

# ECE 6450 Introduction to Microelectronics Technology

*Exam 1*

*September 21, 2004*

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Print your name clearly:

*Solutions*

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**Instructions:**

Read all the problems carefully and thoroughly before you begin working. You are allowed to use 1 sheet of notes (1 page front and back) as well as a calculator. There are 100 total points plus a chance for 10 bonus points in this exam. Observe the point value of each problem and allocate your time accordingly. **SHOW ALL WORK AND CIRCLE YOUR FINAL ANSWER WITH THE PROPER UNITS INDICATED.** Write legibly. If I can not read it, it will be considered to be a wrong answer. Do all work on the paper provided. Turn in all scratch paper, even if it did not lead to an answer. Report any and all ethics violations to the instructor. Good luck!

Sign your name on ONE of the two following cases:

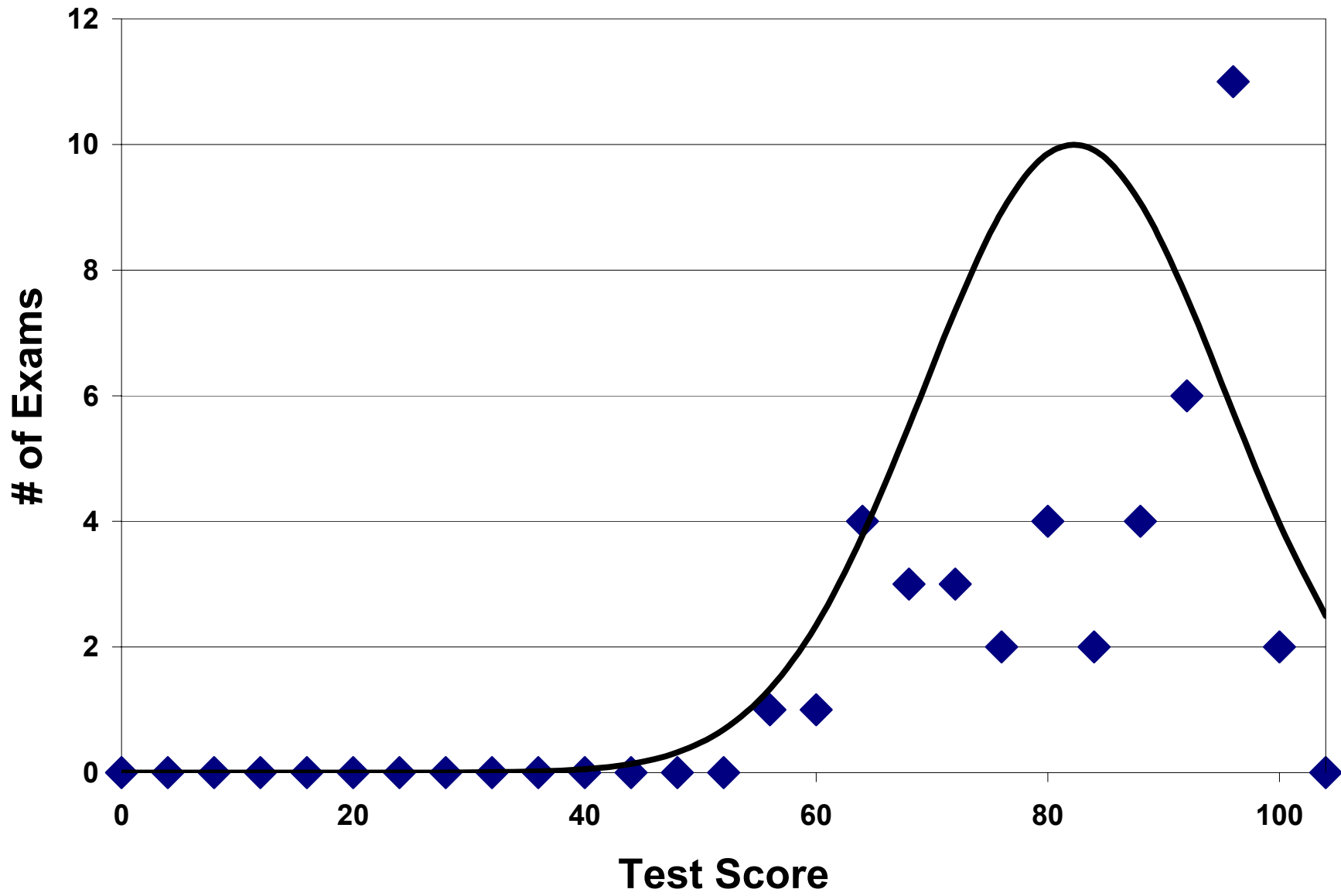
I did not observe any ethical violations during this exam:

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I observed an ethical violation during this exam:

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**Problem 1. (25 points total in 5, 3 point parts):**

True/False and Multiple Choice:

a.) Of the following crystalline bonding mechanisms, which mechanism results in the weakest bond strength?

