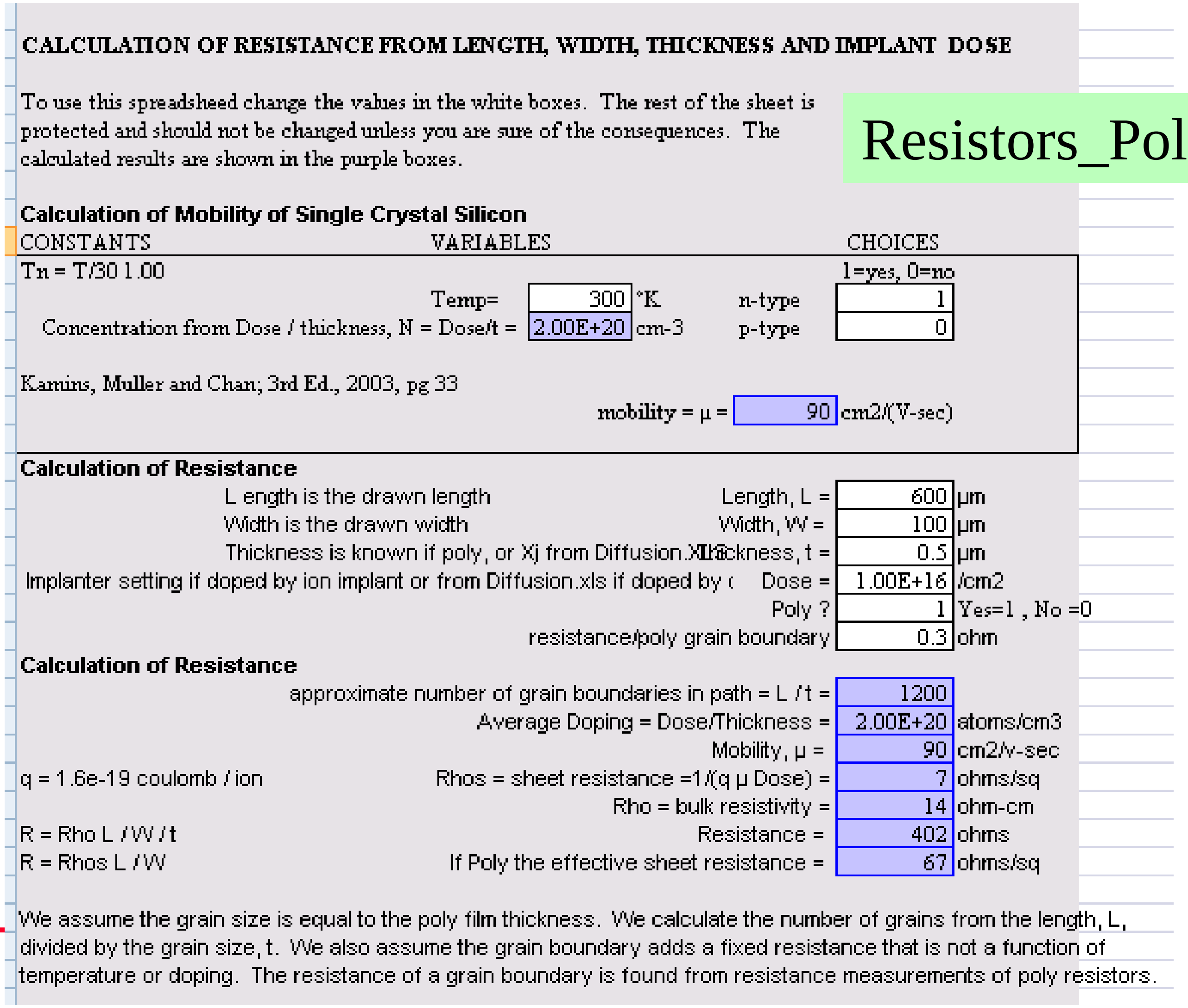
mobility= 163 cm2/(V-sec)

mobility.xls

Rochester Institute of Technology
Microelectronic Engineering

EXCELL WORKSHEET TO CALCULATE RESISTANCE

Resistors_Poly.xls



CALCULATION OF RESISTANCE FROM LENGTH, WIDTH, THICKNESS AND IMPLANT DOSE

To use this spreadsheed change the values in the white boxes. The rest of the sheet is protected and should not be changed unless you are sure of the consequences. The calculated results are shown in the purple boxes.

Calculation of Mobility of Single Crystal Silicon

CONSTANTS VARIABLES CHOICES

Tn = T/30 1.00

1=yes, 0=no

Temp= 300 °K

n-type 1

Concentration from Dose / thickness, N = Dose/t = 2.00E+20 cm-3

p-type 0

Kamins, Muller and Chan; 3rd Ed., 2003, pg 33

mobility = μ = 90 cm2/(V-sec)

Calculation of Resistance

L ength is the drawn length Length, L = 600 µm

Width is the drawn width Width, W = 100 µm

Thickness is known if poly, or Xj from Diffusion.XlThickness, t = 0.5 µm

Implanter setting if doped by ion implant or from Diffusion.xls if doped by Dose = 1.00E+16 /cm2

