A “V_{CB}Control” Point of View

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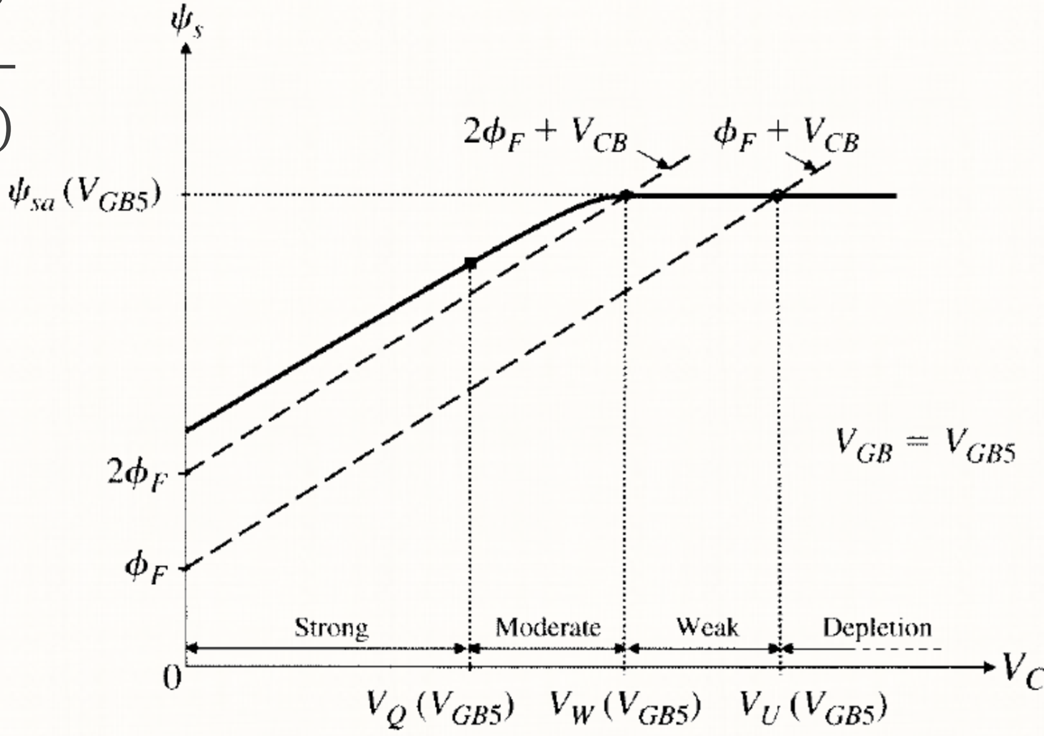
- Fundamentals
  - Our discussion of the three-terminal MOS structure so far was a natural extension of our discussion of the two-terminal structure. In both cases, we described in detail what happens when we increase the gate potential with respect to the body, V_{GB}. →" V_{GB} control.“
  - There is another point of view, which we will call "V_{CB} **control**," in which we fix V_{GB} and observe what happens when we vary V_{CB}.
  - Obviously, the two points of view should give equivalent results.
  - The V_{CB} control viewpoint leads to a different set of models for the MOS transistor.
  - Starting with this figure. If $V_{GB}=V_{GB5}$ and changing the V_{CB} from V_{CB1} to V_{CB3} it can be seen one can change the inversion regime from strong to weak inversion!
  - Further increases in V_{CB} will leave the surface potential value practically unaffected at the value $\psi_{sa}(V_{GB5})$, as seen for example in going from V_{CB3} to V_{CB4}.

