Exercise Series 11

Exercise 1: Improvement of the $V_{\rm oc}$ with the back Surface Field (BSF)

Let's consider a standard Al-BSF solar cell whose base is p-type. As seen in the lecture, to fabricate such cells, different processed are required. To create the front emitter (and then the p-n junction), phosphorus (to create n-type doping) is diffused at the front of the p-type cristalline silicon. The emitter and base doping are $\approx 10^{20}\,\mathrm{cm}^{-3}$ and $\approx 10^{16}\,\mathrm{cm}^{-3}$ respectively. For the back-contact, a film of an Al paste is screen-printed. If the paste is only dried (heating around 210 °C during 20 min) after this step, the resulting contact creates a very bad surface recombination velocity near to $10^{7}\,\mathrm{cm\,s}^{-1}$ leading to a poor $V_{\rm oc}$since the temperature is not high enough to activate the Al diffusion into Si at the back side.
To overcome this issue, the firing-through process (heating around 900°C during 2 min) leads to the insertion of Al atoms into the silicon, creating a cristallised Al-Si alloy at the back side which creates a p-type doped region, called Back Surface Field (BSF). The resulting p+ region provokes the apparition of an electrical field which repels the minority carriers (electrons) from the surface, which decreases the surface recombination velocity (less minority carriers available, so less recombination possible). The doping level (= Al concentration) of this latter region is called N_S.
Fig. 1 shows the $V_{\rm oc}$ dependency with the BSF depth for different N_S and for a surface recombination velocity of $10^{6}\,\mathrm{cm\,s}^{-1}$.

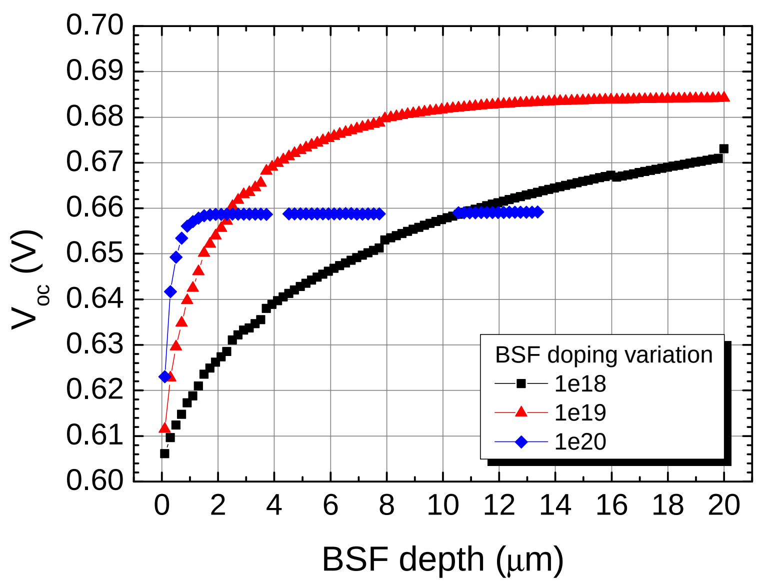

Figure 1: $V_{\rm oc}$ versus BSF depth for different BSF doping levels. From PC1D simulations

a) Explain the dependency of the $V_{\rm oc}$ with the BSF depth.

b) Explain the dependency of the $V_{\rm oc}$ with the BSF doping level.

Exercise 2: Diffusion technologies for p-n junction creation

Two processes are mainly used nowadays in the semiconductor industry for the creation of p-n junctions:

- The ion implantation. This technique was the first used for earliest solar cells and gives a good homogeneity and an accurate control of the junction depth. Moreover, this technique allows the possibility to create more doped regions in the purpose to realize selective emitter solar cells. Nevertheless, if this technique is massively used by the CMOS industry, it plays only a minor role in the solar cell industry nowadays.
- The thermal diffusion of dopants. For n-type doping, a gas containing phosphorus ($POCl_3$) is used with oxygen to create a doped silicon oxide at the surface of the wafer. Then, a thermal diffusion is carried out to transfer the dopant into the silicon. You can find more information about this process on the website of the CMI (http://cmi.epfl.ch/thinfilms/Tube_1-4.php).

The diffusion process follows the second Fick law:

$$\frac{\partial N(x,t)}{\partial t} = D\frac{\partial^2 N(x,t)}{\partial x^2} \tag{1}$$

Where $N(x,t)$ is the density of dopants in function of the position and of the time. The dependency of $D(T)$ with the temperature explains why the diffusion process is carried out at high temperature. Here is two ways to solve the latter differential partial equation (DPE) :

- With a constant surface density of dopants N_S if we suppose an infinite source of dopants. The solution of the DPE is then :

  $$N(x,t) = N_S \cdot erfc(\frac{x}{2\sqrt{Dt}}) \tag{2}$$

  Where the *erfc* function is called the complementary error function distribution. This case is shown by Fig.2.

- With a given number of dopants if we consider a finite source with a surface concentration Q (cm^{-2}) .

