8-09-2015

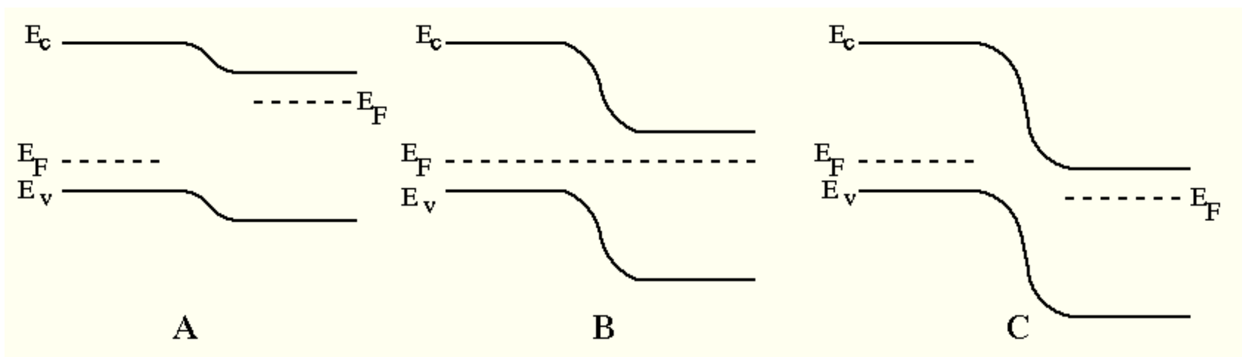
Diode Recovery time:

Aim: to use diode recovery time to extract the lifetime of the minority carrier.

Background Information:

Figure 1 shows the energy band diagram for a pn junction at different bias

In forward bias, the barrier is reduced (compare with barrier in zero bias fig.B). Minority carrier (electrons are injected into P and holes into N region) injection takes place. Minority carrier density increases in the P and N regions.



A) Forward bias B) zero bias C) Reverse bias. P region is on the left.

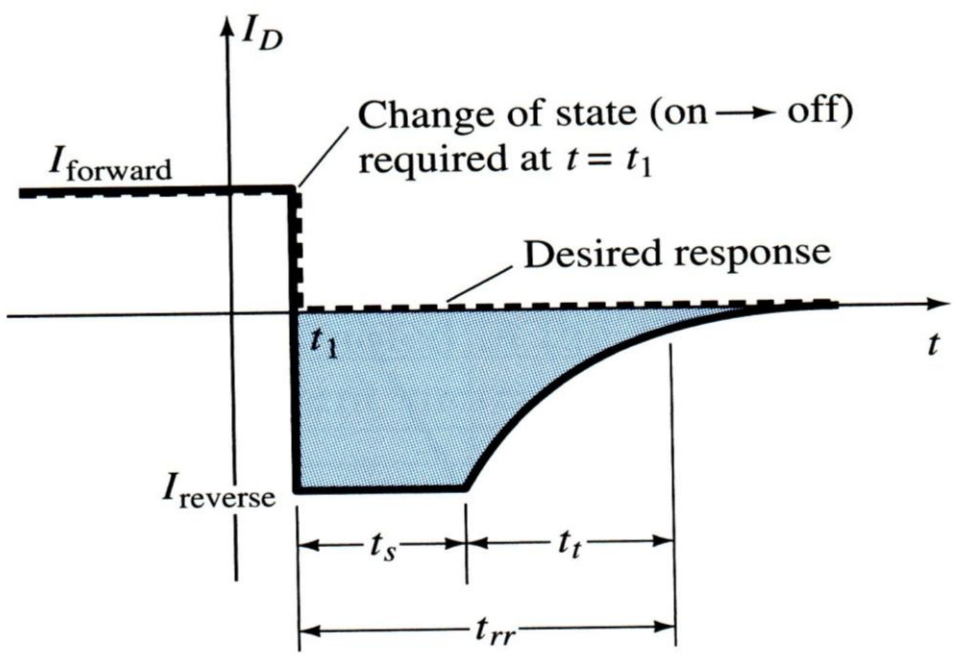


Figure 2: A forwrad bais is applied to a diode. At a time t_1, the bias across the diode is switched to reverse bias. The dashed line shows the current at forward bias and the equilibrium current at reverse bias. The solid line shows the actual current transient.

The dashed line in figure 2 shows the current voltage characteristic of an ideal pn^+ junction. In forward bias at a fixed voltage ,the current is large. The diode conducts in forward bias. In reverse bias, the diode is in the off state- the current is very low and is schematically shown by the dashed line in fig.1. The reverse current is due to minority carriers (electrons in the p base) within a diffusion length of the edge of the depletion region in the base region being swept into the n^+ contact. The minority carrier concentration $N_{p0} = n_i^2/ N_a$ is small. N_a is the base doping and n_i the intrinsic carrier density.

However in practice when a diode is switched from forward bias to reverse bias, the current changes sign and the diode continues to be conducting for a time t_{ss} (known as the storage time) and then decays to zero. (solid line in figure 2). This can be understood as follows:

Consider a N^+P junction. The depletion layer is mostly in the low doped p region. Electrons are the minority carriers in the p region. Under forward bias, the built-in field decreases and electrons are injected into the p base region. The electron concentration N_p at the edge of the depletion region is given by

$N_p = N_{p0} \exp (qV/kT)$..1

where V is the voltage drop across the diode. These electrons will diffuse a length L_d (diffusion length) and then recombine.

If the voltage across the diode is now reversed, the minority carriers from within a diffusion length will be swept across the depletion region. However, since the diode was in forward bias the minority carrier concentration $N_p >> N_{p0}$ (eq.1). Hence the "leakage current" immediately after switching will be large till the "stored minority carrier" in the p base is reduced to its equilibrium value. This explains as to why the diode "is conducting" in reverse bias immediately after switching and the subsequent decay.

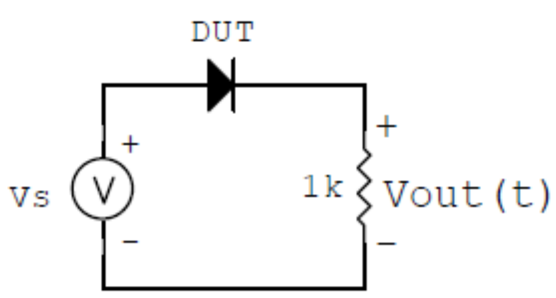


Figure 3

In the experiment, we need to put a small resistor R in series with the diode. This is shown in Figure 3. In far forward bias, most of the voltage is dropped across the resistor. The forward current is

$I_f = (V - 0.6)/R$.

In reverse bias at early times, the diode is conducting. The current must reverse in direction and $I_R = -(V + 0.6)/R$.

The sign is positive as the diode is still at forward bias at short times. As the stored charge decreases, the voltage across the junction increases and the voltage across R decreases resulting in a decrease in the absolute magnitude of current. The storage time t_s is given by

$$t_s = \tau_n \ln (1+I_f/I_R)$$

where I_f and I_R are absolute magnitude of current.

The storage time is directly related to the minority carrier lifetime τ_n. Diode recovery time is a convenient way of measuring minority carrier lifetime in addition to open circuit voltage decay.

The precautions to be taken

1) Voltage switching time must be small wrt the storage time.

2) frequency should be sufficiently low so that the sample can respond

Implications:

Clearly in a switching application it is important to reduce the stored charge.

This can be done by reducing the minority carrier lifetime in the base material. This is done by inducing defects by radiation damage in the base or by introducing impurities (like gold, iron etc) which are lifetime killers.Alternatively one can use Schottky diodes as minority carrier injection is very poor in Schottky diodes.