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AN EQUIVALENT CIRCUIT FOR THE P-JFET
IN DEPLETION MODE

The surface of the P-JFET constructed as in Figure 1 is described by the C-V characteristic of Figure 2 (i.e., the C-V of an N-channel device). The surface depletion layer reduces the number of carriers available within the implanted channel for conduction. Also, the back depletion layer further reduces the carriers available within the implant in exactly the same fashion as is true for the Q_B term for a standard MOS device. Finally, the substrate concentration, being of opposite polarity, reduces the charge available within the channel. These terms being subtracted from the total implant N_I results in the available conduction carriers, N_C,

$$N_C = (N_I - N_{SS}) - \frac{Q_B}{q} - \frac{K_S}{K_0} x_0 C_i [\quad U \quad]$$

where

$$[\quad U \quad] = \left[\sqrt{1 + \frac{2 k_0{}^2 \varepsilon_0}{q C_i k_S x_0{}^2} [V(y) - V_G + V_{FBN}]} - 1 \right]$$

Referring to a plot of $[\sqrt{1 + x} - 1]$ vs. x, we will assume that the term in brackets is best approximated by

$$[\sqrt{1 + x} - 1] \simeq 0.0375 + 0.375\, x \qquad (0.4 < x < 1.2)$$

or

$$[\quad U \quad] = 0.0375 + 0.375 \frac{2 K_0{}^2 \varepsilon_0}{q C_i K_S x_0{}^2} [V(y) - V_G + V_{FBN}]$$

Thus,

$$N_C = (N_I - N_{SS}) - \frac{Q_B}{q} - \frac{K_S}{K_0} x_0 C_i [.0375 + 0.375 \frac{2 K_0^2 \varepsilon_0}{q C_i K_S x_0^2} (V(y) - V_G + V_{FBN})]$$

$$= (N_I - N_{SS}) - \frac{Q_B}{q} - .0375 \frac{K_S}{K_0} x_0 C_i$$

$$- 0.75 \frac{K_S}{K_0} x_0 C_i \frac{K_0^2 \varepsilon_0}{q C_i K_S x_0^2} [V(y) - V_G + V_{FBN}]$$

$$= (N_I - N_{SS}) - \frac{Q_B}{q} - 0.0375 \frac{K_S}{K_0} x_0 C_i - 0.75 \frac{C_0}{q} [V(y) - V_G + V_{FBN}]$$

$$= (N_I - N_{SS}) - \frac{Q_B}{q} - .0375 \frac{K_S}{K_0} x_0 C_i + 0.75 \frac{C_0}{q} [V_G - V(y) - V_{FBN}]$$

$$Q_C = q N_C$$

$$= 0.75\, C_0 [V_G - V(y)] + q(N_I - N_{SS}) - Q_B - .0375\, q \frac{K_S}{K_0} x_0 C_i - 0.75\, C_0 V_{FBN}$$

$$= 0.75 \left\{ C_0 [V_G - V(y)] + \frac{4}{3} q (N_I - N_{SS}) - \frac{4}{3} Q_B - .05\, q \frac{K_S}{K_0} x_0 C_i - C_0 V_{FBN} \right\}$$

Finally, following equation 11.2 of Grove's text:

$$I_D dy = 0.75\, W \mu C_0 \left\{ [V_G - V(y)] + \frac{4}{3} \frac{q}{C_0} (N_I - N_{SS}) - \frac{4}{3} \frac{Q_B}{C_0} - .05 \frac{q}{C_0} \frac{K_S}{K_0} x_0 C_i - V_{FBN} \right\} dV$$

This can be compared to the differential equation for the standard MOS device, derivable from equations 11.2, 11.3, 11.4 and 11.6 in Grove:

$$I_D dy = W \mu C_0 \left\{ [V_G - V(y)] - \frac{Q_B}{C_0} - V_{FBP} - 2\phi_N \right\} dV$$

Comparing these two relationships, it would appear that the implanted device has a lower effective mobility than the standard device. However, such is not the case since the implanted device operates under the influence of bulk mobility (since the current is being conducted in the interior of a channel of substantial thickness) while the standard device operates on surface mobility. For a standard device of $K' = 7 \times 10^{-6}$ and an oxide thickness of .105 μ, the surface mobility is 213. In comparison, if the center of the conduction channel of an implanted device experiences an effective concentration of 2.8×10^{16}, the effective mobility is 283: this is 1.33 times the surface mobility of the standard device. Thus, to some fair approximation we can expect that the implanted device has roughly the same effective mobility as the standard MOS device.

