Homework 4 Fall 2018 TA: Robert Buckley

Problem 1:

For the 248 nm UV machine, the total amount of wafers that can be made in a year:

$$N_w = 80 * 24 * 365 * \frac{4}{10} = 280{,}320\ wafers$$

Cost per wafer: $C_w = \frac{10M}{N_w} = \$35.67$

Number of chips per wafer: $N_c = \frac{A_w}{A_{chip}} = 1413$

Cost per chip: $C_c = \frac{35.67}{1413} = \$0.025$

For the 193nm UV machine:

Wafers per year: $N_{w2} = 70080$

Cost per wafer: $C_{w2} = \$570.78$

Chips per wafer: $N_{c2} = 4580$

Cost per chip: $C_{c2} = \$0.125$

Cost difference $C_\Delta = 0.125 - 0.025 = \$0.1/chip$

Problem 2:

The dielectric constant of SiO_2 = $K_s = 3.9$

The dielectric constant of HfO_2 = $K_H = 25$

-> Thickness of HfO2: $t_{HfO_2} = \frac{25}{3.9} * t_{SiO_2} = 12.82\ nm$

Problem 3:

The total volume of the oxide $V_{ox} = 10nm * 25\ nm * 2.5\ nm = 625\ nm^3$

The volume of one SiO_2 molecule $V_{SiO_2} = 0.044\ nm^3$

Number of SiO_2 molecules per gate $N_m = \frac{V_{ox}}{V_{SiO_2}} = 14204\ molecules$

Problem 4:

Resistivity of Aluminum $2.8 * 10^{-8}\Omega * m$

Resistance of the interconnect: $R = \frac{2.8*10^{-8}\Omega m}{80*10^{-9}m} * \frac{400*10^{-6}m}{60*10^{-9}m} = 2333.33\ \Omega$

Problem 5:

The lowest resistance metal for interconnection is silver. It is often not used because silver is very expensive, and because when using silver there is an electro migration issues during fabrication.

Problem 6:

The average thickness of a 12 inch (300 mm) wafer is 750-800 μm With a 150 μm saw the thickness per cut is 870-920 μm.

A 2 meter pull can create $N_w = \frac{2m}{900*10^{-6}m} \sim \frac{2m}{950*10^{-6}m}$=2105 ~ 2222 wafers

Problem 7:

From the last page we find,

Poly1 sheet resistance = 7.7$\frac{\Omega}{\blacksquare}$

poly1-Insulator-M1 capacitance = 64$\frac{aF}{\mu m^2}$

$$\omega_{3dB} = \frac{1}{RC} = 2\pi f \rightarrow R = \frac{1}{2\pi f * c} = 19.89 * 10^6 \Omega$$

a. The minimum area of a poly1 resistor is

$$A_{Resistor} = \frac{19.89 * 10^6}{7.7} * 0.2^2 \mu m^2 = 103.32 * 10^3 \ \mu m^2$$

The minimum area of a Poly1-Poly2 (864$\frac{aF}{\mu m\text{^}2}$) capacitor is

$$A_{Capacitor} = \frac{10pF}{64\frac{aF}{\mu m\text{^}2}} = 156.25 * 10^3 \ \mu m^2$$

Total Area $A = A_{Res} + A_{Cap} = 103.32 * 10^3 + 156.25 * \ 10^3 = 159.57 * 10^3 \ \mu m^2$

b) We will start with the minimized size resistor has a sheet of x ■ and the capacitor has an area of $y \ \mu m^2$.

Total area $A = (0.2 * 0.2) * x + y = 0.04x + y$

$$\frac{1}{RC} = \omega_{3dB} = 2\pi f \rightarrow RC = \frac{1}{2\pi f} = 0.0001592 \ Hz$$

$$(x * 7.7)(65 * 10^{-18} * y) = 0.0001592 \rightarrow y = \frac{7.952 * 10^{12}}{x}$$

$$A = 0.04x + \left(\frac{7.952 * 10^{12}}{x}\right) \rightarrow A_{min} \ when \ 0.04x = \frac{7.952 * 10^{12}}{x}$$

$$x = 7.0495 * 10^6 \rightarrow y = \frac{7.952 * 10^{12}}{7.0495 * 10^6} = 1.128 * 10^6 \ \mu m\text{^}2$$

$$R = 7.0495 * 10^6 \ * 7.7 = 55.2 \ * 10^6 = 54.2 \ M\Omega$$

$$C = 1.128 * 10^6 * 64 * 10^{-18} = 7.22 * 10^{-11} = 72.2 \ pF$$

Problem 8:

a. Length = $1\mu m$, width = $2\mu m$
b. Positive photoresist underexposed decreases the size.
   Length = $1 - 0.1 + (-0.1) = 0.8\ \mu m$
   Width is unchanged.
c. Underexposing negative photoresist decreases the size
   Length = $1 - 0.1 + 0.1 = 1.0\ \mu m$

Problem 9

Resistivity of Aluminum $2.8 * 10^{-8}\Omega * m$

Resistance of the interconnect $R_{Al} = \frac{\rho l}{wt} \rightarrow t = \frac{\rho l}{wR} = \frac{2.8*10^{-8}*250*10^{-6}}{3*10^{-6}*25} = 93.3 * 10^{-9}m = 93.3nm$

