Impurity Diffusion

- Diffusion: An old concept whose mathematics have been worked out for a long time.
- Diffusion: A concentration gradient will cause a force to redistribute particles until there is no concentration gradient.
- Uses: Drain and Source regions for MOS, active regions for BJTs

Impurity Diffusion

- It is ideal for batch processes.
- It does not induce crystal damage
- Diffusion is very useful for p and n type doping in Si.
- Diffusion in III-V(GaAs, InP) is limited to Zn diffusions for p+ layers for ohmic contacts.

Impurity Diffusion

- Diffusion does not give you as exact control over doping concentration and junction depth as does ion-implantation, but it is an inexpensive process.
- Ion-implantation can place oxygen ions under the surface of Si which can be turned into SiO2.
- Ion-implantation can place a buried layer of dopant atoms in silicon.

Impurity Diffusion (How does it work?)

- At elevated temperatures impurity atoms move around the lattice in a random series of jumps.
  - Three dimensional in nature
  - Only net movement if there is a concentration gradient.

Impurity Diffusion (How does it work?)

- Random series of jumps?
  - Interstitial Diffusion: Impurity atoms jump between the empty spaces in the semiconductor lattice. This is a fast process that Na^+ and Li^+ use to move around the lattice (Bad).
  - Substitutional Diffusion: Impurity atoms jump from one vacant lattice site to an adjacent lattice site. There are not many of these vacant sites so this type of diffusion is slow.

Dopants used for Si diffusion

- Arsenic
  - Low misfit factor which leads to high n-type concentrations. Also has an abrupt doping profile.
- Phosphorus
  - Most common diffusion dopant source. It does not make as abrupt junctions as arsenic.

Dopants used for Si diffusion

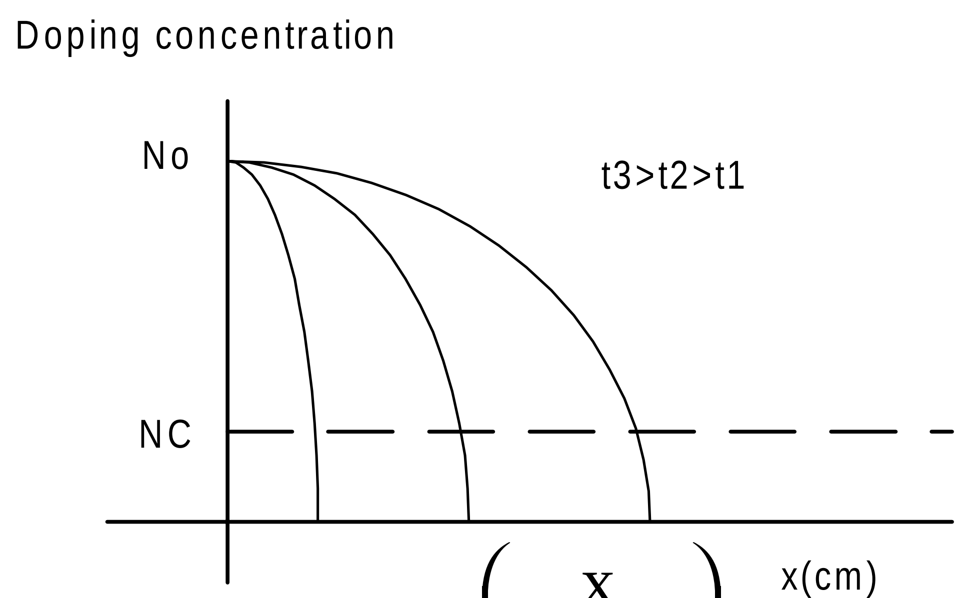
- Boron
  - Used for p and p+ diffusions
- Aluminum
  - Annealed into Si to make p+/p(boron) ohmic contacts.