As a second observation, the implanted device is more affected by the bulk charge than the standard device: indeed, an A factor that is 4/3 larger has to be used for the implanted device.

The terms that remain in each equation other than $V_G - V(y)$ represent a threshold translation of such a polarity as to make the implanted device permanently conductive. This threshold translation ΔV_T is

$$\Delta V_T = \frac{4}{3}\frac{q}{C_0}(N_I - N_{SS}) - .05\,\frac{q}{C_0}\frac{K_S}{K_0}x_0 C_i - V_{FBN} + V_{FB_p} + 2\,\phi_N$$

$$= \frac{4}{3}\frac{q}{C_0}(N_I - N_{SS}) - .05\,\frac{q}{C_0}\frac{K_S}{K_0}x_0 C_i - (V_{FBN} - V_{FB_p} - 2\phi_N)$$

Since

$$V_{FBN} = \phi_{MS_p} + \frac{Q_{SS}}{C_0} = 0.9 + \frac{Q_{SS}}{C_0}$$

$$V_{FB_p} = \Phi_{MSN} + \frac{Q_{SS}}{C_0} = 0.3 + \frac{Q_{SS}}{C_0}$$

$$V_{FBN} - V_{FB_p} = 0.6$$

But

$$2\,\phi_N \simeq 0.6$$

Thus

$$\Delta V_T = \frac{4}{3}\frac{q}{C_0}(N_I - N_{SS}) \quad - \quad .05\,\frac{q}{C_0}\frac{K_S}{K_0}\,x_0 C_i$$

Also

$$\frac{K_S}{K_0} = 3$$

So that

$$\Delta V_T = \frac{4}{3}\frac{q}{C_0}(N_I - N_{SS}) \quad - \quad 0.15\,\frac{q}{C_0}\,x_0 C_i$$

This result is valid if it is true that

$$0.4 < \frac{2\,K_0{}^2\varepsilon_0}{qC_i K_S x_0{}^2}\left[V(y) - V_G + V_{FBN}\right] < 1.2$$

The equivalent circuit then becomes that of a source follower with a source-body factor 4/3 of that found with the standard device and with a battery of polarity to keep the source follower in conduction with a magnitude equal to ΔV_T above. This is summarized in Figure 3.

It should be noted that, if non-saturated measurements are made for the purpose of comparing a J-FET to a standard MOS device, the difference in source-body effect show up in the measured threshold voltage translation. Therefore, instead of the computer-oriented treatment above, one should keep in mind that the measured threshold voltage translation is given by $\Delta V_{T_M} = \frac{4}{3}\frac{q}{C_0}(N_I - N_{SS}) - \frac{1}{3}\frac{Q_B}{C_0} - 0.15\,\frac{q}{C_0}\,x_0 C_i$.

$V_s = V_G$ [Range is $-V_D$ to 0^V]

$-V_D$

x_d

p^{++} P^- p^{++}

N

$V(y)$

Implant conc. $= C_i$

Figure 1

V_{FBN}

0

$V(y) - V_G$

$$x_d = \frac{K_s}{K_o} x_o \left[\sqrt{1 + \frac{2 K_o^2 \epsilon_o}{q C_i K_s x_o^2} \left[V(y) - V_G + V_{FBN} \right]} - 1 \right]$$

$$N_d = x_d C_i$$

Figure 2

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$$K'_{eq} = K'_{standard}$$

$$A_{eq} = \frac{1}{3} A_{standard}$$

$$\Delta V_T = \frac{4}{3} \frac{q}{C_0} (N_I - N_{SS}) - 0.15 \frac{q}{C_0} x_0 C_i$$

Figure 3

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