Diode equivalent circuits

1. Access resistances in vertical devices

There is an “access” resistance connected in series with an “ideal” diode “D” (the diode can be of any type, i.e. rectifier, LED, Varicap, Tunnel diode etc.).

Total access (series) resistance for the diode on the left:

\[ R_s = R_{cp} + R_{sp} + R_{sn} + R_{cn} \]

\[ R_{cp} = \rho_{cp}/A; \quad R_{cn} = \rho_{cn}/A \]

Note the difference between lateral and vertical contacts. For lateral contacts, a \textit{unit-width} contact resistance (\(\Omega \times \text{mm}\) or \(\Omega \times \text{cm}\)) is typically used.

For vertical contacts, a \textit{unit-area} specific resistance (\(\Omega \times \text{mm}^2\) or \(\Omega \times \text{cm}^2\)) is typically used.
1. Access resistances in vertical devices (cont.)

The series resistance associated with the diode base regions: $R_{sp}$ and $R_{sn}$:

$$R_{sp} = \rho_p \frac{d_p}{A}; \quad \text{where} \quad \rho_p = \frac{1}{q \mu_p}$$

is the resistivity of the $p$-material

$$R_{sn} = \rho_n \frac{d_n}{A}; \quad \text{where} \quad \rho_n = \frac{1}{q \mu_n}$$

is the resistivity of the $n$-material

Diagram:

- Top metal contact
- Bottom metal contact
- Area = $A$
- $R_{sp}$ and $R_{sn}$
- $d_p$ and $d_n$
- $R_{cp}$ and $R_{cn}$
1. Access resistances in vertical devices (cont.)

Diode low-frequency equivalent circuit

For a regular p-n junction diode, the total voltage drop across the device:

\[ V = V_D + V_{RS} \]

\[ V_D = \frac{(kT/q)}{\ln(I/I_s + 1)}; \]

\[ V_{RS} = I \times R_s \]
1. Access resistances in vertical devices (cont.)

Diode low-frequency equivalent circuit

- Top metal contact
- Area = A
- Bottom metal contact
- \( R_{cp} \) (p-type)
- \( R_{sp} \)
- \( R_{cn} \) (n-type)
- \( R_{sn} \)
- \( D \)

Ignoring \( R_s \):

\[ I \times R_s \]
2. Access resistances in lateral devices

Example: planar GaAs Schottky diode

\[ R_s = R_c + R_{\text{gap}} + R_{\text{Sch}} \]

\[ R_c = \frac{R_{c1}}{W}; \]

\[ R_{\text{gap}} = R_{sq} \times \frac{L_{\text{gap}}}{W}; \]

\[ R_{\text{Sch}} \approx R_{sq} \times \left(\frac{L_{\text{Sch}}}{3}\right) / W; \text{ - accounts for the current spreading under the Schottky contact.} \]
3. High-frequency equivalent circuits

Example: vertical Schottky diode

At high frequencies, capacitances and inductances associated with the diode itself and the package have significant impact on the device performance.

\[ C_B = \frac{\varepsilon_S \varepsilon_0 A}{W_{\text{depl}}} \]

- \( C_B \) - capacitance associated with the diode depletion region

\[ C_p \]

- \( C_p \) - the capacitance associated with the device contact pads or package

\[ L_p \]

- \( L_p \) - the inductance associated with the device wiring and/or package
3. High-frequency equivalent circuits

Frequency dependence of the device impedance

Example: Consider Schottky diode with the DC differential resistance of 10 Ω.

Comment: the differential resistance, \( R_d = \frac{\partial V}{\partial I} = \left( \frac{kT}{q} \right) / I \approx \frac{0.026V}{I} \) at 300 K;

Suppose: \( C_B = 20 \text{ pF}; \ C_p = 5 \text{ pF}; \ R_s = 1 \text{ Ω}; \ L_p = 0.5 \text{ nH} \)

The diode impedance can be found as follows:

1. \( Y_{d1} = 1/R_d + j\omega C_B; \ Z_{d1} = 1/ Y_{d1}; \) where \( \omega = 2\pi f; \)
2. \( Z_{d2} = Z_{d1} + R_s; \ Y_{d2} = 1/Z_{d2}; \)
3. \( Y_{d3} = Y_{d2} + j\omega C_p; \ Z_{d3} = 1/ Y_{d3}; \)
4. \( Z_{\text{diode}} = Z_{d3} + j\omega L_p; \)
Diode impedance frequency dependence

%Diode impedance frequency dependence
%Suppose: Rd=10 Ohm;
%CB = 20 pF; Cp = 5 pF;
%Rs = 1 Ohm; Lp = 0.5 nH

Rd=10;
CB = 20e-12;
Cp = 5e-12;
Rs = 1;
Lp = 0.5e-9;
%<<<Calculations>>>>>

f=1e6:1e6:3e9;
om=2*pi*f;

Yd1 = 1/Rd + i*om*CB;
Zd1 = 1./Yd1;
Zd2 = Zd1 + Rs;
Yd2 = 1./Zd2;
Yd3 = Yd2 + i*om*Cp;
Zd3 = 1./Yd3;
Zdiode = Zd3 + i*om*Lp;
Req=real(Zdiode);
Xeq=imag(Zdiode);
figure(1);
plot(f*1e-6,Req);
figure(2);
plot(f*1e-6,Xeq);
Diode impedance frequency dependence
Diode impedance frequency dependence