ECE 3030: Physical Foundations of Computer Engineering
Fall 2021
Homework 2—Total points 100
Due on Thursday 9/16/2021 at 11.59am.

Q1 Figure 1 shows the cross-section of an Intel Broadwell chip (2014). Clearly identify different classes materials in this cross-section. How many layers of metal are there in this chip as visible in this cross-sectional image? [20 pts]

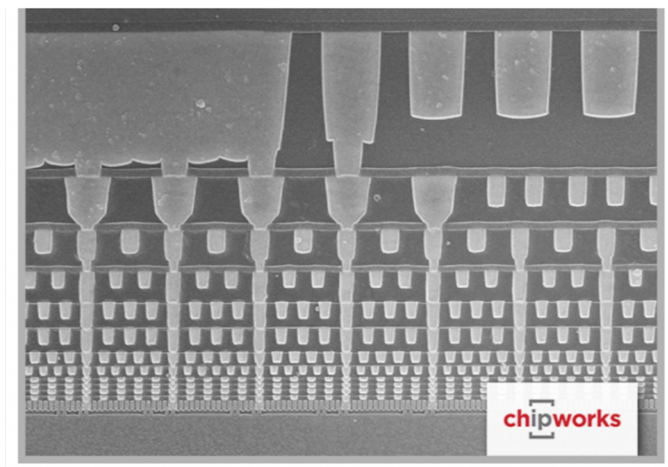
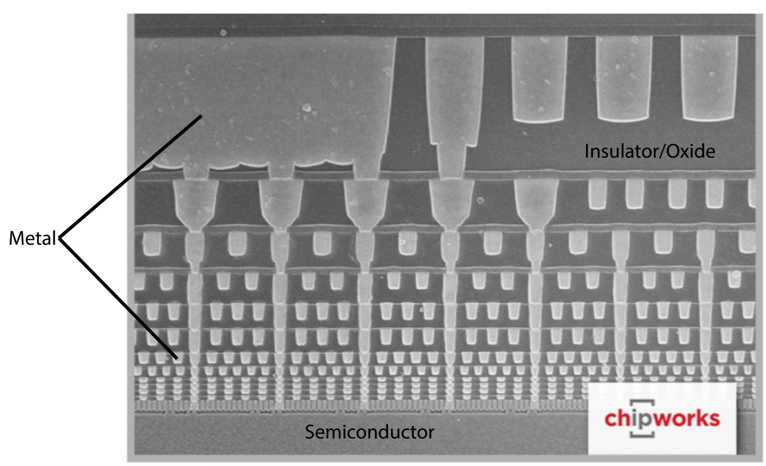


Figure 1: Image source: Extremetech

Solution to Q1:
There are 12 metal layers.



Q2 Starting with the Ohm's law derive the equation $v = \mu E$. All variables carry their usual meanings. Explicitly state the meaning of all variables used in the derivation. [20 pts]

Solution to Q2:

$V = IR \Rightarrow$ [illegible] $EL = JAR \Rightarrow J = \frac{L}{AR} E \Rightarrow J = \sigma E$

V = Voltage applied across the conductor

I = Current through the conductor

R = Resistance of the conductor.

E = Electric field inside the conductor = $\frac{V}{L}$

L = Length of the conductor

$I = JA$

J = Current density

A = Area of crossection of the conductor

$\sigma = \frac{L}{AR}$ = conductivity of the material

J = # of charge carrier/volume × velocity of charge carriers × q

$= nvq$

q = Charge of the charge carrier

$J = nvq = \sigma E \Rightarrow v = \frac{\sigma}{nq} E \Rightarrow \boxed{v = \mu E}$

$\mu = \frac{\mu}{nq}$ = Mobility of the charge carrier in the material.

Q3 Show that $\sigma = \frac{n\tau^2 q}{m}$. All variables carry their usual meanings. Explicitly state the meaning of all variables used in the derivation. [20 pts]

Solution to Q3:

Q4 In the microprocessor chips like ones in laptops and cell-phones, transistors are made of crystalline silicon. On the other hand, in the LED TVs, the transistors that control the LED pixels are made of silicon that is not crystalline (it is either polycrystalline or amorphous). The silicon in which type of transistor has a higher mobility and why? [20 pts]

Solution to Q4: Crystalline Si will have a larger mobility compared to that in a polycrystalline/amorphous Si. Polycrystalline/amorphous materials are signicantly more disordered and contains more impurities which impede the flow of charge carriers (electrons and holes) resulting in lower mobility.

Q5 The mobility and carrier density of Al are 1.2×10^{-3} m^2/Vs and 1.98×10^{29} m^{-3}, respectively. The mobility and carrier density of Cu are 4.32×10^{-3} m^2/Vs and 8.5×10^{29} m^{-3}, respectively. Which one would you use as interconnects in advanced CMOS nodes? [20 pts]

Solution to Q5: Solution in the next page.

3.

The conductivity ~~for~~ of ~~a~~ Al, $\sigma_{Al} = q n_{Al} \mu_{Al}$

$= 1.6 \times 10^{-19} C \times 1.98 \times 10^{29} m^{-3}$

$\times 1.2 \times 10^{-3} m^2/Vs$

$= 38.016 \times 10^6$ S/m

$\approx 0.38 \times 10^8$ S/m

The conductivity of Cu, $\sigma_{Cu} = q n_{Cu} \mu_{Cu}$

$= 1.6 \times 10^{-19} C \times 8.5 \times 10^{29} m^{-3}$

~~$\times 8.5 \times$~~ $\times 4.32 \times 10^{-3} m^2/Vs$

$= 5.8752 \times 10^8$ S/m

$= 5.9 \times 10^8$ S/m

$\sigma_{Cu} > \sigma_{Al}$. ∴ We should use Cu as interconnects in advanced CMOS nodes.

Q5 Say you doped a wafer of pure (intrinsic) Si with P (doping density=10^{23} m^{-3}). Now the wafer has a lot more free electrons than it had before. Do you expect the piece of Si wafer to be charge neutral? Why or why not? Will your answer change had you doped it with Al? [20 pts]

Solution to Q5: A doped semiconductor is always charge neutral since the dopant atoms since the dopant atoms themselves are charge neutral.