Exercise 5

Exercise 1: Metal-amorphous silicon Schottky barriers

In this exercise we are going to study the Schottky junction, namely the metal-semiconductor junction, made by our amorphous silicon (a-Si:H) with different metals.
Let us start from the general description of the Schottky junction.
The figure below[1] shows what happens in the band diagram when a metal and an n-type semiconductor are put closer and closer until they get in contact.

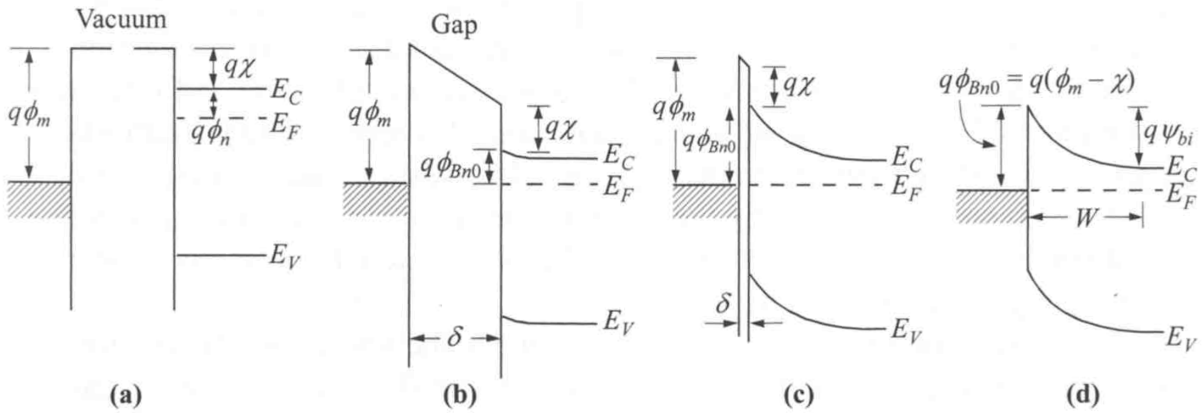


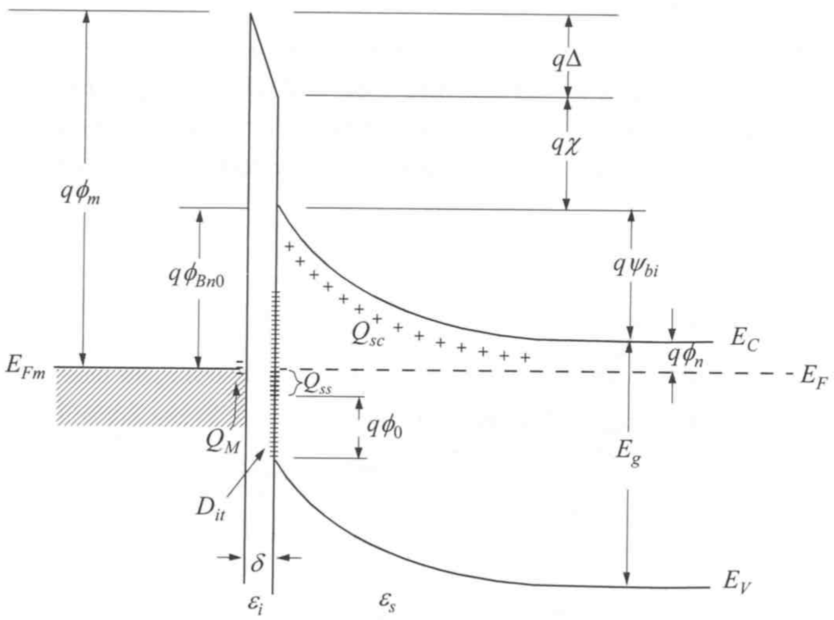
Fig. 1 Energy-band diagrams of metal-semiconductor contacts. Metal and semiconductor (a) in separated systems, and (b) connected into one system. As the gap δ (c) is reduced and (d) becomes zero. (After Ref. 7.)