Lateral diffusion

- At the beginning of the diffusion process, there is no concentration gradient in the Si.
- As soon as there are impurity atoms in the Si, there is an impurity gradient in all directions thus diffusion occurs in all directions.
- This causes impurities to diffusion underneath the mask. (not so the ion-implantation)

Types of Diffusion

- "Infinite Source" or Pre-deposition

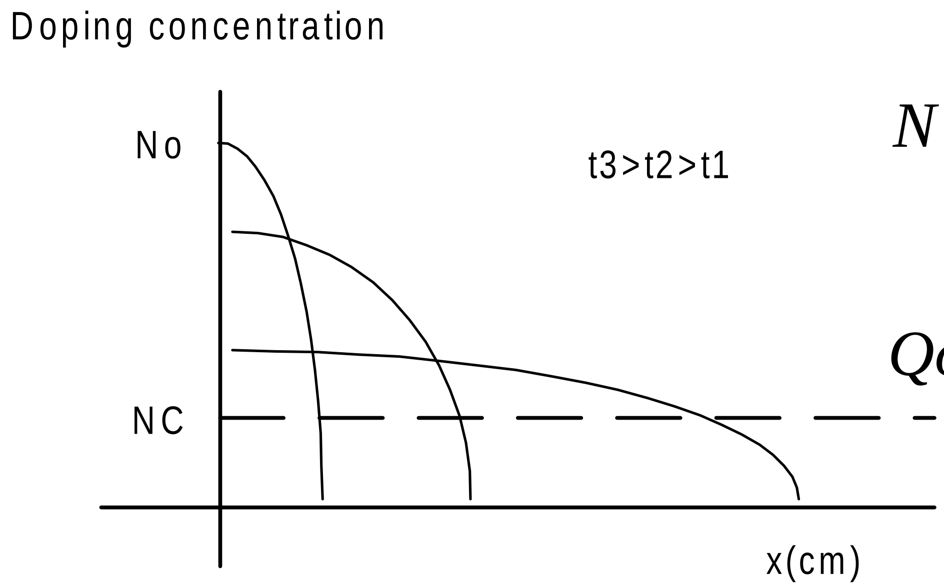


$$N(x,t) = No\,erfc\left(\frac{x}{2\sqrt{Dt}}\right)$$

$$No(cm^{-3}),\ D(cm^{2}/s),\ x(cm),\ t(s)$$

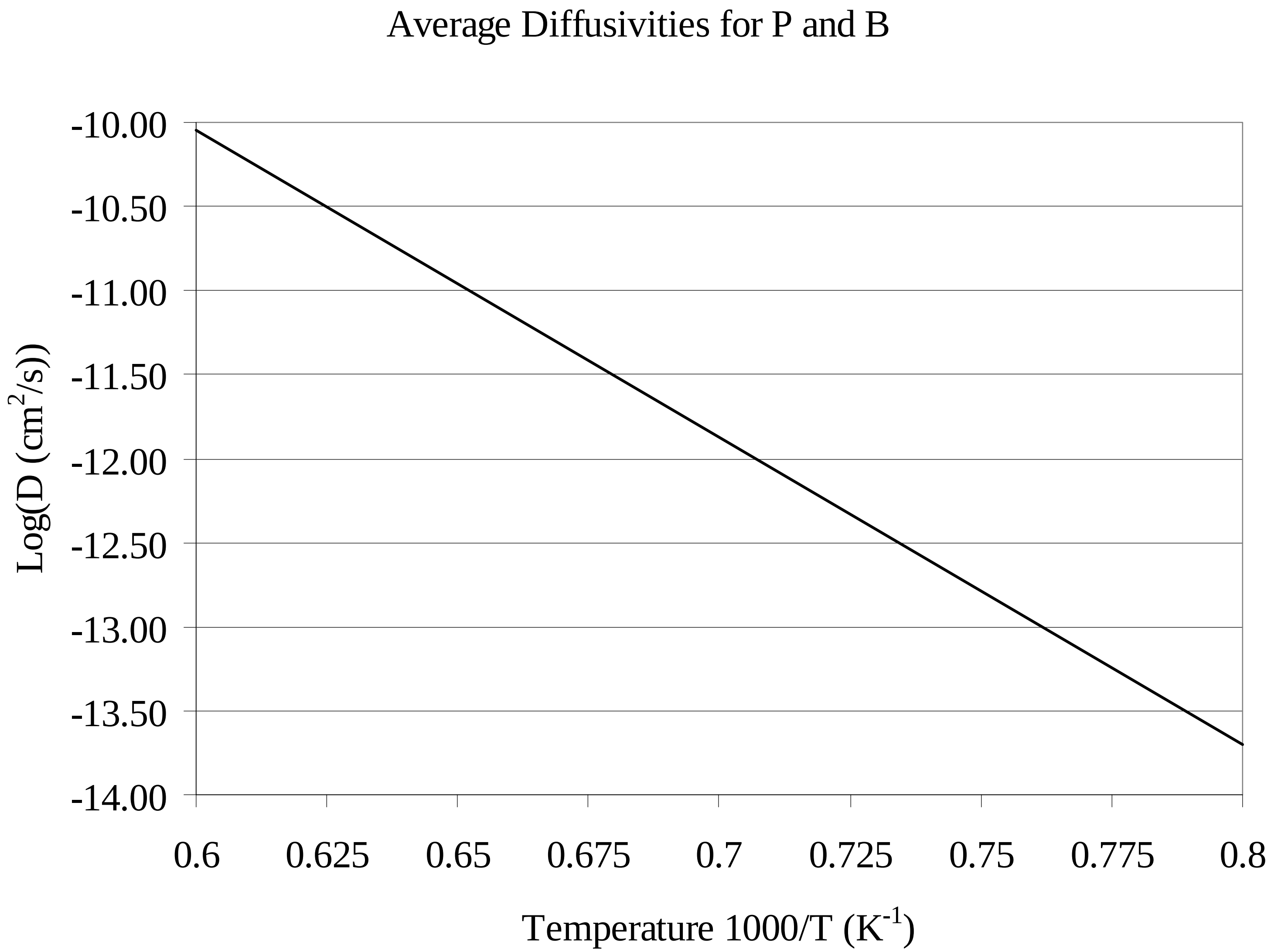
Types of Diffusion

- “Limited Source” or Drive-in

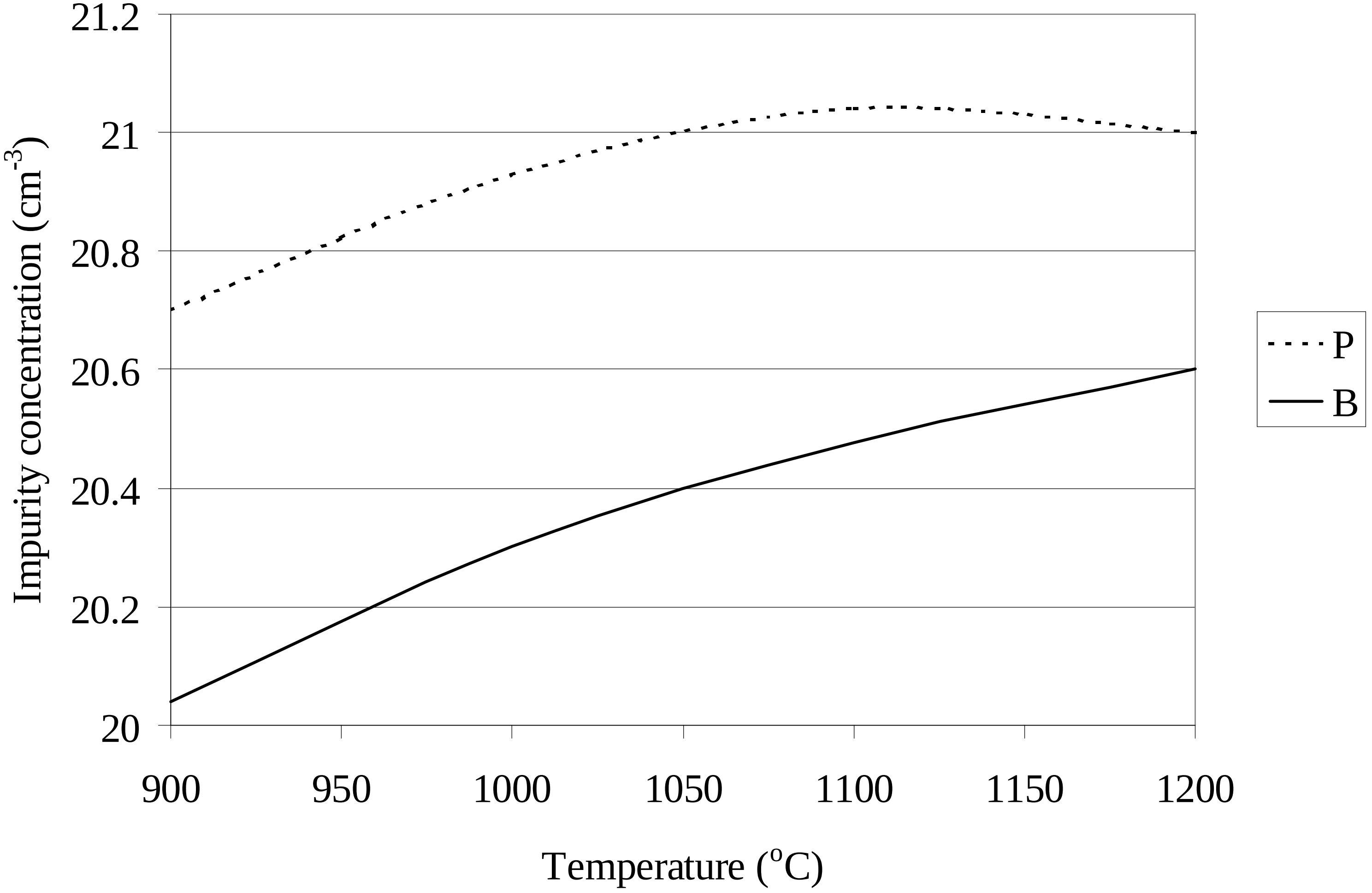


$$N(x,t) = \frac{Qo}{\sqrt{\pi D t}} e^{-\left(\frac{x}{2\sqrt{Dt}}\right)^2}$$

$$Qo = 2N_{o1}\left(\frac{D_1 t_1}{\sqrt{\pi}}\right)^{\frac{1}{2}}$$


Average Diffusivities for P and B
-10.00
-10.50
-11.00
-11.50
-12.00
-12.50
-13.00
-13.50
-14.00
Log(D (cm2/s))
0.6
0.625
0.65
0.675
0.7
0.725
0.75
0.775
0.8
Temperature 1000/T (K-1)