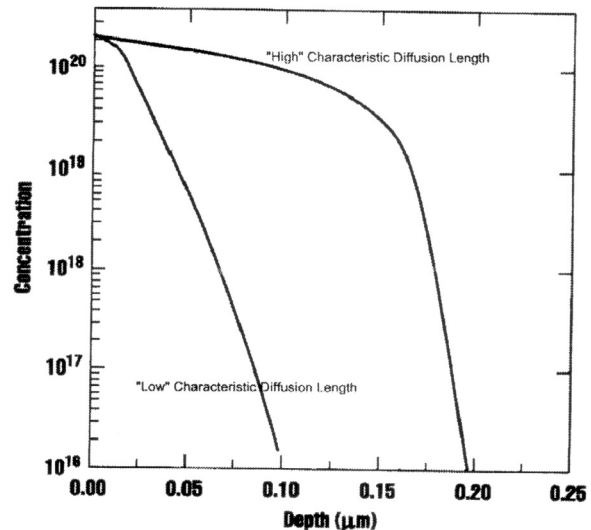
- 1.) Ionic
- 2.) Covalent
- 3.) Metallic
- 4.) Van der Waals
- 5.) None of the above

b.) Which of the following are considered to be area defects (may have more than one answer)?

- 1.) Vacancies
- 2.) Interstitials
- 3.) Dislocations
- 4.) Stacking faults
- 5.) Precipitates
- 6.) Grain Boundaries

c.) Given the diffusion profiles obtained below for the same temperature in both cases, which of the following are true (may have more than one answer)?

- 1.) This is a predeposition diffusion.
- 2.) This is a drive in diffusion.
- 3.) The diffusion coefficient is constant.
- 4.) The diffusion coefficient is higher at high concentrations.
- 5.) The diffusion coefficient is lower at high concentrations.



d.) Denuding a wafer results in a higher precipitate defect concentration in the wafer interior and thus should be avoided.

True or False (circle the correct answer)

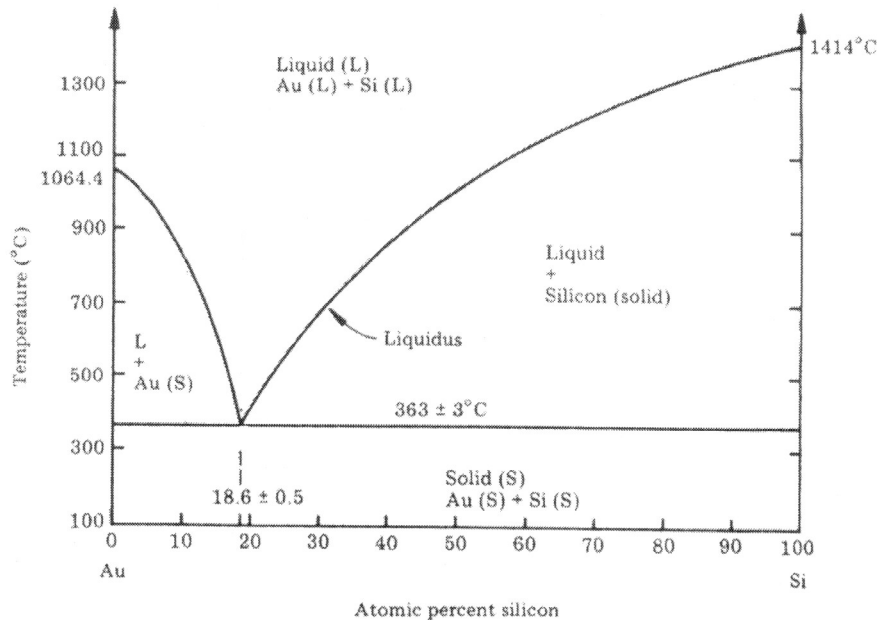
e.) Oxidizing a diffused junction can move the junction depth differently than would be observed for a simple heat treatment (anneal) at the same temperature due to the presence of higher silicon interstitial concentrations.