  The solution of the DPE is then :

  $$N(x,t) = \frac{Q}{\sqrt{\pi Dt}} exp\left\{-\left(\frac{x}{2\sqrt{Dt}}\right)^2\right\} \tag{3}$$

  This case is shown by Fig.3

a) Prove that the latter $N(x,t)$ for the finite source case is a solution of the Fick law.

b) Explain Fig.3

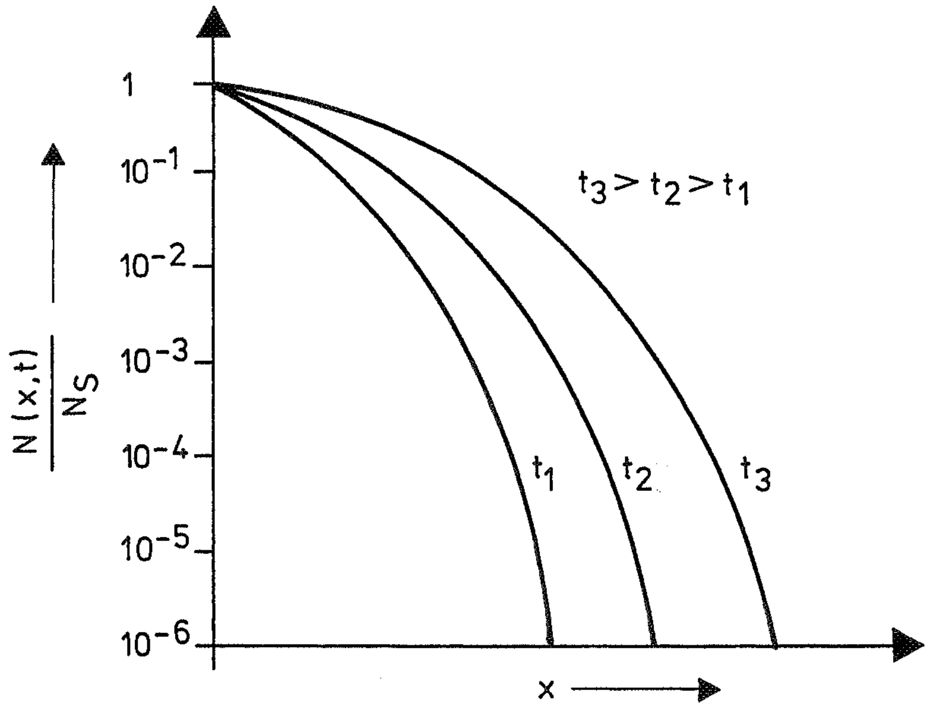

Figure 2: Diffusion case with an infinite source of dopants. From "Crystalline Silicon Solar Cells" A. Götzberger

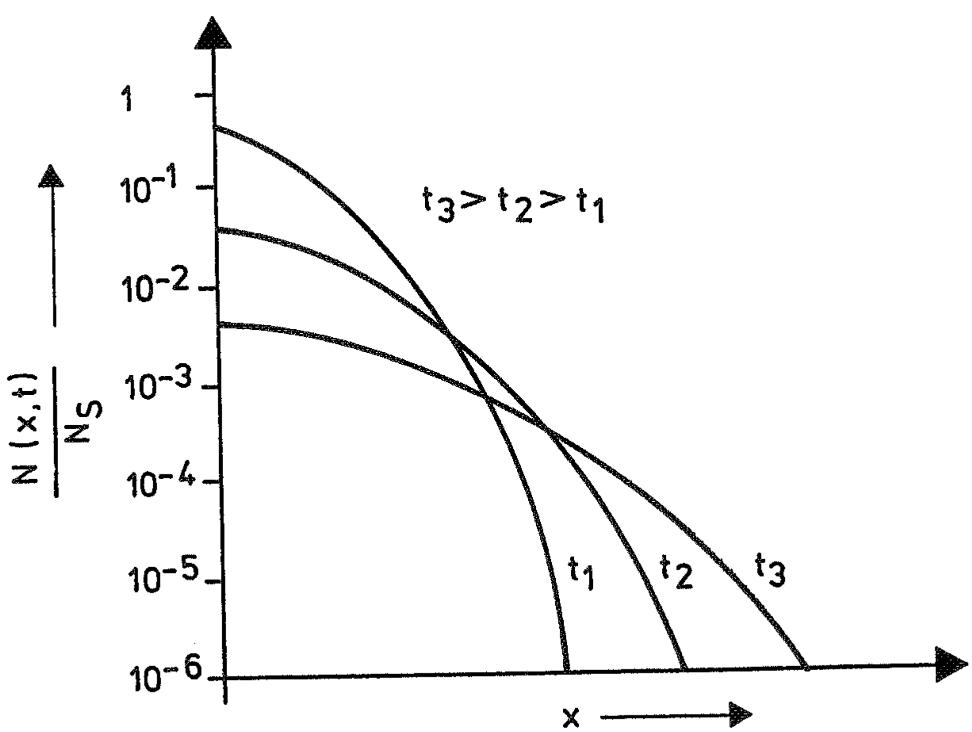

Figure 3: Diffusion case with a finite source of dopants. From "Crystalline Silicon Solar Cells" A. Goetzberger