Fundamentals

- These observations can clearly be displayed by plotting ψ_s, vs. $\boldsymbol{V_{CB}}$ with $\boldsymbol{V_{GB}} = \boldsymbol{V_{GB5}}$ using following equation:

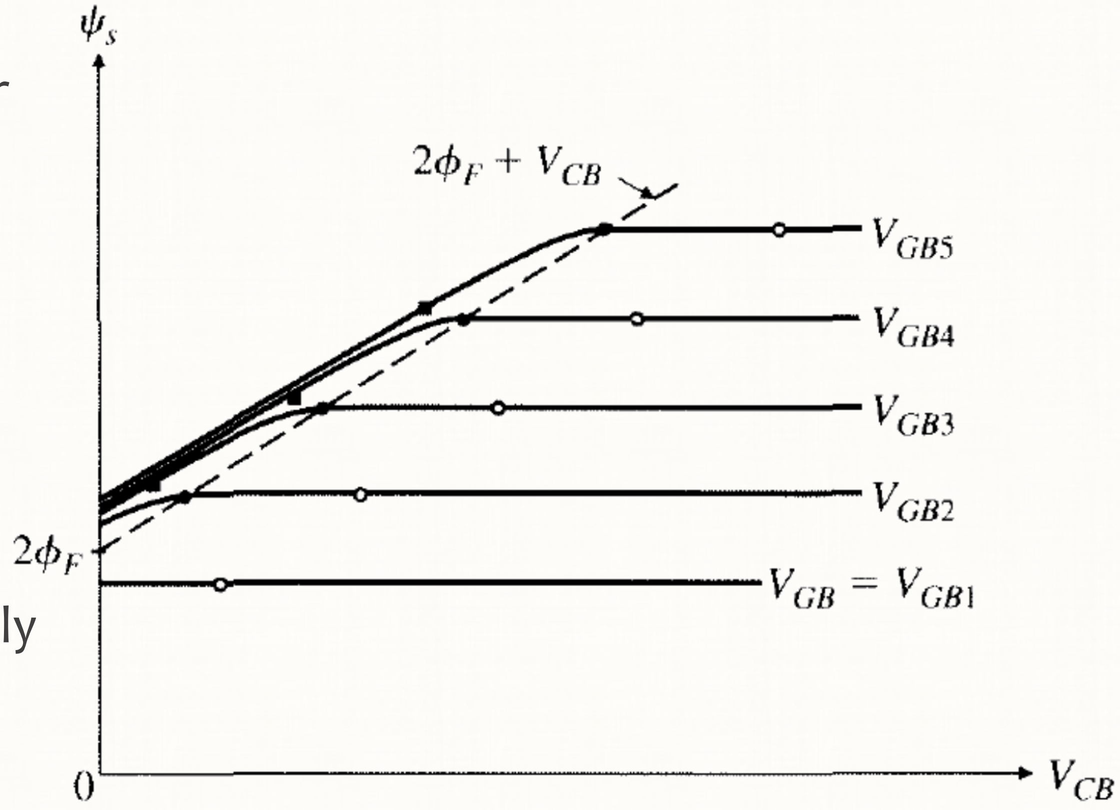
$$V_{GB5} = V_{FB} + \psi_s + \gamma\sqrt{\psi_s + e^{-(2\phi_F + \boldsymbol{V_{CB}})/\phi_T}(\phi_T e^{\psi_s/\phi_T})}$$

- Notice to limits, same as previous discussions!
- For large $\boldsymbol{V_{CB}}$, the inversion layer disappears and ψ_s, flattens out at the value ψ_{sa}, which is given by Eq. and *depends only on* $\boldsymbol{V_{GB}}$.
- Note that as $\boldsymbol{V_{CB}}$ is increased, we go from strong, to moderate, to weak inversion.
- Thus, these regions are encountered in *opposite* order from the case where $\boldsymbol{V_{GB}}$ is increased.



Fundamentals…

- The effect of decreasing V_{GB} is shown in figure.
- The two curves below the top one behave in a similar manner as just discussed, only now V_{GB} is smaller, and thus smaller values of V_{CB} are needed to reduce the level of inversion to a given point.
- The value V_{GB2} (< V_{GB3}) is low, so even with $V_{CB} = 0$, the surface is only in moderate inversion. Increasing V_{CB} above zero can then only drive the structure into weak inversion and eventually into depletion.
- Finally, V_{GB1} (< V_{GB2}) is so low that the device is only in weak inversion when $V_{CB} = 0$. Increasing V_{CB} above zero then will eventually drive the device into depletion.



