In More Depth: Integrated Circuit Cost

The "In More Depth" sections provide extra material and accompanying exercises; we leave it up to the instructor whether to cover the material in class, have students read it on their own, or skip the material altogether. This first such section gives more information on the cost of integrated circuits and is used in Exercises 1.59 through 1.64.

The cost of an integrated circuit can be expressed in three simple equations:

$$\text{Cost per die} = \frac{\text{Cost per wafer}}{\text{Dies per wafer} \times \text{yield}}$$

$$\text{Dies per wafer} \approx \frac{\text{Wafer area}}{\text{Die area}}$$

$$\text{Yield} = \frac{1}{(1 + (\text{Defects per area} \times \text{Die area}/2))^2}$$

The first equation is straightforward to derive. The second is an approximation, since it does not subtract the area near the border of the round wafer that cannot accommodate the rectangular dies. The final equation is based on years of empirical observations of yields at integrated circuit factories, with the exponent related to the number of critical processing steps in the manufacturing process.

1.59 [5] <§§1.4, 1.5> What is the approximate relationship between cost and die area? The approximate relationship can be described as

   $\text{Cost} = f((\text{Die area})^x)$

for some x. You don't have to determine f, but you can determine x by first writing

   $\text{Dies per wafer} = f((\text{Die area})^y)$

   $\text{Yield} = f((\text{Die area})^z)$

and then examining how these two equations impact the first one (you need to figure out what y and z are). What implications does this have for designers?

1.60 [15] <§§1.4, 1.5> Compare the estimate of the number of dies per wafer calculated in the formula above to the actual number given in the caption of Figure 1.15 on page 31. Propose a formula that gives a more accurate estimate of the number of dies per wafer, and give an explanation of your formula.

1.61 [10] <§§1.4, 1.5> What is the approximate cost of a die in the wafer shown in Figure 1.15 on page 31? Assume that an 8-inch wafer costs $1000 and that the defect density is 1 per square centimeter. Use the number of dies per wafer given in the figure caption.

Exercises 1.62 through 1.64 DRAM chips have significantly increased in die size with each generation, yet yields have stayed about the same (43% to 48%). Figure 1.8.1 shows key statistics for DRAM production over 12 years.

Year	Capacity (Kbits)	Die area (sq. cm)	Wafer diameter (inches)	Yield
1980	64	0.16	5	48%
1983	256	0.24	5	46%
1985	1,024	0.42	6	45%
1989	4,096	0.65	6	43%
1992	16,384	0.97	8	48%

FIGURE 1.8.1 History of DRAM capacity, die size, wafer size, and yield. Source: Howard Dicken of DM Data Inc., of Scottsdale, Arizona.

1.62 [5] <§§1.4, 1.5> Given the increase in die area of DRAMs, what parameter (see the equations) must improve to maintain yield?

1.63 [10] <§§1.4, 1.5> Derive a formula for the improving parameter found in Exercise 1.62 from the other parameters.

1.64 [10] <§§1.4, 1.5> Using the formula in the answer to Exercise 1.63, what is the calculated improvement in that parameter between 1980 and 1992?