Poly ? 1 Yes=1 , No =0

resistance/poly grain boundary 0.3 ohm

Calculation of Resistance

approximate number of grain boundaries in path = L / t = 1200

Average Doping = Dose/Thickness = 2.00E+20 atoms/cm3

Mobility, μ = 90 cm2/v-sec

q = 1.6e-19 coulomb / ion

Rhos = sheet resistance =1/(q μ Dose) = 7 ohms/sq

Rho = bulk resistivity = 14 ohm-cm

R = Rho L / W / t

Resistance = 402 ohms

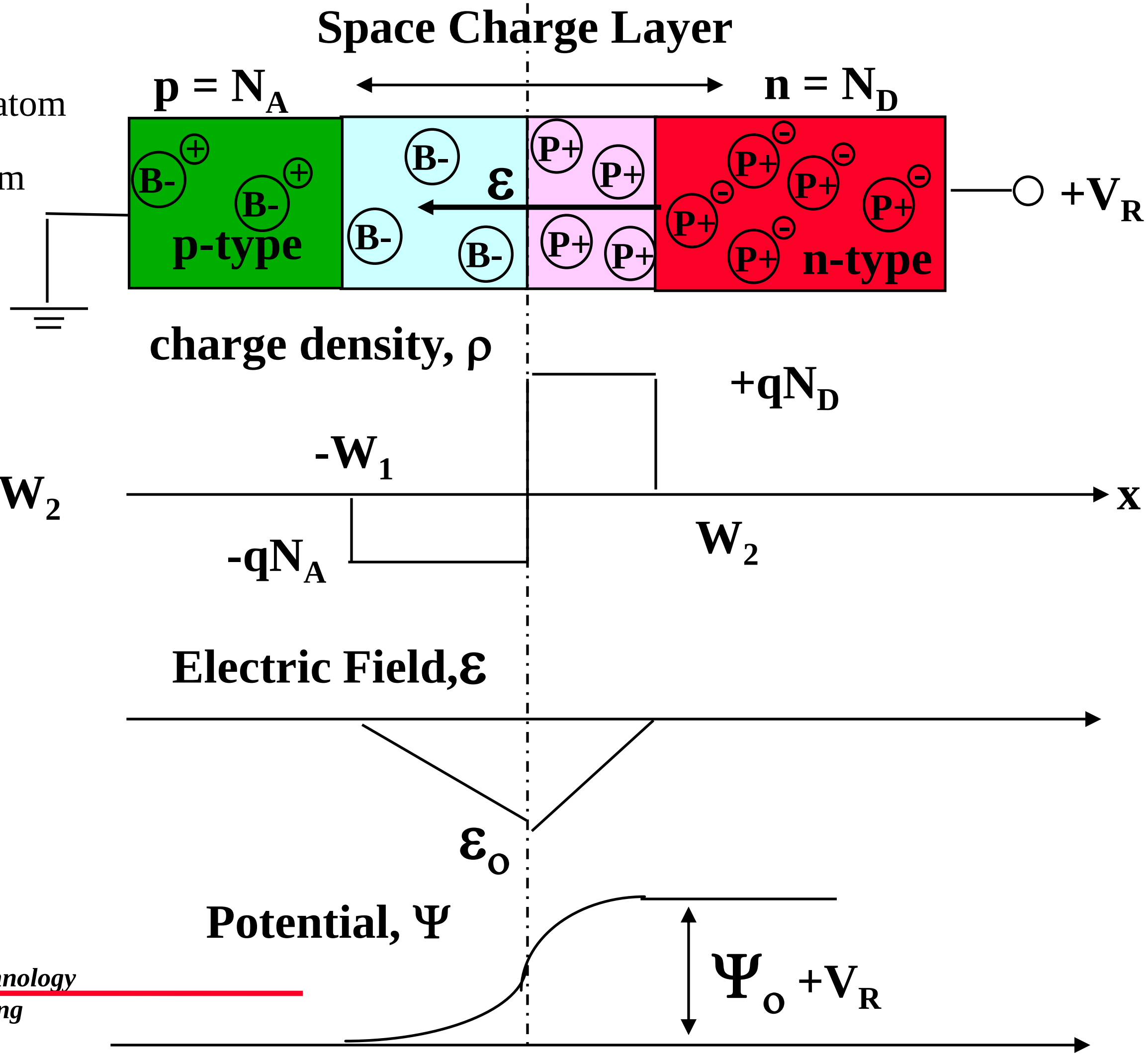
R = Rhos L / W

If Poly the effective sheet resistance = 67 ohms/sq

We assume the grain size is equal to the poly film thickness. We calculate the number of grains from the length, L, divided by the grain size, t. We also assume the grain boundary adds a fixed resistance that is not a function of temperature or doping. The resistance of a grain boundary is found from resistance measurements of poly resistors.

UNIFORMLY DOPED PN JUNCTION

P+ ⊖	Phosphrous donor atom and electron
P+	Ionized Immobile Phosphrous donor atom
B-	Ionized Immobile Boron acceptor atom
B- ⊕	Boron acceptor atom and hole



$$qN_A W_1 = qN_D W_2$$

UNIFORMLY DOPED PN JUNCTION

Built in Voltage:

$$\Psi_o = KT/q \quad \ln (N_A N_D / ni^2)$$

$ni = 1.45E10\ cm^{-3}$

Width of Space Charge Layer, W: with reverse bias of V_R volts

$$W = (W_1 + W_2) = [\,(2\varepsilon/q)(\Psi_o + V_R)(1/N_A + 1/N_D)]^{1/2}$$

W_1 width on p-side **W_2 width on n-side**

$W_1 = W\,[N_D/(N_A + N_D)]$ $W_2 = W\,[N_A/(N_A + N_D)]$

Maximum Electric Field:

$$E_o = -\,[(2q/\varepsilon)(\Psi_o + V_R)(N_A N_D/(N_A + N_D))]^{1/2}$$

Junction Capacitance per unit area:

$$C_j' = \varepsilon_o \varepsilon_r / W = \varepsilon_o \varepsilon_r / [(2\varepsilon/q)(\Psi_o + V_R)(1/N_A + 1/N_D)]^{1/2}$$

$$\varepsilon = \varepsilon_o \varepsilon_r = 8.85E^{-12}\ (11.7)\ F/m$$
$$= 8.85E^{-14}\ (11.7)\ F/cm$$

EXAMPLE

Example: If the doping concentrations are Na=1E15 and Nd=3E15 cm^{-3} and the reverse bias voltage is 0, then find the built in voltage, width of the space charge layer, width on the n-side, width on the p-side, electric field maximum and junction capacitance. Repeat for reverse bias of 10, 40, and 100 volts.