True or False (circle the correct answer)

## Problem 2. (15 points total):

Fully processed (all fabrication of transistors completed) silicon chips are often bonded to gold (Au) coated "final packages" as one of the final processes. The back side of the wafer (the empty side without transistors on it) is alloyed into a Au coated layer to form a solid connection similar to a standard "solder contact" used to join metal parts on printed circuit boards. This step must be performed at less than ~400 degrees C to prevent diffusion of junctions, and other stress related problems. Given

that the melting point of silicon (Si) is 1414 degrees C and the melting point of gold (Au) is 1064.4 degrees C use the following phase diagram to explain how and at what temperature the solid connection is made. **For full credit, keep your description to 3 sentences or less and feel free to draw on the phase diagram to further explain your answer.**



Au-Si phase diagram. [After Hansen (1958).]

A eutectic forms @  $T > 363^\circ\text{C}$  where the Si/Au mixture melts creating a liquid solution. When the chip cools below  $363^\circ\text{C}$  it solidifies into a solid "solder".

### Problem 3. (30 points total):

Boron (B) is deposited into a n-type silicon (Si) wafer for one hour, using  $BBr_3$ , at 975 degrees C where the solubility of B in Silicon is  $3.5 \times 10^{20} \text{ cm}^{-3}$ . The bulk wafer concentration of n-type, phosphorous atoms is  $1 \times 10^{15} \text{ cm}^{-3}$ . Assuming a neutral vacancy controlled diffusion with  $D_0 = 0.037 \text{ cm}^2/\text{sec}$  and  $E_a = 3.46 \text{ eV}$ , (a-20 points) what is the junction depth? (b-10 points) If the boron is then driven into the wafer at 1100 degrees C for 4.5 hours, what is the new junction depth?

$$D_{@975} = 0.037 e^{-3.46 / (273 + 975) \cdot \frac{1}{2}} = 4.1844 \times 10^{-16} \text{ cm}^2/\text{s}$$

$$D_{@1100} = 0.037 e^{-3.46 / (273 + 1100) \cdot \frac{1}{2}} = 7.7867 \times 10^{-15} \text{ cm}^2/\text{s}$$

$$\sqrt{Dt} \Big|_{\text{predep}} = \sqrt{(4.1844 \times 10^{-16})(3600)} = 1.2274 \times 10^{-6} \text{ cm}$$

$$\sqrt{Dt} \Big|_{\text{drive in}} = \sqrt{(7.7867 \times 10^{-15})(4.5 \cdot 3600)} = 1.1231 \times 10^{-5} \text{ cm}$$

2 steps  
assumptions  
justified

a) Predep:

$$X_j = 2 \sqrt{Dt} \operatorname{erfc}^{-1} \left( \frac{C_0}{C_s} \right)$$

$\swarrow 1 \times 10^{15} \text{ cm}^{-3}$   
 $\nwarrow 3.5 \times 10^{20} \text{ cm}^{-3}$

$$= 2 (1.2274 \times 10^{-6}) \operatorname{erfc}^{-1} (2.8571 \times 10^{-6})$$

what argument gives  
compl. erf =  $2.8571 \times 10^{-6}$   
is same argument as  
gives erf of  $(1 - 2.8571 \times 10^{-6})$

$$\left[ 1 - (2.8571 \times 10^{-6}) \right] = 0.999997$$

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From tables

$$Z = 3.31$$

$$\therefore X_j = 2 (1.2274 \times 10^{-6}) 3.31$$

$$X_j = 8.125 \times 10^{-6} \text{ cm or } 0.0812 \mu\text{m}$$

b) Drive in: From pre-deposition:

$$Q_T = \frac{2}{\sqrt{\pi}} (3.5 \times 10^{20}) (1.2274 \times 10^{-6}) = 4.847 \times 10^{14} \text{ cm}^{-2}$$

3 cont'd)

You may show your work here

$$\begin{aligned} X_j &= \sqrt{4 D_x \ln \left( \frac{Q_T}{C_B \sqrt{\pi} \sqrt{D_x}} \right)} \\ &= 2 \sqrt{D_x} \sqrt{\ln \left( \frac{Q_T}{C_B \sqrt{\pi} \sqrt{D_x}} \right)} \\ &= 2 (1.1231e-5) \sqrt{\ln \left( \frac{4.847 \times 10^{14}}{(1 \times 10^{15}) \sqrt{\pi} (1.1231e-5)} \right)} \end{aligned}$$

$$X_j = 7.1 \times 10^{-5} \text{ cm}$$

or

$$0.71 \mu\text{m}$$

**Problem 4. (30 points total):**

**Problem Statement:**

A p-type wafer has a diffused phosphorous n-type junction with a junction depth of ~~0.125~~ <sup>0.125</sup>  $\mu\text{m}$ .