Sheet resistance $= \frac{\rho}{t} = \frac{2.8*10^{-8}}{93.3*10^{-9}} = 0.3\ \Omega/\blacksquare$

Problem 10

Resistivity of Copper $1.68 * 10^{-8}\Omega * m$

$$R_{Al} = \frac{\rho l}{wt} \rightarrow l = \frac{Rwt}{\rho} = \frac{2 * 10^{-6} * 25 * 93.3 * 10^{-9}}{1.68 * 10^{-8}} = 11.107 * 10^{-6} = 11.107\ \mu m$$

Problem 11

Approximately 53% of the oxide grows above the wafer, and 47% grows into the wafer.
The increased wafer height $W_{height} = 0.53 * 5000 = 2650Å$

Problem 12

Poly 1: $7.7\Omega/\blacksquare$
P+: $7.5\Omega/\blacksquare$

For 10k Ohms

Poly1: $\frac{5{,}000}{7.7} = 649.4\ \blacksquare's$

P+: $\frac{5{,}000}{7.5} = 666.7\ \blacksquare's$

There are a lot of different ways to create the serpentine layout, depending on how many rows you want to make, but it will take approximately 2.3x the area for the P+ resistor. The main reason for this is that a P+ ■is 0.3x0.3 microns while a Poly ■ is 0.2x0.2 microns

Problem 13-14

Code

```
module NOR2 (i_A, i_B, o_F);
  input i_A, i_B;
  output o_F;

  assign o_F = ~(i_A||i_B);

endmodule
```

```
module AND2 (i_A, i_B, o_F);
  input i_A, i_B;
  output o_F;
  wire A_not, B_not;

  NOR2 nor0(.i_A(i_A), .i_B(i_A), .o_F(A_not));
  NOR2 nor1(.i_A(i_B), .i_B(i_B), .o_F(B_not));
  NOR2 nor2(.i_A(A_not), .i_B(B_not), .o_F(o_F));

endmodule
```

```
module OR2 (i_A, i_B, o_F);
  input i_A, i_B;
  output o_F;
  wire A_nor_B;

  NOR2 nor0(.i_A(i_A), .i_B(i_B), .o_F(A_nor_B));
  NOR2 nor1(.i_A(A_nor_B), .i_B(A_nor_B), .o_F(o_F));

endmodule
```

```
module Mux_2_1 (i_A, i_B, i_S, o_F);
  input [1:0] i_A, i_B;
  input i_S;
  output [1:0] o_F;
  wire [1:0] AS, BS;
  wire w_Sn;

  NOR2 nor0(.i_A(i_S), .i_B(i_S), .o_F(w_Sn))   ;
  AND2 and0(.i_A(i_A[1]), .i_B(i_S), .o_F(AS[1]));
  AND2 and1(.i_A(i_A[0]), .i_B(i_S), .o_F(AS[0]));
  AND2 and2(.i_A(i_B[1]), .i_B(w_Sn), .o_F(BS[1]));
  AND2 and3(.i_A(i_B[0]), .i_B(w_Sn), .o_F(BS[0]));
  OR2  or0 (.i_A(AS[0]), .i_B(BS[0]), .o_F(o_F[0]));
  OR2  or1 (.i_A(AS[1]), .i_B(BS[1]), .o_F(o_F[1]));

endmodule
```

```
module Inverter4 (i_A,o_F);
  input  [3:0] i_A;
  output [3:0] o_F;

  NOR2 nor0(.i_A(i_A[0]), .i_B(i_A[0]), .o_F(o_F[0]));
  NOR2 nor1(.i_A(i_A[1]), .i_B(i_A[1]), .o_F(o_F[1]));
  NOR2 nor2(.i_A(i_A[2]), .i_B(i_A[2]), .o_F(o_F[2]));
  NOR2 nor3(.i_A(i_A[3]), .i_B(i_A[3]), .o_F(o_F[3]));

endmodule
```

```
module Mux4_2_1 (i_A, i_B, i_S, o_F);
  input [3:0] i_A, i_B;
  input i_S;
  output [3:0] o_F;

    Mux_2_1 mux0(.i_A(i_A[1:0]), .i_B(i_B[1:0]), .i_S, .o_F(o_F[1:0]));
    Mux_2_1 mux1(.i_A(i_A[3:2]), .i_B(i_B[3:2]), .i_S, .o_F(o_F[3:2]));

endmodule
```

Testbench:

```
module HW4_Problem();
  reg [3:0] r_A;
  reg r_S;
  wire [3:0] w_An, w_F;

  initial
  begin
    r_A = 4'b0000;
    r_S = 1'b0;
  end

  always
    #10 r_S = ~r_S;
  always
    #20 r_A = r_A+1;

  Inverter4 inv0(.i_A(r_A), .o_F(w_An));
  Mux4_2_1  mux0(.i_A(w_An), .i_B(r_A), .i_S(r_S), .o_F(w_F));

endmodule
```

Output: