

Fall, 1996
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EE 440/396K IC Fabrication Techniques

Exam 1

CLOSED BOOK AND NOTES; NO CRIB SHEETS

You will have one hour to complete the exam. Read all the problems before beginning since not all the problems are of equal difficulty. Where possible, I have tried to leave enough room on the exam sheet to write your answers, but you may use other paper if you need it. Most of the questions have very brief, to the point answers; don't waste time with long explanations that are not directly applicable to the question. I will not give credit for a random list of all the facts you can remember if one of them happens to be the correct answer to the problem. Good luck.

SHOW YOUR WORK!!!!

Things you may or may not find useful:

various integrals:

$$\begin{aligned} \operatorname{erf}(z) &= \frac{2}{\sqrt{\pi}} \int_0^z \exp(-x^2) dx \\ &= \frac{2 \cdot z}{\sqrt{\pi}} \left[1 - \frac{z^2}{1! \cdot 3} + \frac{z^4}{2! \cdot 5} - \frac{z^6}{3! \cdot 7} + \dots \right] \\ &\cong 1 - \frac{\exp(-z^2)}{z \cdot \sqrt{\pi}} \left[1 - \frac{1}{2 \cdot z^2} + \frac{1 \cdot 3}{2^2 \cdot z^4} - \frac{1 \cdot 3 \cdot 5}{2^3 \cdot z^6} + \dots \right] \end{aligned}$$

$$\operatorname{erfc}(z) = \frac{2}{\sqrt{\pi}} \int_z^\infty \exp(-x^2) dx = 1 - \operatorname{erf}(z)$$

erfc diffusion profile:

$$N(x, t) = N_s \operatorname{erfc} \left(\frac{x}{2\sqrt{Dt}} \right)$$

gaussian diffusion profile:

$$N(x, t) = \frac{Q_0}{\sqrt{Dt}} \exp \left(\frac{-x^2}{4Dt} \right)$$

pre dep dose approximation:

$$Q_0 \approx 2N_s(Dt)^{1/2}$$

Boltzmann constant

$$k = 8.62 \times 10^{-5} \text{ eV/Kelvin}$$

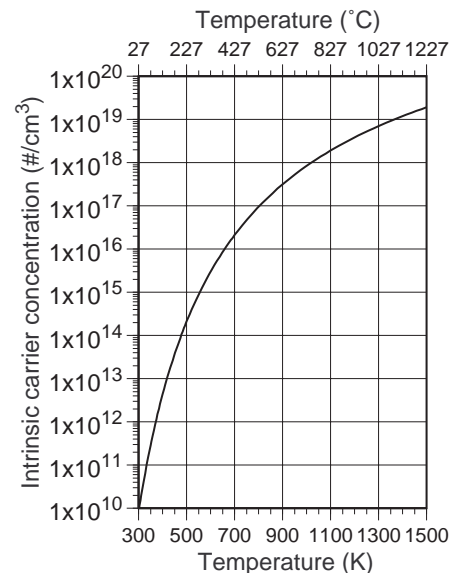
$$\text{electron charge: } q = 1.6 \times 10^{-19} \text{ Coul.}$$

Grove and Deal oxidation equation:

$$x = \frac{A}{2} \cdot \sqrt{1 + \frac{t + \tau}{A^2/4B}} - \frac{A}{2} ;$$

$$\tau = \frac{x_i^2 + A \cdot x_i}{B} ; \quad A = 2D/k ;$$

$$B = 2DN_o/n$$



SAMPLE EXAM for F97 class

1. (10 points) What is the difference between a deep-lying impurity and a shallow-lying impurity? Which makes a better dopant? Why?

2. (10 points) Describe the structural difference between the two major oxygen complexes in silicon, the so called "old thermal donors" and "new thermal donors." Where does the oxygen come from? When do these defects form?

3. (10 points) What is an "oxidation induced stacking fault"? What processing step causes them? Is there anything that can be done to reduce their occurrence?