Solubility limits of B and P



Z	erf(Z)	Z	erf(Z)	Z	erf(Z)	Z	erf(Z)
0.00	0.000000000	0.50	0.520499878	1.00	0.842700793	1.50	0.966105146
0.01	0.011283416	0.51	0.529243620	1.01	0.846810496	1.51	0.967276748
0.02	0.022564575	0.52	0.537898630	1.02	0.850838018	1.52	0.968413497
0.03	0.033841222	0.53	0.546464097	1.03	0.854784211	1.53	0.969516209
0.04	0.045111106	0.54	0.554939250	1.04	0.858649947	1.54	0.970585690
0.05	0.056371978	0.55	0.563323366	1.05	0.862436106	1.55	0.971622733
0.06	0.067621594	0.56	0.571615764	1.06	0.866143587	1.56	0.972628122
0.07	0.078857720	0.57	0.579815806	1.07	0.869773297	1.57	0.973602627
0.08	0.090078126	0.58	0.587922900	1.08	0.873326158	1.58	0.974547009
0.09	0.101280594	0.59	0.595936497	1.09	0.876803102	1.59	0.975462016
0.10	0.112462916	0.60	0.603856091	1.10	0.880205070	1.60	0.976348383
0.11	0.123622896	0.61	0.611681219	1.11	0.883533012	1.61	0.977206837
0.12	0.134758352	0.62	0.619411462	1.12	0.886787890	1.62	0.978038088
0.13	0.145867115	0.63	0.627046443	1.13	0.889970670	1.63	0.978842840
0.14	0.156947033	0.64	0.634585829	1.14	0.893082328	1.64	0.979621780
0.15	0.167995971	0.65	0.642029327	1.15	0.896123843	1.65	0.980375585
0.16	0.179011813	0.66	0.649376688	1.16	0.899096203	1.66	0.981104921
0.17	0.189992461	0.67	0.656627702	1.17	0.902000399	1.67	0.981810442
0.18	0.200935839	0.68	0.663782203	1.18	0.904837427	1.68	0.982492787
0.19	0.211839892	0.69	0.670840062	1.19	0.907608286	1.69	0.983152587
0.20	0.222702589	0.70	0.677801194	1.20	0.910313978	1.70	0.983790459
0.21	0.233521923	0.71	0.684665550	1.21	0.912955508	1.71	0.984407008
0.22	0.244295912	0.72	0.691433123	1.22	0.915533881	1.72	0.985002827
0.23	0.255022600	0.73	0.698103943	1.23	0.918050104	1.73	0.985578500
0.24	0.265700059	0.74	0.704678078	1.24	0.920505184	1.74	0.986134595
0.25	0.276326390	0.75	0.711155634	1.25	0.922900128	1.75	0.986671671
0.26	0.286899723	0.76	0.717536753	1.26	0.925235942	1.76	0.987190275
0.27	0.297418219	0.77	0.723821614	1.27	0.927513629	1.77	0.987690942
0.28	0.307880068	0.78	0.730010431	1.28	0.929734193	1.78	0.988174196
0.29	0.318283496	0.79	0.736103454	1.29	0.931898633	1.79	0.988640549
0.30	0.328626759	0.80	0.742100965	1.30	0.934007945	1.80	0.989090502
0.31	0.338908150	0.81	0.748003281	1.31	0.936063123	1.81	0.989524545
0.32	0.349125995	0.82	0.753810751	1.32	0.938065155	1.82	0.989943156
0.33	0.359278655	0.83	0.759523757	1.33	0.940015026	1.83	0.990346805
0.34	0.369364529	0.84	0.765142711	1.34	0.941913715	1.84	0.990735948
0.35	0.379382054	0.85	0.770668058	1.35	0.943762196	1.85	0.991111030
0.36	0.389329701	0.86	0.776100268	1.36	0.945561437	1.86	0.991472488
0.37	0.399205984	0.87	0.781439845	1.37	0.947312398	1.87	0.991820748
0.38	0.409009453	0.88	0.786687319	1.38	0.949016035	1.88	0.992156223
0.39	0.418738700	0.89	0.791843247	1.39	0.950673296	1.89	0.992479318
0.40	0.428392355	0.90	0.796908212	1.40	0.952285120	1.90	0.992790429
0.41	0.437969090	0.91	0.801882826	1.41	0.953852439	1.91	0.993089940
0.42	0.447467618	0.92	0.806767722	1.42	0.955376179	1.92	0.993378225
0.43	0.456886695	0.93	0.811563559	1.43	0.956857253	1.93	0.993655650
0.44	0.466225115	0.94	0.816271019	1.44	0.958296570	1.94	0.993922571
0.45	0.475481720	0.95	0.820890807	1.45	0.959695026	1.95	0.994179334
0.46	0.484655390	0.96	0.825423650	1.46	0.961053510	1.96	0.994426275
0.47	0.493745051	0.97	0.829870293	1.47	0.962372900	1.97	0.994663725
0.48	0.502749671	0.98	0.834231504	1.48	0.963654065	1.98	0.994892000
0.49	0.511668261	0.99	0.838508070	1.49	0.964897865	1.99	0.995111413