Ψ_o = Vbi = KT/q ln $(N_A N_D / ni^2)$ =

W = $(W_1 + W_2)$ = $[\,(2\varepsilon/q)\,(\Psi_o + V_R)\,(1/N_A + 1/N_D)]^{1/2}$ =

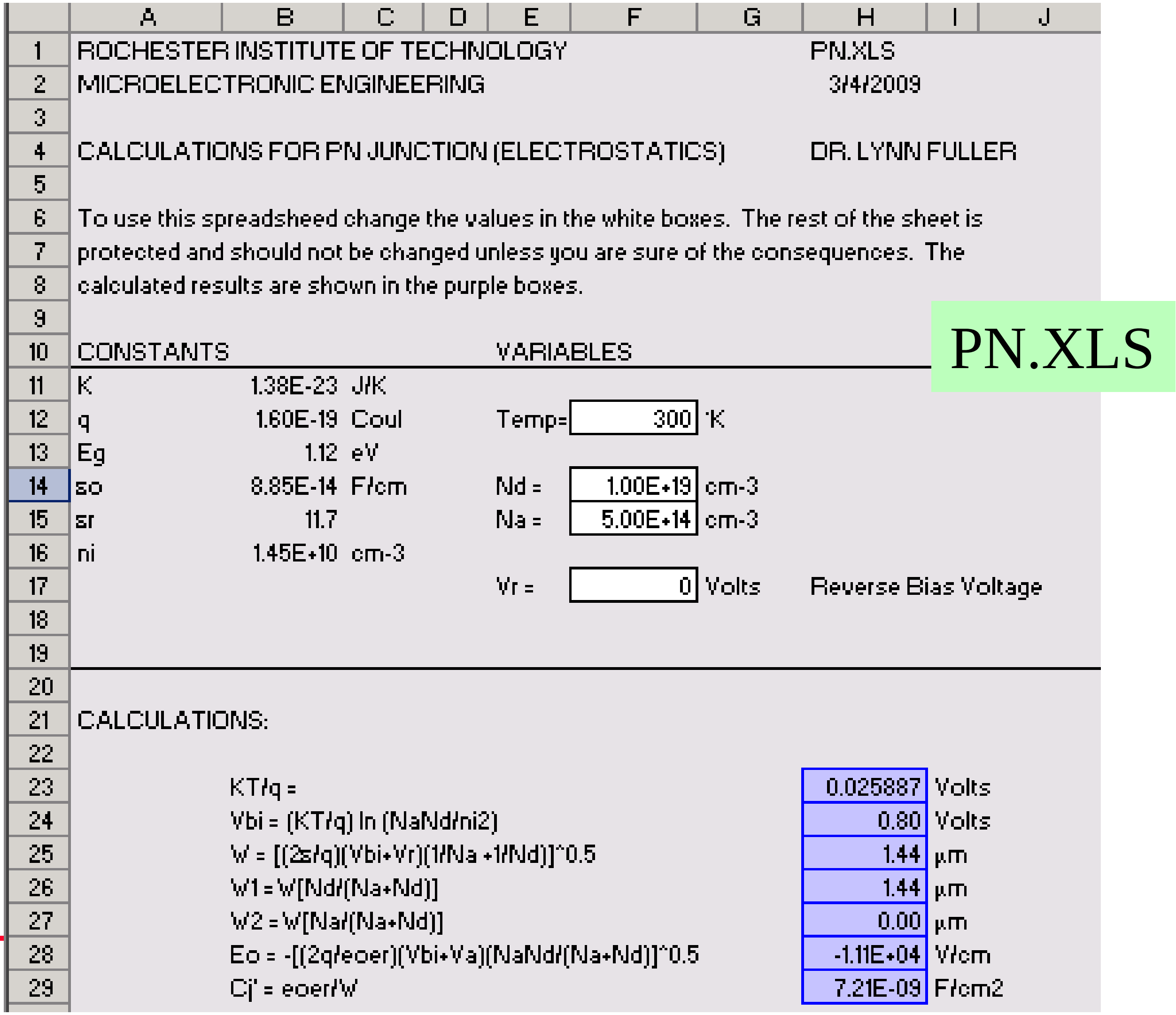
W1 =

W2 =

Emax =

Cj =

EXAMPLE CALCULATIONS



ROCHESTER INSTITUTE OF TECHNOLOGY PN.XLS
MICROELECTRONIC ENGINEERING 3/4/2009

CALCULATIONS FOR PN JUNCTION (ELECTROSTATICS) DR. LYNN FULLER

To use this spreadsheed change the values in the white boxes. The rest of the sheet is protected and should not be changed unless you are sure of the consequences. The calculated results are shown in the purple boxes.

CONSTANTS			VARIABLES		
K	1.38E-23	J/K			
q	1.60E-19	Coul	Temp=	300	°K
Eg	1.12	eV			
εo	8.85E-14	F/cm	Nd =	1.00E+19	cm-3
εr	11.7		Na =	5.00E+14	cm-3
ni	1.45E+10	cm-3			
			Vr =	0	Volts Reverse Bias Voltage

CALCULATIONS:

KT/q =	0.025887	Volts
Vbi = (KT/q) ln (NaNd/ni2)	0.80	Volts
W = [(2ε/q)(Vbi+Vr)(1/Na +1/Nd)]^0.5	1.44	µm
W1 = W[Nd/(Na+Nd)]	1.44	µm
W2 = W[Na/(Na+Nd)]	0.00	µm
Eo = -[(2q/eoer)(Vbi+Va)(NaNd/(Na+Nd)]^0.5	-1.11E+04	V/cm
Cj' = eoer/W	7.21E-09	F/cm2

PN.XLS

LONG CHANNEL THRESHOLD VOLTAGE, VT

Flat-band Voltage $V_{FB} = \phi_{ms} - \frac{Q_{ss}}{C'_{ox}} - \frac{1}{C'_{ox}} \int_{0}^{Xox} \frac{X}{X_{ox}} \rho(x)\, dx$

p-type substrate (n-channel)

n-type substrate (p-channel)

