Birla Institute of Technology and Science, Pilani
MEL G611 IC Fabrication Technology
Comprehensive Exam   Closed Book
Time:105 Mins   Date: 11.12.2017   M.M: 50

You may need: Atomic weight of Si = 28.09 g/mol, density of Si = 2.33 g/cm^3, atomic weight of SiO_2 = 60.08 g/mol. density of SiO_2 = 2.21 g/cm^3, Distribution coefficient (k_0) of B = 0.8, P= 0.35,As= 0.3,Ga = $8*10^{-3}$,Sb = 0.023, Al = $2.8*10^{-3}$, O = 1.25

Q 1(a) A CZ grown crystal is doped with boron. Why is the boron concentration larger at the tail end of the crystal than at the seed end? In a CZ growth, oxygen diffuses into the molten silicon from the silica crucible used to contain it; will the concentration of oxygen in the crystal be larger at the tail end or the seed end? Explain.

1(b) For a particular lithography process based on projection printing, the minimum resolution is 1μm and the depth of focus is 1μm. By placing a smaller aperture over the projection lens, the numerical aperture (NA) is reduced by a factor of 2, calculate the new values of minimum resolution and depth of focus.

1(c) 1000 keV boron was implanted into n-type Si ($N_B = 10^{15}/cm^3$) to a dose of $10^{15}/cm^2$.What are the junction depths? **[1(a-c) each 2M]**

1(d) A Si wafer has an unknown initial oxide thickness (x_i). After thermal oxidation for 1 hour, the total oxide thickness is measured to be x µm. With an additional 3 hours of oxidation, the total oxide thickness becomes 2x µm. Given: Linear oxidation constant B/A=1µm /hour and parabolic oxidation constant B= 0.3 µm^2/hour. (i) Find the numerical value of x and x_i.

1(e) A BOE (Buffered HF) etches SiO_2 isotropically at 100 nm/min. Further, assume that BOE has very high selectivity against Si and photoresist that it wouldn't etch them.
(i) For the structure shown in the figure (1) below, how long should this wafer be placed in BOE etchant to record a 10% over-etch?
(ii) What is the width of SiO_2 removed at the top of the resulting trench (at the Photoresist/SiO_2 interface), and what is the width of SiO_2 removed at the bottom of the trench (at the SiO2/Si interface) after the 10% over-etch? Also draw a schematic of the structure after 10% over-etch.

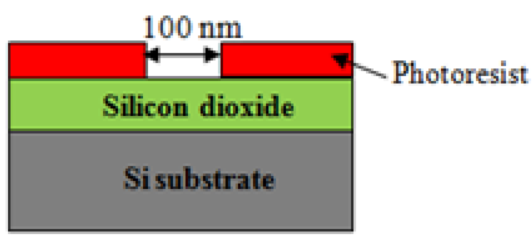

Figure (1)

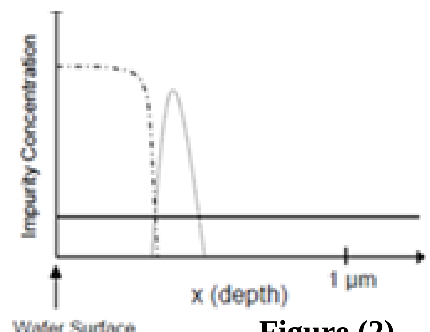

Figure (2)

1(f) The figure (2) shows the phosphorous and arsenic impurity profiles for a p-type sample (uniformly doped with boron) that has gone through a phosphorous diffusion step followed by an arsenic ion implantation and an ultra-short annealing step. Assume all dopants are electrically active. Please label each curve in the plot i.e., B, P, As. Also, draw a plot for net carrier concentration (|n-p|) profile. Indicate all p/n junctions on the new plot.