Z	erf(Z)	Z	erf(Z)	Z	erf(Z)	Z	erf(Z)
2.00	0.995322265	2.50	0.999593048	3.00	0.999977910	3.50	0.999999257
2.01	0.995524849	2.51	0.999614295	3.01	0.999979261	3.51	0.999999309
2.02	0.995719451	2.52	0.999634501	3.02	0.999980534	3.52	0.999999358
2.03	0.995906348	2.53	0.999653714	3.03	0.999981732	3.53	0.999999403
2.04	0.996085810	2.54	0.999671979	3.04	0.999982859	3.54	0.999999445
2.05	0.996258096	2.55	0.999689340	3.05	0.999983920	3.55	0.999999485
2.06	0.996423462	2.56	0.999705837	3.06	0.999984918	3.56	0.999999521
2.07	0.996582153	2.57	0.999721511	3.07	0.999985857	3.57	0.999999555
2.08	0.996734409	2.58	0.999736400	3.08	0.999986740	3.58	0.999999587
2.09	0.996880461	2.59	0.999750539	3.09	0.999987571	3.59	0.999999617
2.10	0.997020533	2.60	0.999763966	3.10	0.999988351	3.60	0.999999644
2.11	0.997154845	2.61	0.999776711	3.11	0.999989085	3.61	0.999999670
2.12	0.997283607	2.62	0.999788809	3.12	0.999989774	3.62	0.999999694
2.13	0.997407023	2.63	0.999800289	3.13	0.999990422	3.63	0.999999716
2.14	0.997525293	2.64	0.999811181	3.14	0.999991030	3.64	0.999999736
2.15	0.997638607	2.65	0.999821512	3.15	0.999991602	3.65	0.999999756
2.16	0.997747152	2.66	0.999831311	3.16	0.999992138	3.66	0.999999773
2.17	0.997851108	2.67	0.999840601	3.17	0.999992642	3.67	0.999999790
2.18	0.997950649	2.68	0.999849409	3.18	0.999993115	3.68	0.999999805
2.19	0.998045943	2.69	0.999857757	3.19	0.999993558	3.69	0.999999820
2.20	0.998137154	2.70	0.999865667	3.20	0.999993974	3.70	0.999999833
2.21	0.998224438	2.71	0.999873162	3.21	0.999994365	3.71	0.999999845
2.22	0.998307948	2.72	0.999880261	3.22	0.999994731	3.72	0.999999857
2.23	0.998387832	2.73	0.999886985	3.23	0.999995074	3.73	0.999999867
2.24	0.998464231	2.74	0.999893351	3.24	0.999995396	3.74	0.999999877
2.25	0.998537283	2.75	0.999899378	3.25	0.999995697	3.75	0.999999886
2.26	0.998607121	2.76	0.999905082	3.26	0.999995980	3.76	0.999999895
2.27	0.998673872	2.77	0.999910480	3.27	0.999996245	3.77	0.999999903
2.28	0.998737661	2.78	0.999915587	3.28	0.999996493	3.78	0.999999910
2.29	0.998798606	2.79	0.999920418	3.29	0.999996725	3.79	0.999999917
2.30	0.998856823	2.80	0.999924987	3.30	0.999996942	3.80	0.999999923
2.31	0.998912423	2.81	0.999929307	3.31	0.999997146	3.81	0.999999929
2.32	0.998965513	2.82	0.999933390	3.32	0.999997336	3.82	0.999999934
2.33	0.999016195	2.83	0.999937250	3.33	0.999997515	3.83	0.999999939
2.34	0.999064570	2.84	0.999940898	3.34	0.999997681	3.84	0.999999944
2.35	0.999110733	2.85	0.999944344	3.35	0.999997838	3.85	0.999999948
2.36	0.999154777	2.86	0.999947599	3.36	0.999997983	3.86	0.999999952
2.37	0.999196790	2.87	0.999950673	3.37	0.999998120	3.87	0.999999956
2.38	0.999236858	2.88	0.999953576	3.38	0.999998247	3.88	0.999999959
2.39	0.999275064	2.89	0.999956316	3.39	0.999998367	3.89	0.999999962
2.40	0.999311486	2.90	0.999958902	3.40	0.999998478	3.90	0.999999965
2.41	0.999346202	2.91	0.999961343	3.41	0.999998582	3.91	0.999999968
2.42	0.999379283	2.92	0.999963645	3.42	0.999998679	3.92	0.999999970
2.43	0.999410802	2.93	0.999965817	3.43	0.999998770	3.93	0.999999973
2.44	0.999440826	2.94	0.999967866	3.44	0.999998855	3.94	0.999999975
2.45	0.999469420	2.95	0.999969797	3.45	0.999998934	3.95	0.999999977
2.46	0.999496646	2.96	0.999971618	3.46	0.999999008	3.96	0.999999979
2.47	0.999522566	2.97	0.999973334	3.47	0.999999077	3.97	0.999999980
2.48	0.999547236	2.98	0.999974951	3.48	0.999999141	3.98	0.999999982
2.49	0.999570712	2.99	0.999976474	3.49	0.999999201	3.99	0.999999983

Example #1

- Starting with n-type Si<100>, $N_D=10^{14}cm^{-3}$, how long do we need to to a "infinite source" B diffusion at 1000^oC to make a junction depth (x_j) equal to $.5 \times 10^{-4}$ cm?

Example #2

- Starting with p-type Si<111>, $N_A=10^{15}cm^{-3}$, how deep will the junction depth (x_j in cm) if we do an “infinite source” P *pre-dep* diffusion at 1000^{o}C for 10 minutes?
- What will be the junction depth (x_j in cm) if we do an “finite source” P *drive in* diffusion at 1000^{o}C for 30 minutes?