$Q_{ss} = q\, N_{ss}$

Bulk Potential : $\phi_p = -KT/q \;\; \ln (N_A / n_i)$ | $\phi_n = +KT/q \;\; \ln (N_D / n_i)$

Work Function Difference: $\phi_{M\,S} = \phi_M - (X + Eg/2q + [\phi_p])$ | $\phi_{M\,S} = \phi_M - (X + Eg/2q - [\phi_n])$

Maximum Depletion Width: (W_{dmax}) $\sqrt{\frac{4\, \varepsilon s [\phi_p]}{qNa}}$ | $\sqrt{\frac{4\, \varepsilon s [\phi_n]}{qNd}}$

Threshold Voltage: $VT = V_{FB} + 2\, [\phi_p] + \frac{1}{C'_{ox}} \sqrt{2\, \varepsilon s\, q\, Na\, (2[\phi_p])}$

p-type substrate

Threshold Voltage: $VT = V_{FB} - 2\, [\phi_n] - \frac{1}{C'_{ox}} \sqrt{2\, \varepsilon s\, q\, Nd\, (2[\phi_n])}$

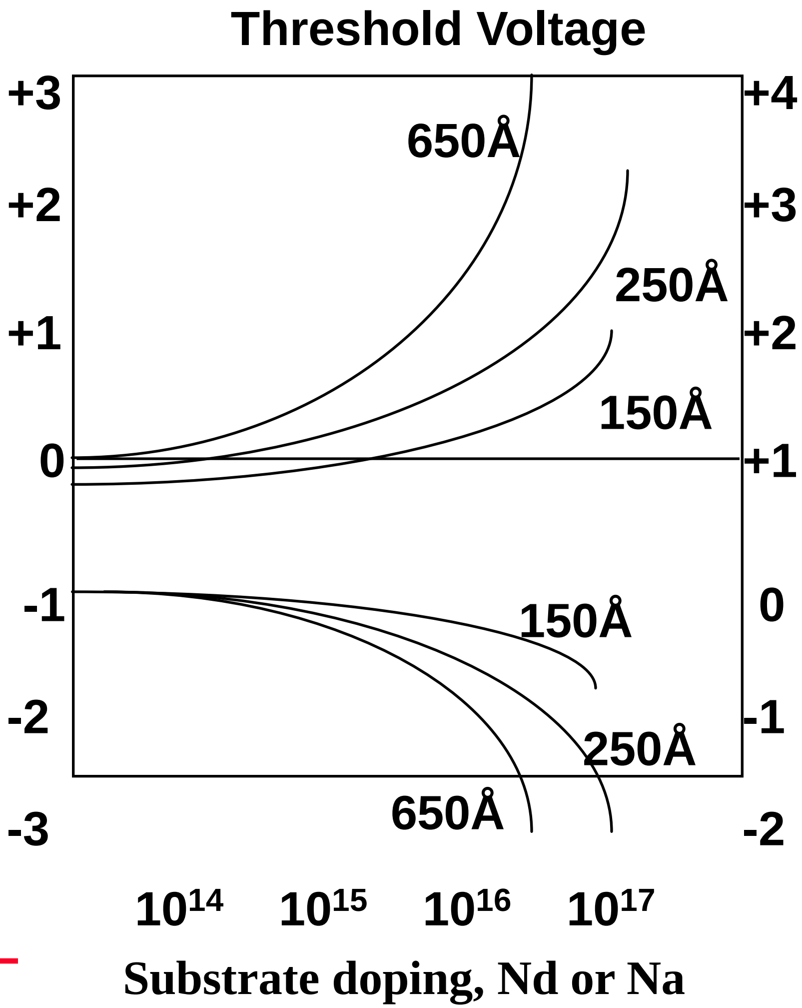
n-type substrate

PLAY

LONG CHANNEL Vt

Gate work function, n+, p+, aluminum
Substrate doping, Nd or Na
Oxide thickness, Xox
Surface State Density, Nss or Qss
also
Substrate to Source voltage difference

PLAY



n+ poly gate left scale
p+ poly gate right scale
Qf = 0
Vbs = 0
implant dose = zero

VT ADJUST IMPLANT

Assume that the total implant is shallow (within W_{dmax})

$$\boxed{+/- \Delta Vt = q\ Dose^*/Cox'}$$

where Dose* is the dose that is added to the Si

Cox' is gate oxide capacitance/cm^2

$Cox' = \varepsilon o \varepsilon r / Xox$

Boron gives + shift

Phosphorous gives - shift

Example: To shift +1.0 volts implant Boron through 1000 Å Kooi oxide at an energy to place the peak of the implant at the oxide/silicon interface. Use a Dose = $\Delta Vt\ \ Cox'/q$