(a. 10 points) This silicon wafer (no pre-existing oxide) is to be oxidized with a "high quality, dense, non-porous" oxide at 1200 degrees C for one hour. What is the thickness of the oxide after this step.

(b. 15 points) This process is to be followed by a "lower quality, faster growth oxide" grown at the same temperature. If the final oxide grown is 0.1  $\mu\text{m}$  thicker than in the first step, what time is needed in the second step.

(c. 5 points) Does the original junction still exist? Justify your answer.

**Assumptions:**

Assume no lateral oxidation occurs (I.E. consider only the 1 dimensional case), the wet oxide parameters are valid for all regions, regardless of initial conditions, and the porosity and density of wet and dry oxides are the same. To answer this question you must know which oxide, wet or dry is of higher quality.

At 1200 degrees C:

$A=0.04 \mu\text{m}$ ,  $B=0.045 \mu\text{m}^2/\text{hr}$  and  $\tau=0.027 \text{ hr}$  for dry oxides

$A=0.05 \mu\text{m}$ ,  $B=0.72 \mu\text{m}^2/\text{hr}$  and  $\tau=0.0 \text{ hr}$  for wet oxides.

high quality

"lower" quality

$$a) \quad x_{\text{oxide}} = \frac{1}{2} A \left[ -1 + \sqrt{1 + 4 \frac{B(x+\tau)}{A^2}} \right]$$

$$= \frac{1}{2} (0.04) \left[ -1 + \sqrt{1 + 4 \frac{(0.045)(1+0.027)}{(0.04)^2}} \right]$$

$$x_{\text{oxide}} = 0.196 \mu\text{m}$$

$$b) \quad \tau = \frac{x_o^2 + A x_o}{B} = \frac{(0.196)^2 + 0.05(0.196)}{0.72} = 0.0669\bar{6} \text{ hrs}$$

$$(x_{\text{ox}})^2 + A(x_{\text{ox}}) = B(x + \tau)$$

$$(0.196 + 0.1)^2 + 0.05(0.196 + 0.1) = 0.72(x + 0.0669\bar{6})$$

$$x = 7.527 \times 10^{-2} \text{ hrs or}$$

$$x = 4.52 \text{ minutes}$$

c) Amount of silicon consumed =  $0.44(0.296) = 0.13 \mu\text{m}$   
 If diffusion ignored: No junction remains.