Fundamentals…

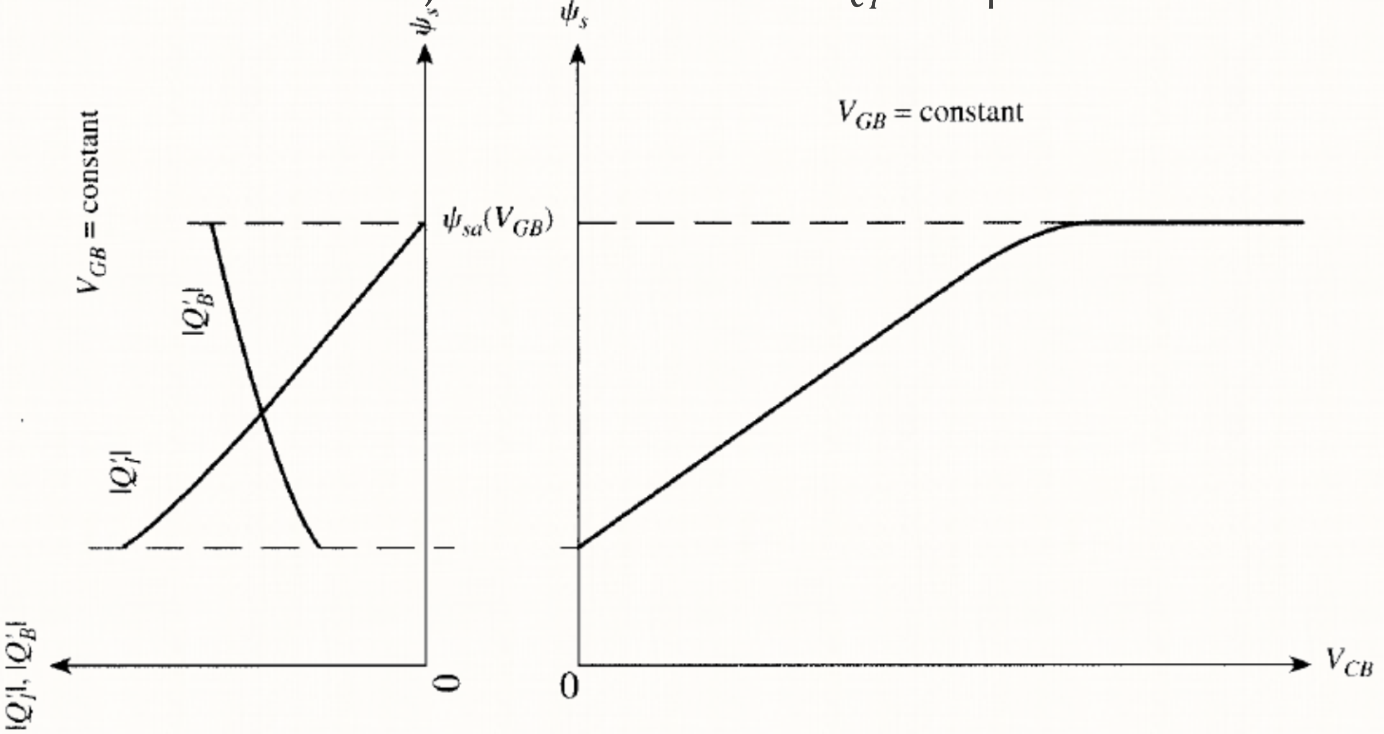
- Finding boundaries: V_Q, V_W and V_U in terms of $\boldsymbol{V_{CB}}$
  - For example V_W

$$\boldsymbol{V_{GB}} = V_{FB} + V_W + 2\phi_F + \gamma\sqrt{V_W + 2\phi_F} \rightarrow V_W = \left(-\frac{\gamma}{2} + \sqrt{\frac{\gamma^2}{4} + \boldsymbol{V_{GB}} - V_{FB}}\right)^2 - 2\phi_F$$

  - This quantity is an increasing function of $\boldsymbol{V_{GB}}$.
  - Table.
  - $\boldsymbol{V_{CB}}$ is assumed nonnegative, in order for the junction formed by the n+ region and the substrate not to become forward-biased.
  - In some cases, the expressions in the last row of Table can result in negative or even imaginary values. This indicates that there are no positive (or zero) values of $\boldsymbol{V_{CB}}$, which will bring the structure to the desired point. (the bottom curve of figure)