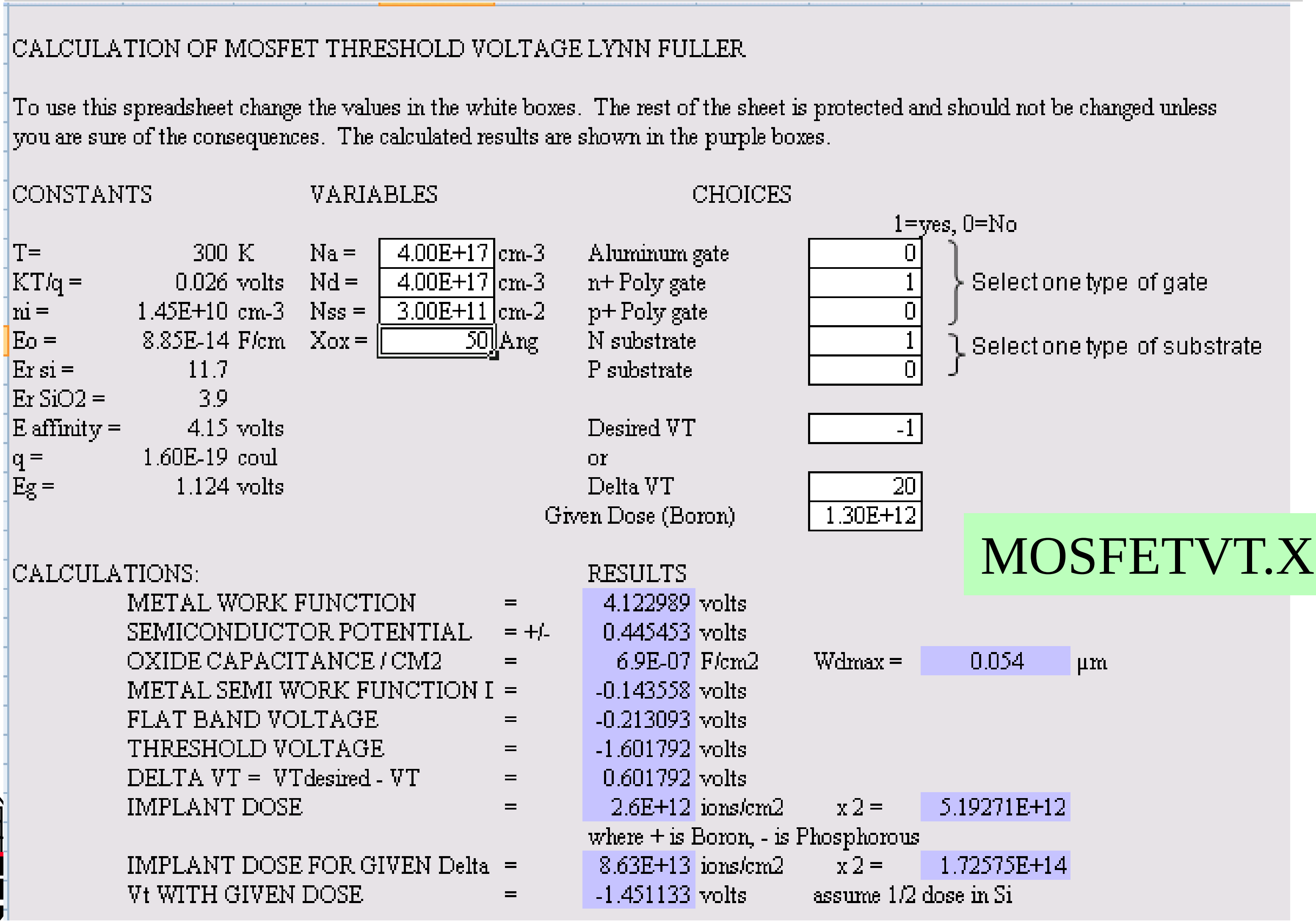
$=(1.0)(3.9)(8.85E\text{-}14)/(1.6E\text{-}16)=2.16E11$ ions/cm^2

but multiply by 2 since 1/2 goes into silicon

Rochester Institute of Technology
Microelectronic Engineering

PLAY

MOSFET THRESHOLD VOLTAGE CALCULATION



CALCULATION OF MOSFET THRESHOLD VOLTAGE LYNN FULLER

To use this spreadsheet change the values in the white boxes. The rest of the sheet is protected and should not be changed unless you are sure of the consequences. The calculated results are shown in the purple boxes.

CONSTANTS			VARIABLES			CHOICES	
							1=yes, 0=No
T=	300	K	Na =	4.00E+17	cm-3	Aluminum gate	0
KT/q =	0.026	volts	Nd =	4.00E+17	cm-3	n+ Poly gate	1
ni =	1.45E+10	cm-3	Nss =	3.00E+11	cm-2	p+ Poly gate	0
Eo =	8.85E-14	F/cm	Xox =	50	Ang	N substrate	1
Er si =	11.7					P substrate	0
Er SiO2 =	3.9						
E affinity =	4.15	volts				Desired VT	-1
q =	1.60E-19	coul				or	
Eg =	1.124	volts				Delta VT	20
						Given Dose (Boron)	1.30E+12

} Select one type of gate

} Select one type of substrate

MOSFETVT.XLS

CALCULATIONS:		RESULTS				
METAL WORK FUNCTION	=	4.122989	volts			
SEMICONDUCTOR POTENTIAL	= +/-	0.445453	volts			
OXIDE CAPACITANCE / CM2	=	6.9E-07	F/cm2	Wdmax =	0.054	µm
METAL SEMI WORK FUNCTION I	=	-0.143558	volts			
FLAT BAND VOLTAGE	=	-0.213093	volts			
THRESHOLD VOLTAGE	=	-1.601792	volts			
DELTA VT = VTdesired - VT	=	0.601792	volts			
IMPLANT DOSE	=	2.6E+12	ions/cm2	x 2 =	5.19271E+12	
		where + is Boron, - is Phosphorous				
IMPLANT DOSE FOR GIVEN Delta	=	8.63E+13	ions/cm2	x 2 =	1.72575E+14	
Vt WITH GIVEN DOSE	=	-1.451133	volts	assume 1/2 dose in Si		