## Erf Table

Table A.1 Error Function erf  $z^a$ 

$z$	erf( $z$ )	$z$	erf( $z$ )	$z$	erf( $z$ )	$z$	erf( $z$ )
0.00	0.000 000	0.50	0.520 500	1.00	0.842 701	1.50	0.966 105
0.01	0.011 283	0.51	0.529 244	1.01	0.846 810	1.51	0.967 277
0.02	0.022 565	0.52	0.537 899	1.02	0.850 838	1.52	0.968 413
0.03	0.033 841	0.53	0.546 464	1.03	0.854 784	1.53	0.969 516
0.04	0.045 111	0.54	0.554 939	1.04	0.858 650	1.54	0.970 586
0.05	0.056 372	0.55	0.563 323	1.05	0.862 436	1.55	0.971 623
0.06	0.067 622	0.56	0.571 616	1.06	0.866 144	1.56	0.972 628
0.07	0.078 858	0.57	0.579 816	1.07	0.869 773	1.57	0.973 603
0.08	0.090 078	0.58	0.587 923	1.08	0.873 326	1.58	0.974 547
0.09	0.101 281	0.59	0.595 936	1.09	0.876 803	1.59	0.975 462
0.10	0.112 463	0.60	0.603 856	1.10	0.880 205	1.60	0.976 348
0.11	0.123 623	0.61	0.611 681	1.11	0.883 533	1.61	0.977 207
0.12	0.134 758	0.62	0.619 411	1.12	0.886 788	1.62	0.978 038
0.13	0.145 867	0.63	0.627 046	1.13	0.889 971	1.63	0.978 843
0.14	0.156 947	0.64	0.634 586	1.14	0.893 082	1.64	0.979 622
0.15	0.167 996	0.65	0.642 029	1.15	0.896 124	1.65	0.980 376
0.16	0.179 012	0.66	0.649 377	1.16	0.899 096	1.66	0.981 105
0.17	0.189 992	0.67	0.656 628	1.17	0.902 000	1.67	0.981 810
0.18	0.200 936	0.68	0.663 782	1.18	0.904 837	1.68	0.982 493
0.19	0.211 840	0.69	0.670 840	1.19	0.907 608	1.69	0.983 153
0.20	0.222 703	0.70	0.677 801	1.20	0.910 314	1.70	0.983 790
0.21	0.233 522	0.71	0.684 666	1.21	0.912 956	1.71	0.984 407
0.22	0.244 296	0.72	0.691 433	1.22	0.915 534	1.72	0.985 003
0.23	0.255 023	0.73	0.698 104	1.23	0.918 050	1.73	0.985 578
0.24	0.265 700	0.74	0.704 678	1.24	0.920 505	1.74	0.986 135
0.25	0.276 326	0.75	0.711 156	1.25	0.922 900	1.75	0.986 672
0.26	0.286 900	0.76	0.717 537	1.26	0.925 236	1.76	0.987 190
0.27	0.297 418	0.77	0.723 822	1.27	0.927 514	1.77	0.987 691
0.28	0.307 880	0.78	0.730 010	1.28	0.929 734	1.78	0.988 174
0.29	0.318 283	0.79	0.736 103	1.29	0.931 899	1.79	0.988 641
0.30	0.328 627	0.80	0.742 101	1.30	0.934 008	1.80	0.989 091
0.31	0.338 908	0.81	0.748 003	1.31	0.936 063	1.81	0.989 525
0.32	0.349 126	0.82	0.753 811	1.32	0.938 065	1.82	0.989 943
0.33	0.359 279	0.83	0.759 524	1.33	0.940 015	1.83	0.990 347
0.34	0.369 365	0.84	0.765 143	1.34	0.941 914	1.84	0.990 736
0.35	0.379 382	0.85	0.770 668	1.35	0.943 762	1.85	0.991 111
0.36	0.389 330	0.86	0.776 100	1.36	0.945 561	1.86	0.991 472
0.37	0.399 206	0.87	0.781 440	1.37	0.947 312	1.87	0.991 821
0.38	0.409 009	0.88	0.786 687	1.38	0.949 016	1.88	0.992 156
0.39	0.418 739	0.89	0.791 843	1.39	0.950 673	1.89	0.992 479
0.40	0.428 392	0.90	0.796 908	1.40	0.952 285	1.90	0.992 790
0.41	0.437 969	0.91	0.801 883	1.41	0.953 852	1.91	0.993 090
0.42	0.447 468	0.92	0.806 768	1.42	0.955 376	1.92	0.993 378
0.43	0.456 887	0.93	0.811 564	1.43	0.956 857	1.93	0.993 656
0.44	0.466 225	0.94	0.816 271	1.44	0.958 297	1.94	0.993 923
0.45	0.475 482	0.95	0.820 891	1.45	0.959 695	1.95	0.994 179
0.46	0.484 655	0.96	0.825 424	1.46	0.961 054	1.96	0.994 426
0.47	0.493 745	0.97	0.829 870	1.47	0.962 373	1.97	0.994 664
0.48	0.502 750	0.98	0.834 232	1.48	0.963 654	1.98	0.994 892
0.49	0.511 668	0.99	0.838 508	1.49	0.964 898	1.99	0.995 111