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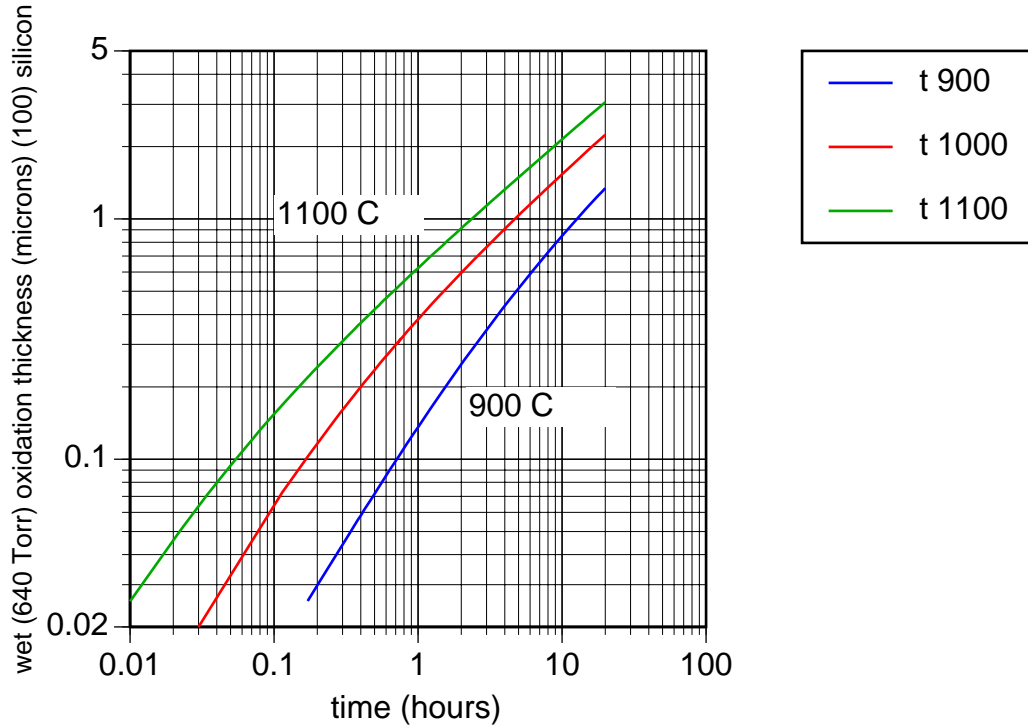
4. (10 points) Current state-of-the-art MOSFETs use gate oxide thicknesses of less than 100 Å thickness. What oxidizing ambient (i.e., dry O₂ or H₂O) is used to grow these gate oxides? What oxidation process parameter is the most important in allowing the controlled growth of such thin oxides?

5. (10 points) If the concentration of an impurity is 10¹⁸ cm⁻³, can you safely assume the diffusivity for the impurity in silicon is constant (i.e., independent of impurity concentration) at 500° C? At 1000° C? Explain.

6. (10 points) Boron and phosphorus pre-deps are to be performed into two silicon samples (for instance, your MPT chips). In each case the pre-dep temperature is 950° C, and the pre-dep times are identical. The solid solubility of phosphorus in Si at 950° C is 8x10²⁰ cm⁻³, while that of boron is 1.4x10²⁰ cm⁻³. Would you expect the effective dose produced by these two pre-deps to be different? Explain very briefly!!