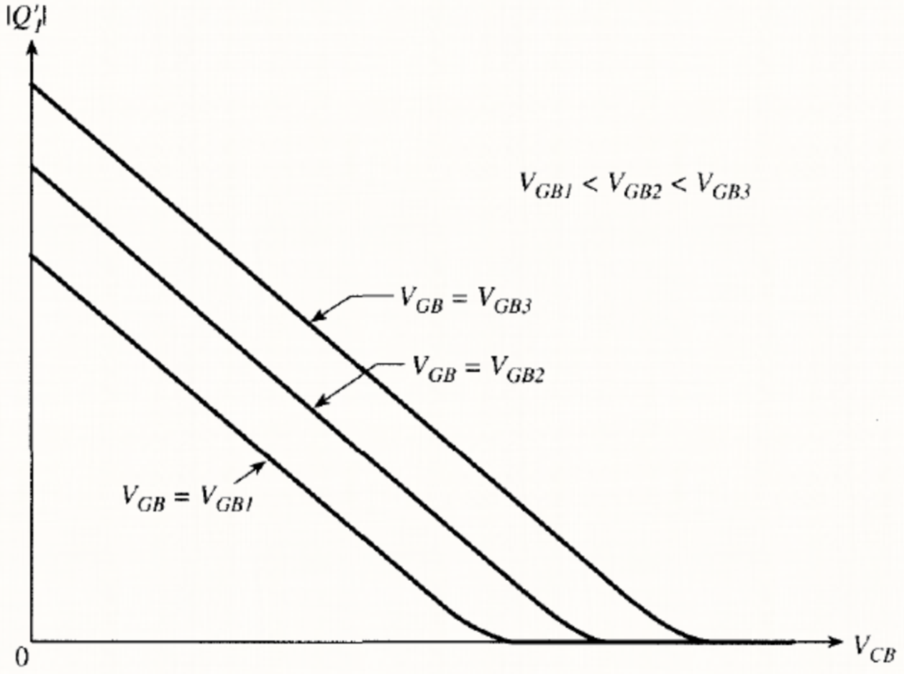
Fundamentals…

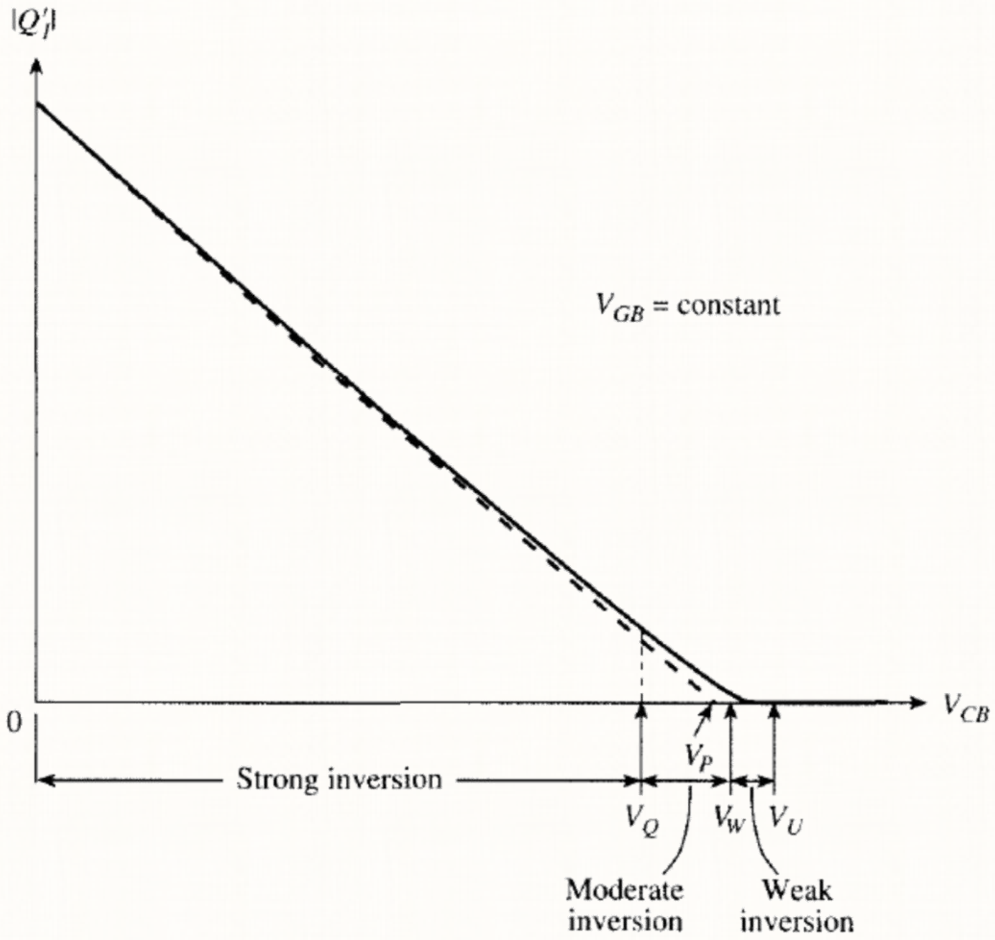
- Relation between ψ_s and Q'_B and Q'_I can be find here and here for constant value of $\boldsymbol{V_{GB}}$.
- These plots are not shown for values of ψ_s larger than $\psi_s(V_{GB})$ because ψ_s, *cannot* attain such values.
- Thus, Q'_B is expected to tend to a constant, maximum value and Q'_I is expected to tend to zero, as $\boldsymbol{V_{CB}}$ is raised.