ION IMPLANT EQUATIONS

Gaussian Implant Profile

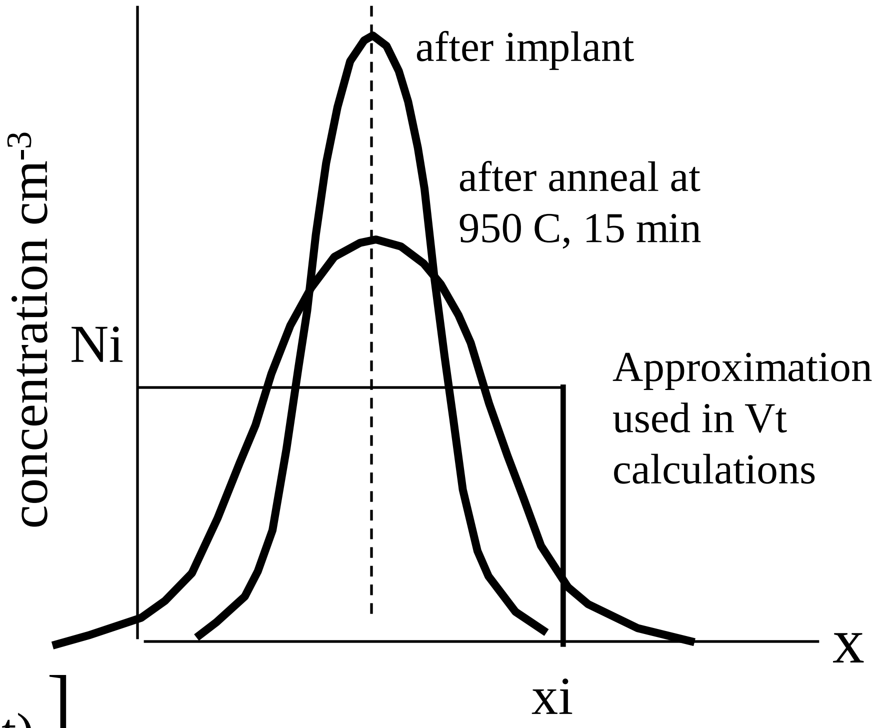
$$N(x) = \frac{N'}{\sqrt{2\pi}\ \Delta Rp} \ \exp\left[\ \frac{-(X-Rp)^2}{2\Delta Rp^2}\ \right]$$

$$\left.\begin{array}{l} Rp = \text{Range} \\ \Delta Rp = \text{Straggle} \end{array}\right\} \text{From Curves}$$

$$N' = \text{Dose} = \int \frac{I}{mqA}\ dt$$

After Anneal

$$N(x) = \frac{N'}{\sqrt{2\pi}\sqrt{\Delta Rp^2 + 2Dt}} \ \exp\left[\ \frac{-(X-Rp)^2}{2(\Delta Rp^2+Dt)}\ \right]$$