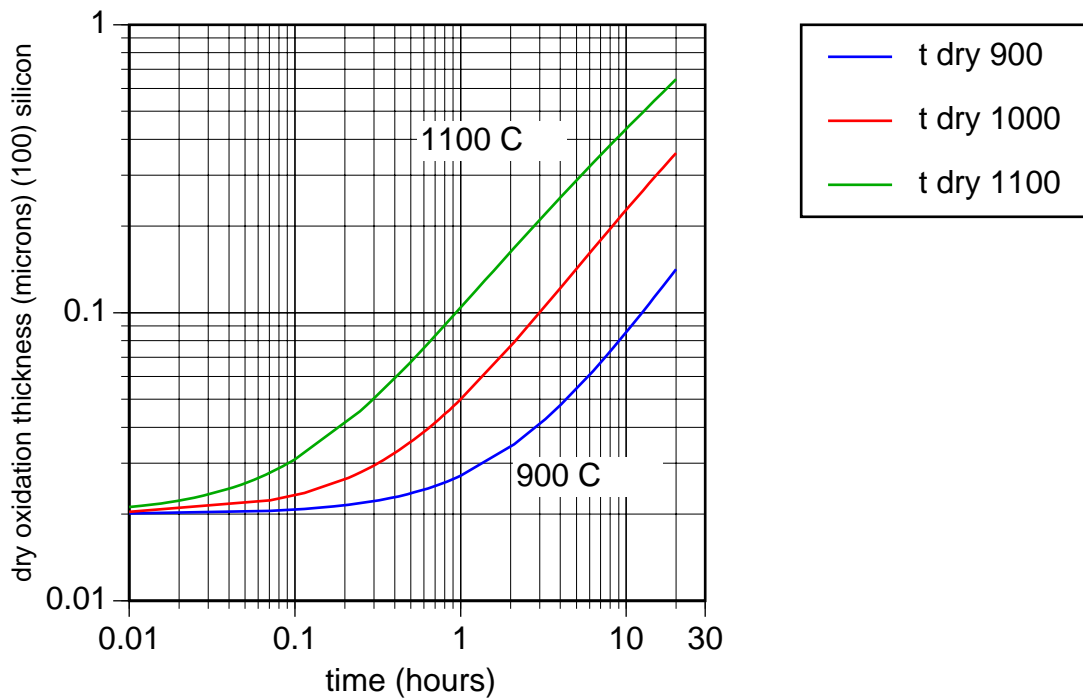
SAMPLE EXAM for F97 class

7. (20 points) The Grove and Deal model is used to fit actual thickness measurements to produce the graphs of oxide thickness versus time for wet and dry oxidations, with the results shown below.



a) Consider the wet oxidation curve at 1100° C. For about what range of time is the growth in the "linear" regime? What physical mechanism limits the growth rate during these times? As temperature decreases, does this time increase or decrease?

b) Again consider the wet oxidation curve at 1100° C. For about what range of time is the growth in the "parabolic" regime? What physical mechanism limits the growth rate during these times?