1(g) (i) What is the benefit of using Faraday cup in the ion implantation system?
(ii) You want to create a shallow p-n junction near the surface of a doped Si wafer and need to maintain the highest possible dopant concentration near the wafer surface.
ii (a) Would you prefer to use B or As as a dopant? Explain.
ii(b) Which type of Si wafer would you then start with, p-type or n-type? **[1(d-g) each 3 M]**

Q-2 A silicon wafer with n-type background doping of 10^{16} cm^{-3} is subjected to a boron implant. The implant energy is 100 keV and the dose is 10^{13} cm^{-2}. Then the wafer is annealed for 30 minutes at 1000°C, which provides a 'Dt' = $2.5*10^{-11}$ cm^2. Find the peak concentration and junction depth(s) immediately after implantation and then after annealing. **[8M]**

Q-3 (a) You are using KOH etching to define a thru-hole in a (100) Si wafer as shown in figure (3). What should be the size of your mask (W_m) if you are using 400 um thick wafer.
3 (b) Explain the isotropic and anisotropic wet etching through a diagram. Also write the name of isotropic and anisotropic wet etchant of silicon. **[8M]**

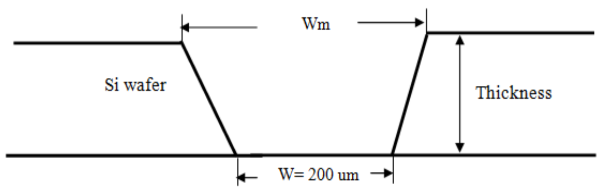

Figure (3)

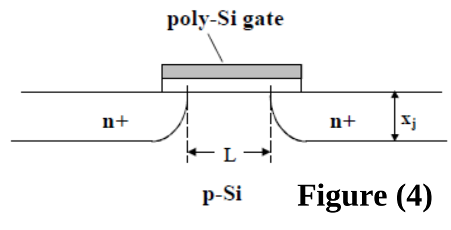

Figure (4)

Q-4 Three doping processes are proposed to form the source and drain of a MOS transistor as shown in figure (4) above.
(**Process A**) Shallow diffusion predeposition dose of Q phosphorus atoms /unit area, followed by a drive-in at 1100°C for 60 minutes.
(**Process B**) Shallow diffusion predeposition dose of Q phosphorus atoms /unit area, followed by a drive-in at 1150°C for 30 minutes.
(**Process C)** Shallow implantation dose of Q phosphorus atoms / unit area, followed by a drive-in at 950°C for 10 minutes.
Take the lateral junction depth (y_j) from masking edge is ~ 0.7 of the vertical junction depth x_j .

(i) Which process will give the shortest MOSFET channel length (L) ? Explain your reasoning.
(ii) If the substrate doping N_A is increased, which of the three processes will exhibit the biggest change in channel length L? Use a qualitative sketch to illustrate your reasoning. **[8M]**
Use the following diffusivity values and neglect high concentration effects:

Temperature	D (Phosphorus)
950 °C	$5*10^{-5}$ μm^2/min
1100 °C	$2*10^{-3}$ μm^2/min
1150 °C	$5*10^{-3}$ μm^2/min

Q-5 The profile given in the figure (5) was created using a projection photolithography method. The light source was an ArF excimer laser at 193 nm.

(a) If the projection system is 10:1. What is the actual width of the mask feature shown in the figure?
(b) Calculate the numerical aperture (N.A) necessary to produce this patterned feature size. Assume k_1=0.5.
(c) If the half- angle of the maximum cone of light that can enter or exit the objective lens is 70°, what is the index of refraction between the lens and photoresist.
(d) How you can achieve the index of refraction of part (c). **[8M]**

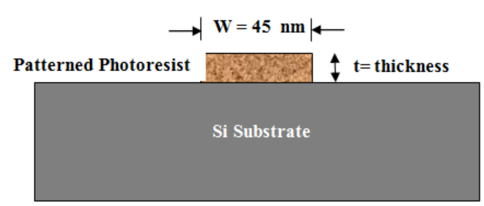

Figure (5)