Erf cont'd

2.00	0.995 322	2.50	0.999 593	3.00	0.999 977 91	3.50	0.999 999 257
2.01	0.995 525	2.51	0.999 614	3.01	0.999 979 26	3.51	0.999 999 309
2.02	0.995 719	2.52	0.999 634	3.02	0.999 980 53	3.52	0.999 999 358
2.03	0.995 906	2.53	0.999 654	3.03	0.999 981 73	3.53	0.999 999 403
2.04	0.996 086	2.54	0.999 672	3.04	0.999 982 86	3.54	0.999 999 445
2.05	0.996 258	2.55	0.999 689	3.05	0.999 983 92	3.55	0.999 999 485
2.06	0.996 423	2.56	0.999 706	3.06	0.999 984 92	3.56	0.999 999 521
2.07	0.996 582	2.57	0.999 722	3.07	0.999 985 86	3.57	0.999 999 555
2.08	0.996 734	2.58	0.999 736	3.08	0.999 986 74	3.58	0.999 999 587
2.09	0.996 880	2.59	0.999 751	3.09	0.999 987 57	3.59	0.999 999 617
2.10	0.997 021	2.60	0.999 764	3.10	0.999 988 35	3.60	0.999 999 644
2.11	0.997 155	2.61	0.999 777	3.11	0.999 989 08	3.61	0.999 999 670
2.12	0.997 284	2.62	0.999 789	3.12	0.999 989 77	3.62	0.999 999 694
2.13	0.997 407	2.63	0.999 800	3.13	0.999 990 42	3.63	0.999 999 716
2.14	0.997 525	2.64	0.999 811	3.14	0.999 991 03	3.64	0.999 999 736
2.15	0.997 639	2.65	0.999 822	3.15	0.999 991 60	3.65	0.999 999 756
2.16	0.997 747	2.66	0.999 831	3.16	0.999 992 14	3.66	0.999 999 773
2.17	0.997 851	2.67	0.999 841	3.17	0.999 992 64	3.67	0.999 999 790
2.18	0.997 951	2.68	0.999 849	3.18	0.999 993 11	3.68	0.999 999 805
2.19	0.998 046	2.69	0.999 858	3.19	0.999 993 56	3.69	0.999 999 820
2.20	0.998 137	2.70	0.999 866	3.20	0.999 993 97	3.70	0.999 999 833
2.21	0.998 224	2.71	0.999 873	3.21	0.999 994 36	3.71	0.999 999 845
2.22	0.998 308	2.72	0.999 880	3.22	0.999 994 73	3.72	0.999 999 857
2.23	0.998 388	2.73	0.999 887	3.23	0.999 995 07	3.73	0.999 999 867
2.24	0.998 464	2.74	0.999 893	3.24	0.999 995 40	3.74	0.999 999 877
2.25	0.998 537	2.75	0.999 899	3.25	0.999 995 70	3.75	0.999 999 886
2.26	0.998 607	2.76	0.999 905	3.26	0.999 995 98	3.76	0.999 999 895
2.27	0.998 674	2.77	0.999 910	3.27	0.999 996 24	3.77	0.999 999 903
2.28	0.998 738	2.78	0.999 916	3.28	0.999 996 49	3.78	0.999 999 910
2.29	0.998 799	2.79	0.999 920	3.29	0.999 996 72	3.79	0.999 999 917
2.30	0.998 857	2.80	0.999 925	3.30	0.999 996 94	3.80	0.999 999 923
2.31	0.998 912	2.81	0.999 929	3.31	0.999 997 15	3.81	0.999 999 929
2.32	0.998 966	2.82	0.999 933	3.32	0.999 997 34	3.82	0.999 999 934
2.33	0.999 016	2.83	0.999 937	3.33	0.999 997 51	3.83	0.999 999 939
2.34	0.999 065	2.84	0.999 941	3.34	0.999 997 68	3.84	0.999 999 944
2.35	0.999 111	2.85	0.999 944	3.35	0.999 997 838	3.85	0.999 999 948
2.36	0.999 155	2.86	0.999 948	3.36	0.999 997 983	3.86	0.999 999 952
2.37	0.999 197	2.87	0.999 951	3.37	0.999 998 120	3.87	0.999 999 956
2.38	0.999 237	2.88	0.999 954	3.38	0.999 998 247	3.88	0.999 999 959
2.39	0.999 275	2.89	0.999 956	3.39	0.999 998 367	3.89	0.999 999 962
2.40	0.999 311	2.90	0.999 959	3.40	0.999 998 478	3.90	0.999 999 965
2.41	0.999 346	2.91	0.999 961	3.41	0.999 998 582	3.91	0.999 999 968
2.42	0.999 379	2.92	0.999 964	3.42	0.999 998 679	3.92	0.999 999 970
2.43	0.999 411	2.93	0.999 966	3.43	0.999 998 770	3.93	0.999 999 973
2.44	0.999 441	2.94	0.999 968	3.44	0.999 998 855	3.94	0.999 999 975
2.45	0.999 469	2.95	0.999 970	3.45	0.999 998 934	3.95	0.999 999 977
2.46	0.999 497	2.96	0.999 972	3.46	0.999 999 008	3.96	0.999 999 979
2.47	0.999 523	2.97	0.999 973	3.47	0.999 999 077	3.97	0.999 999 980
2.48	0.999 547	2.98	0.999 975	3.48	0.999 999 141	3.98	0.999 999 982
2.49	0.999 571	2.99	0.999 976	3.49	0.999 999 201	3.99	0.999 999 983

<sup>a</sup> For a more complete table, see L. J. Comrie, *Chambers Six Figure Mathematical Tables*, Vol. 2, W. & R. Chambers, Edinburgh, 1949.