Exercice #1 – Tunnel Diode

Consider the Esaki tunnel diode with the characteristic I-V of Fig. 1 with the high frequency equivalent circuit of Fig. 2, for a tunnel diode biased into the negative-resistance region.

a. Is the tunnel diode always a dissipative device or not (consider that it may have a region of differential negative resistance)? Is energy being dissipated in a process of direct band-to-band tunneling?
b. This device can be seen as a nonlinear resistor that is voltage controlled; the current i is a function of the voltage v. By virtue of the nonlinearity of the tunnel diode a network including the tunnel diode can have more solutions. Redraw the V-I characteristics (if the device would be operated at constant injected current) and highlight the negative resistance region.
c. Can this device considered as being active (amplify the signal) in any of the operation regions?
d. Calculate the expressions of resistive cutoff frequency (frequency at which the real part becomes zero) for RQ = - 20 Ohm and RS = 2Ohm, C = 0.1pF.

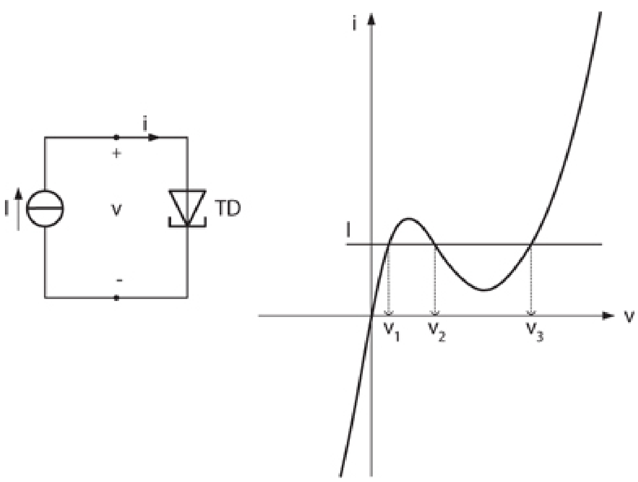

Figure 1.

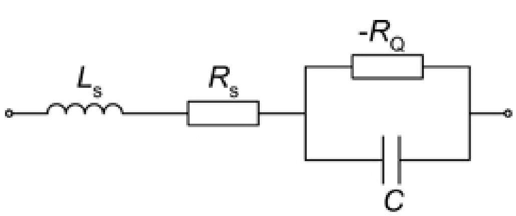

Figure 2.

Exercice 2

How much energy is needed for one electron to tunnel onto a metallic island that has already n electrons and a total capacitance C_{Σ} to the ground?

Exercice 3:

Propose and explain with a schematic and a discussion of the principle, how a Single Electron Transistor (SET) can be used for charge detection and exact quantification of the charge measured?

Exercice 4

The self-capacitance of a metallic grain is sometimes estimated by C_{self} = V/q, where V denotes the potential of the grain and q the charge transferred onto it from infinity (at zero potential). For a sphere, C_{self} equals $4\pi\varepsilon r$, whereas, for a circular disk, $C_{self} = 4\pi\varepsilon r$ (r denotes the radius of the island).

a. Estimate C_{self} and the charging energy using both the sphere and circular disk approximations for some reasonable grain radii: 100nm, 10nm and 1nm if the surrounding dielectric is SiO2 ($\varepsilon r = 4$).

b. Calculate the radius of metallic grain surrounded by HfO_2 ($\varepsilon r = 20$) needed to use this grain for a Single Electron Transistor capable to operate at T=10K. Recalculate the same for T=300K.

Exercice 5: Single Electron Transistors

The SET is a discrete charge device using three conductive nanodots as source, drain and gate and with thin tunneling oxides between central island and the source and the drain, operating under the orthodox theory of Coulomb blockade. Choose the correct properties of this family of devices:

1. A SET inverter can be built with two identical SETs, in contrast with a CMOS inverter that needs one n-type and one p-type MOSFET. This is due to the fact that an SET shows both positive and negative transconductance, depending on the applied gate voltage.

2. SET logic is a wireless logic.

3. The Id-Vd output characteristic of a SET transistor saturates because of the Coulomb blockade effect.

4. The effect of background charge on a SET affects the values of its threshold voltages.

5. The PADOX technology for SETs uses metal (like Al) dots and SiO2 as a tunneling dielectric.

6. With a metallic central island of around 2nm in diameter, one can obtain a Coulomb blockade effective at room temperature (T=300K).

7. A SET inverter consumes static power in logic 1 and logic 0 states which is contrary to the behavior of a CMOS inverter.

8. The SET can be used as an ultra-high sensitive elementary charge detector.

9. In a SETMOS hybrid device the period of the oscillations is independent of the amplification of the current provided by the MOSFET device.

10. The intrinsic frequency operation (speed) of SETs is limited to kHZ to MHz range due to their very low currents (typically less than nAs).