As you can see, on the semiconductor side, there is a parabolic curvature of the bands which extends to a depth of W_D. This is due to the presence of space charge in the depleted region of the semiconductor. This region is formed by lining up the Fermi levels of metal and semiconductor, which makes the conduction and valence band to bend.
Firstly, you are asked to calculate the literary expression of Q_{sc} that is schematically shown in the Figure 1 [2]. To do so, you need to use the Poisson's equation in the approximation of abrupt junction, namely $\rho \approx qN_D$ for $x < W_D$ and $\rho \approx 0$ ($E = 0$) for $x > W_D$:

$$\frac{d^2\phi(x)}{dx^2} = -\frac{dE(x)}{dx} = \frac{\rho(x)}{\epsilon_s} \quad (1)$$

where $\epsilon_s = \epsilon_0\epsilon_r$ and $E(x)$ is the corresponding electric field.
After that, the other involved charge is Q_{ss} that is the interface-trap charge density on the semiconductor side. This takes into account a more realistic representation of the Schottky barrier with an interfacial layer that depends only on the semiconductor and it is as thin as

[1] S. M. Sze, Physics of Semiconductor Devices, third edition, p. 135, 2007
[2] S. M. Sze, Physics of Semiconductor Devices, third edition, p. 140, 2007



ϕ_m = Work function of metal
ϕ_{Bn0} = Barrier height (without image-force lowering)
ϕ_0 = Neutral level (above E_V) of interface states
Δ = Potential across interfacial layer
χ = Electron affinity of semiconductor
ψ_{bi} = Built-in potential
δ = Thickness of interfacial layer
Q_{sc} = Space-charge density in semiconductor
Q_{ss} = Interface-trap charge
Q_M = Surface-charge density on metal
D_{it} = Interface-trap density
ε_i = Permittivity of interfacial layer (vacuum)
ε_s = Permittivity of semiconductor

Detailed energy-band diagram of a metal-*n*-semiconductor contact with an interfacial layer (vacuum) of the order of atomic distance. (After Ref. 14.)

Figure 1: Schottky junction with interfacial layer.

the atomic dimensions. This means that it is transparent to electrons but can withstand a potential across it.
By looking at the figure, you are asked to give the literary expression of Q_{ss} that is measured in $[\mathrm{C\,cm^{-2}}]$.
Because of charge neutrality, to the charges Q_{sc} and Q_{ss} correspond an opposite charge on the metal side:

$$Q_M = -(Q_{sc} + Q_{ss}) \tag{2}$$

Another important parameter is the potential Δ across the interfacial layer. How can you define it by inspecting the energy band diagragm of Figure 1.

You can also obtained Δ by applying Gauss' law to the surface charge on the metal and semiconductor:

$$\Delta = -\frac{\delta Q_M}{\epsilon_i} \tag{3}$$

Now by combining the two formulas of Δ (the one you obtained and (3)) and the one of Q_M (eq. (2)), you are asked to obtain the final equation where all the parameters of Figure 1 come into play.

Eventually some parameters can be gathered into two quantities:

$$c_1 = \frac{2q\epsilon_s N_D \delta^2}{\epsilon_i^2} \tag{4}$$

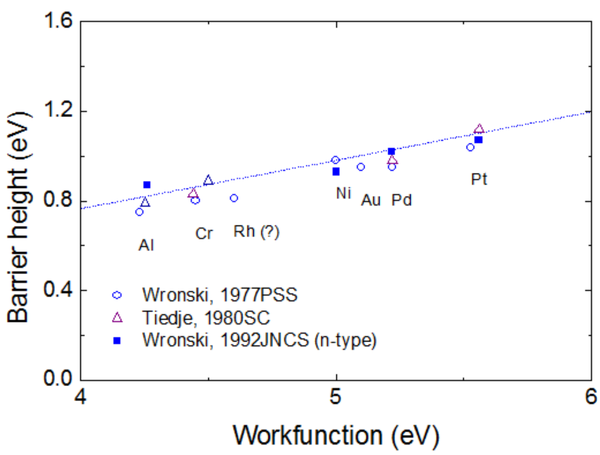
and

$$c_2 = -\frac{\epsilon_i}{\epsilon_i + q^2 \delta D_{it}} \tag{5}$$

When the semiconductor in Schottky junction is a-Si:H, c_1 and c_2 were obtained experimentally by fitting φ_{Bn0} versus φ_M in a work by Wronski and Carlson [3], as shown in the figure below (open circles). They studied the junction between a-Si:H and many different metals. By fitting with the method of the least squares they obtained the following equation:

$$\phi_B = C_1\phi_M + C_2 = 0.28\phi_M - 0.44 \tag{6}$$

What can you conclude from this graph?



[3] Wronski, PSS, vol.23, p. 421, 1977.