Approximation

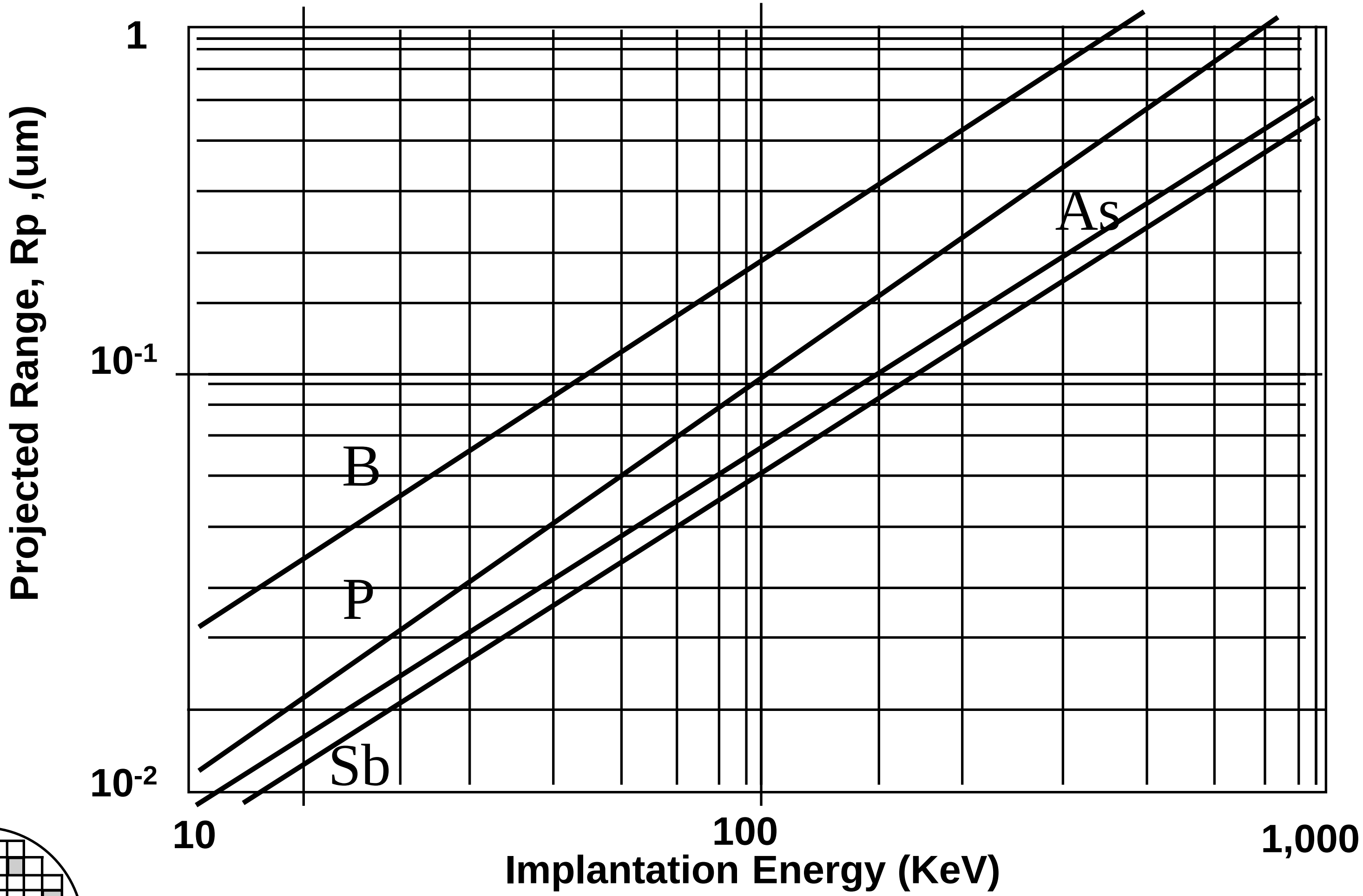
$N' = Ni\ xi$

where D is diffusion constant at the anneal temperature

t is time of anneal

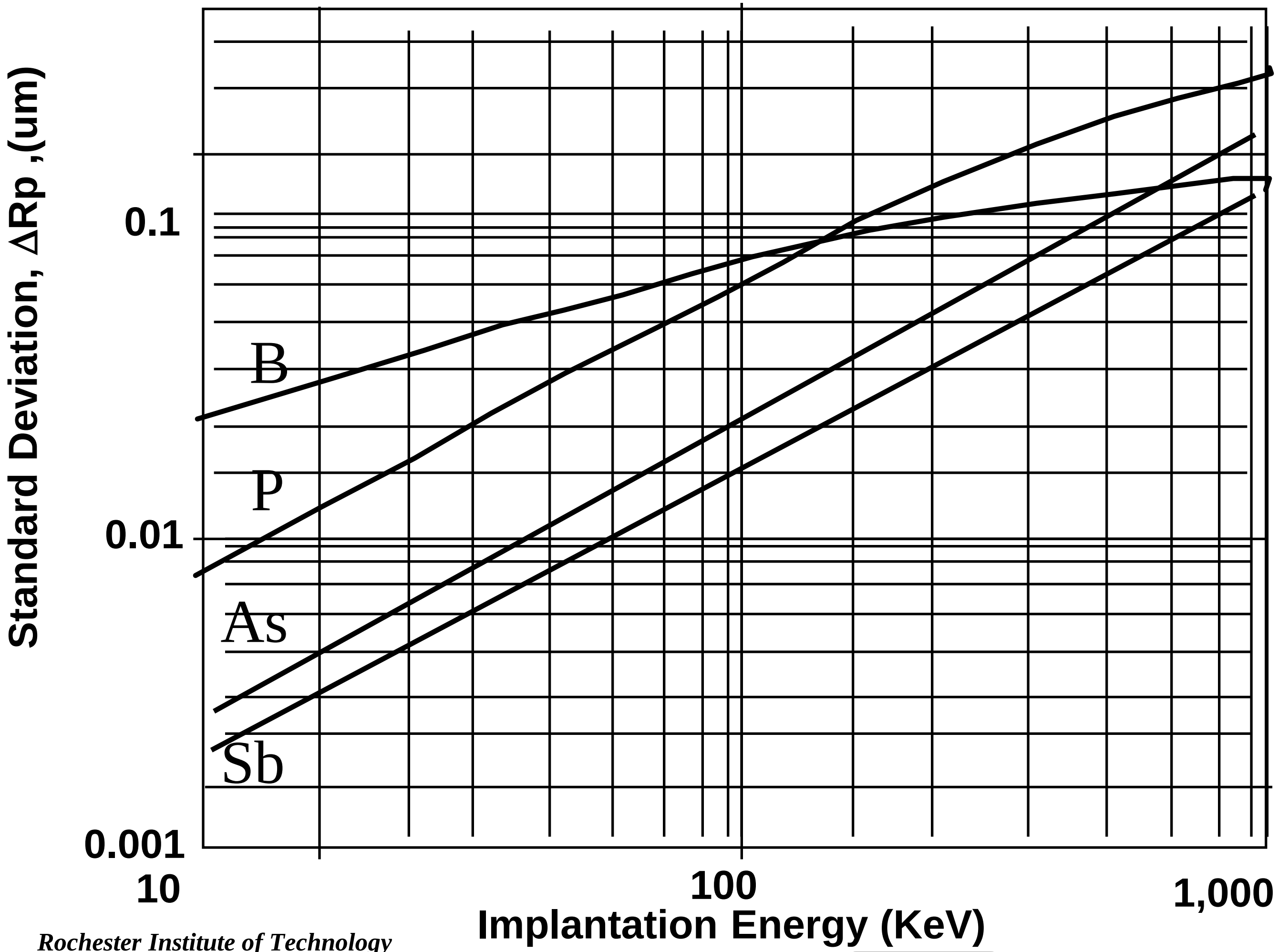
PLAY

ION IMPLANT RANGE



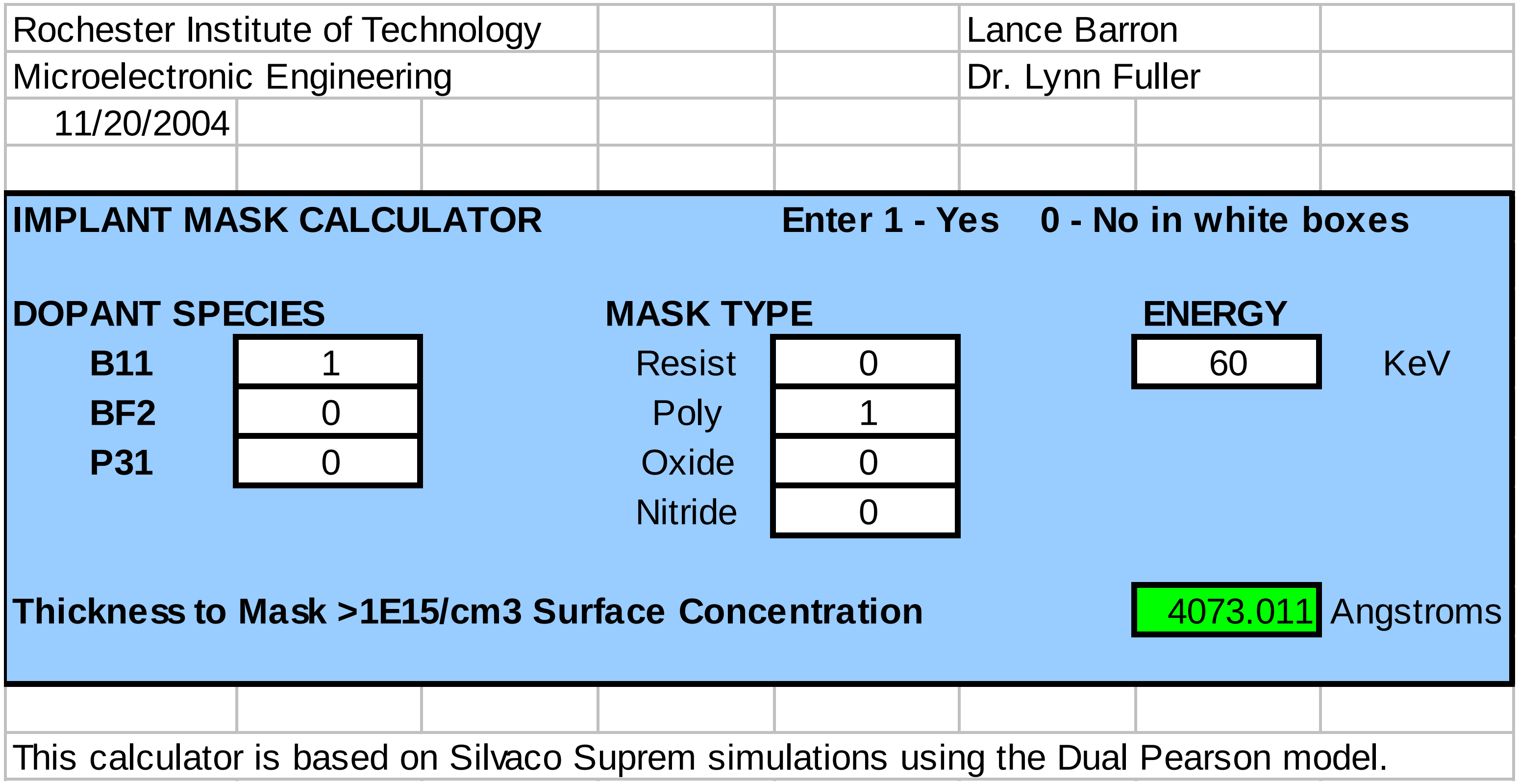
PLAY

ION IMPLANT STANDARD DEVIATION



PLAY

ION IMPLANT MASKING CALCULATOR



Rochester Institute of Technology | Lance Barron
Microelectronic Engineering | Dr. Lynn Fuller
11/20/2004

IMPLANT MASK CALCULATOR **Enter 1 - Yes 0 - No in white boxes**

DOPANT SPECIES		**MASK TYPE**		**ENERGY**	
B11	1	Resist	0	60	KeV
BF2	0	Poly	1		
P31	0	Oxide	0		
		Nitride	0		

Thickness to Mask >1E15/cm3 Surface Concentration 4073.011 Angstroms

This calculator is based on Silvaco Suprem simulations using the Dual Pearson model.

In powerpoint click on spread sheet to change settings for a new calculation

Rochester Institute of Technology
Microelectronic Engineering

Lance Baron, Fall 2004

REFERENCES

1. Basic Integrated Circuit Engineering, Douglas J. Hamilton, William G. Howard, McGraw Hill Book Co., 1975.
2. Micro Electronics Processing and Device Design, Roy a. Colclaser, John Wiley & Sons., 1980.
3. Device Electronics for Integrated Circuits, Richard S. Muller, Theodore I. Kamins, Mansun Chan, John Wiley & Sons.,3rd Ed., 2003.
4. VLSI Technology, Edited by S.M. Sze, McGraw-Hill Book Company, 1983.
5. Silicon Processing for the VLSI Era, Vol. 1., Stanley Wolf, Richard Tauber, Lattice Press, 1986.
6. The Science and Engineering of Microelectronic Fabrication, Stephen A. Campbell, Oxford University Press, 1996.

HOMEWORK - REVIEW OF IC TECHNOLOGY

1. If a window is etched in 5000 Å of oxide and the wafer is oxidized again for 50 min in wet O2 at 1050 °C what is the new thickness (where it was 5000 Å), the thickness in the etch window, and the step height in the silicon if all the oxide is etched off the wafer. Draw a picture showing original Si surface.