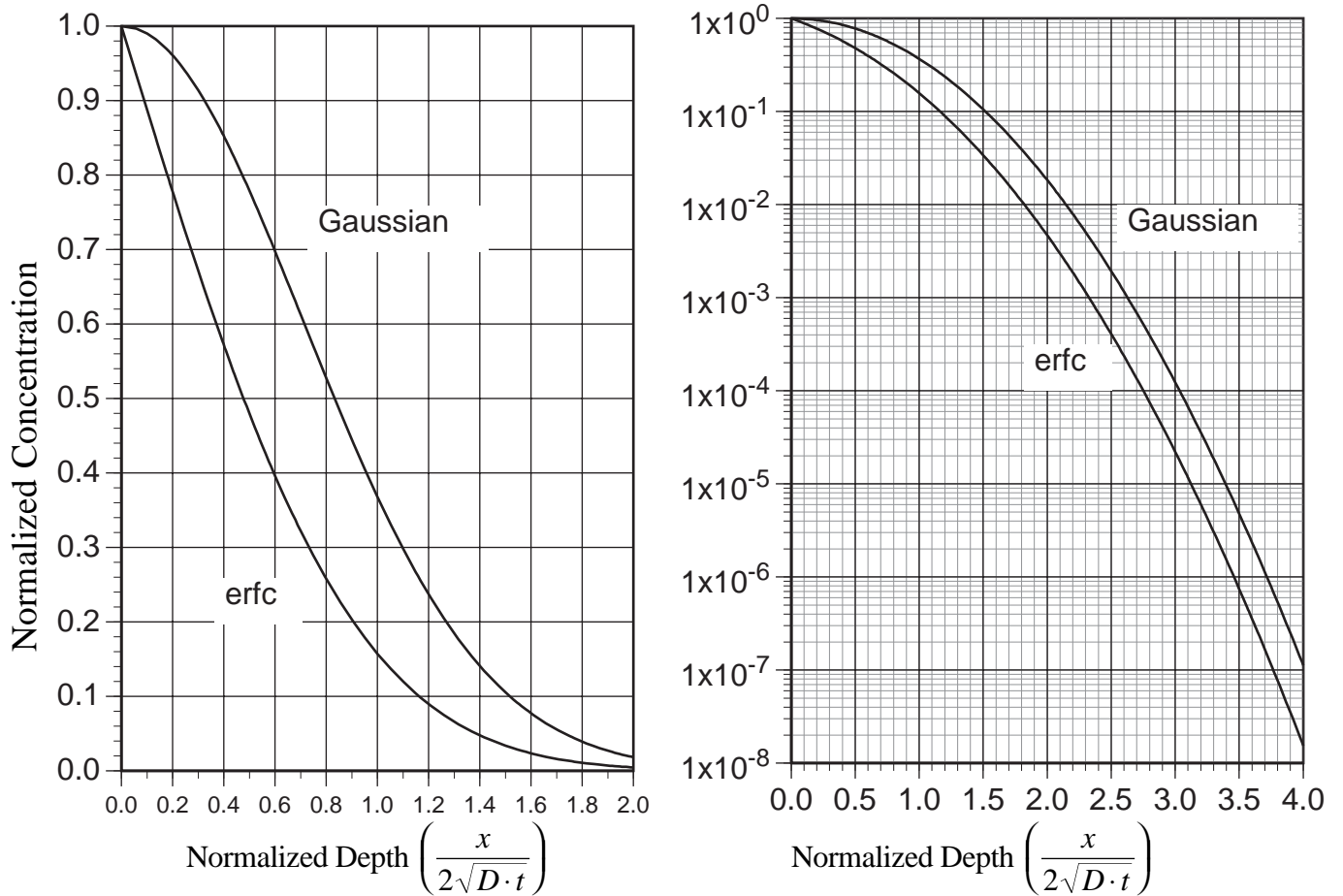


c) For the dry oxidation curves, **data** was taken only for thicknesses greater than about $0.03 \mu\text{m}$. The curves shown on the graph are the result of **fitting** the data using a simple Grove and Deal model. What is occurring at thicknesses less than about $0.03 \mu\text{m}$? Can you use these curves to predict thickness versus time for these thin oxides? Explain very briefly.

SAMPLE EXAM for F97 class

8. (20 points) Two different boron diffusions are carried out, one under constant source conditions, and another under limited source conditions. The temperatures and times of the two processes are such that the Dt products are identical, and D can be assumed to be independent of impurity concentration. The normalized complementary error and gaussian functions are shown below.

Gaussian and Complementary Error Functions



a) If the two processes result in diffusion profiles that have identical surface concentrations, which diffusion has a higher dose, the limited source or the constant source? Approximately what is the ratio of the constant source dose to the limited source dose? HINT: This problem can be solved graphically!

SAMPLE EXAM for F97 class

b) If the constant source diffusion produces a surface concentration of 10^{20} cm^{-3} and the wafer background concentration is 10^{15} cm^{-3} , what is the junction depth (in units of \sqrt{Dt})?

c) If the limited source diffusion produced exactly the same junction depth as the constant source diffusion (as in part (b) above), what must the surface concentration of the limited source diffusion be?

d) If the processes result in diffusion profiles that have identical junction depths as in parts (b) and (c) above, which diffusion has a higher dose, the limited source or the constant source?