p-channel SOI MOSFET

PD devices with N^+ poly gate: buried-channel devices.

Thin-film, enhancement-mode p-channel devices possible, but imprectical for thin oxide and N^+ gate. To avoid this problem: use p-type body instead of n-type. This results in accumulation-mode device.

Note: device FD for 0V on gate (positive Q_{ss} and negative $\Phi_{MS1} = -E_g/2 - V_{therm}\ln(N_a/n_i)$. When turned on, the Si film is not FD and conduction occurs both in the body as well as at the surface (accumulation channel).

Accumulation threshold reached when $\Phi_{s1} = 0$, i.e. flat band on surface: $V_{th,acc} = V_{fb1} = \Phi_{MS1} - Q_{ox1}/C_{ox1}$. Note: applied voltage is negative!

Use gradual channel approximation current is:

$$I_{acc} = (W/L)\mu_s C_{ox1}\left[(V_{G1} - V_{fb1})V_{DS} - V_{DS}^2/2\right] \text{ linear region} \quad (1)$$

$$I_{acc} = (W/L)\mu_s C_{ox1}(V_{G1} - V_{fb1})^2 \text{ saturation region} \quad (2)$$

The body portion of current appears if there is undepleted region in the body — similar to JFET. The width of the conducting channel is modulated by gate voltages. Solving Poisson's eq. as before, but now BCs are that the field and potential at the edge of the depletion region are zero: $E(xdepl) = \Phi(xdepl) = 0$.
$\rightarrow V_G - V_{FB} = qN_a x_{depl}^2/(2\epsilon_{Si}) + qN_a x_{depl}/C_{ox}$

If a neutral portion exists, than the depth of the depletion region is

$$x_{d1}(y) = -\frac{\epsilon_{Si}}{C_{ox1}} + \sqrt{\frac{\epsilon_{Si}^2}{C_{ox1}^2} + \frac{2\epsilon_{Si}(V_{G1} - V_{fb1} - V(y))}{qN_a}} \tag{3}$$

and similarly for back-gate related depl. layer.

If the sum of the two depletion layers is equal to t_{Si} then the device is fully depleted. For simplicity: assume that x_{d2} thickness is constant ($V(y)$ =const.). The next step is finding the resistance of a small cross-section and using that to find body current

$$dR = \frac{dy}{W\mu_b qN_p a(t_{eff} - x_{d1})} \text{ and } I_{body}dR = dV \tag{4}$$

$$I_{body}L = WqN_a\mu_b \int \left(t_{eff} + \frac{\epsilon_{Si}}{C_{ox1}} - \sqrt{\frac{\epsilon_{Si}^2}{C_{ox1}^2} + \frac{2\epsilon_{Si}(V_{G1} - V_{fb1} - V(y))}{qN_a}} \right) \tag{5}$$

The form of the equation for current is $I_{body} = qN_a\mu_b(W/L)\alpha$, where α varies with applied biases. Also, define V'_{depl} as the voltages needed to deplet the Si film.

Several different cases:

- $\alpha = 0$, i.e. Si film is fully depleted. No accumulation channel either. $V_{G1} > V_{fb1} + V^{'}_{depl}$. case A.
- $\alpha = t_{eff} V_{DS}$ when $V_{g1} - V_{fb1} < 0$ and $V_{G1} - V_{fb1} - V_{DS} < 0$. case E. front interface in accumulation from S to D. Bulk accumulated but not pinched-off.
- $0 < V_{G1} - V_{fb1} < V^{'}_{depl}$ and $0 < V_{G1} - V_{fb1} - V_{DS} < V^{'}_{depl}$. No pinch-off, but accumulation only in the body. case D.
- $0 < V_{G1} - V_{fb1} < V^{'}_{depl}$ and $V_{G1} - V_{fb1} - V_{DS} > V^{'}_{depl}$. Body is pinched-off, but no accumulation at interface. case B.
- $0 > V_{G1} - V_{fb1}$ and $0 < V_{G1} - V_{fb1} - V_{DS} < V^{'}_{depl}$. Body not pinched off, but there is accumulation at the source end of the interface. case C
- $0 > V_{G1} - V_{fb1}$ and $V_{G1} - V_{fb1} - V_{DS} > V^{'}_{depl}$. Body pinched off, and accumulation at source end at interface. case F.

Total current: $I_D = I_{acc} + I_{body}$. See fig for linear region I-V. It looks like V_{th} depends on back-gate V. In reality, it is the appearance or closing of the body channel that changes the $_D$. Back-channel conduction not recommended.

See fig. for output I-V. Most applications: negative voltage on back-gate. Bulk mobility > surface mobility.