2. A Boron diffusion is done into 5 ohm-cm n-type wafer involving two steps. First a short predeposit at 950 C for 30 min., followed by removal of the diffusion source and a drive in at 1100 C for 2 hours. Calculate the junction depth and the sheet resistance of the diffused layers. Estimate the oxide thickness needed to mask this diffusion.
3. For a pn junction with the p side doping of 1E17 and the n side at 1E15 calculate, width of space charge layer, width on p side, on n side, capacitance per unit area, max electric field.
4. Calculate the threshold voltage for an aluminum gate PMOSFET fabricated on an n-type wafer with doping of 5E15, a surface state density of 7E10, and gate oxide thickness of 150 Å. What is the threshold voltage if the surface state density is 3E11?
5. Calculate the ion implant dose needed to shift the threshold voltage found in the problem above to -1 Volts.

PLAY

HOMEWORK - EXACT CALCULATION OF SHEET RESISTANCE FOR A DIFFUSED LAYER

1. A Boron p-type layer is diffused into an n-type silicon wafer (1E15 cm-3) at 1100 °C for 1 hour. Calculate the exact value of the sheet resistance and compare to the approximate value.

Sheet Resistance $= \rho_s = 1/\left(\int q\,\mu(N)\,N(x)\,dx\right) \sim 1/(q\mu\ \text{Dose})$ ohms/square

$$\mu(N) = \mu_{min} + \frac{(\mu_{max}-\mu_{min})}{\{1 + (N/N_{ref})^{\alpha}\}}$$

Let $Q'_A(tp) = 5.633\text{E}15\ \text{cm-2}$

$D = 1.55\text{E-13 cm2/s}$

$t = 1$ hour

for Boron

μ_{min}	44.9
μ_{max}	470.5
N_{ref}	2.23X10^17
α	0.719

$$N(x,t) = \frac{Q'_A(tp)\ \text{Exp}\ (-\,x^2/4Dt)}{\sqrt{\pi D t}}$$

HW SOLUTION - EXACT CALCULATION OF SHEET RESISTANCE FOR A DIFFUSED LAYER

Divide the diffused layer up into 100 slices and for each slice find the doping and exact mobility. Calculate the sheet resistance from the reciprocal of the sum of the conductance of each slice.