Fundamentals…

- The behavior of Q_I' vs. $\boldsymbol{V_{CB}}$ is shown in Figure. (here)
- the plot in Figure is for a given $\boldsymbol{V_{GB}}$; if $\boldsymbol{V_{GB}}$ changes, the plot will also change, as shown in below Figure





The "Pinchoff Voltage"

- As discussed before in strong inversion regime we have:

$$Q_I' = -C_{ox}'\left(V_{GB} - V_{TB}(\boldsymbol{V_{CB}})\right) \ where \ V_{TB} = V_T + \boldsymbol{V_{CB}}$$

$$V_T = V_{FB} + \phi_0 + \gamma\sqrt{\phi_0 + \boldsymbol{V_{CB}}} \rightarrow V_{TB}(\boldsymbol{V_{CB}}) = V_{FB} + \boldsymbol{V_{CB}} + \phi_0 + \gamma\sqrt{\phi_0 + \boldsymbol{V_{CB}}}$$

- As seen, as $\boldsymbol{V_{CB}}$ is increased, $V_{TB}(\boldsymbol{V_{CB}})$ rises and $|Q_I'|$ is reduced (figure broken line).
- It is close to a straight line, although it is *not* exactly a straight line.
- The "Pinchoff Voltage": $where \ \ Q_I' = 0$ $(where \ the \ stright \ line \ cross \ the \ horizental \ axis)$
- The *Pinchoff voltage,* V_P, is the value of $\boldsymbol{V_{CB}}$ that makes V_{TB} equal to the externally applied gate-body voltage, and thus causes the strong inversion *approximation* to predict zero inversion layer charge.
- The pinchoff voltage finds some use in simplified modeling.

$$V_P = \boldsymbol{V_{CB}}\Big|_{V_{TB} = \boldsymbol{V_{GB}}}$$

$$V_p = \boldsymbol{V_{CB}} = \left(-\frac{\gamma}{2} + \sqrt{\frac{\gamma^2}{4} + \boldsymbol{V_{GB}} - V_{FB}}\right)^2 - \phi_F = \psi_{sa}(V_{GB}) - \phi_F$$

Uses for Three-Terminal MOS Structures

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- Our main reason for covering the three-terminal MOS structure here is that it leads smoothly to the four-terminal MOS transistor.
- However, three-terminal MOS structures have interesting properties of their own, which can lead to applications:
  - The body terminal has been used as a control terminal for a MOS ***varactor*** in very low voltage circuits.
- Instead of an actual three-terminal structure, one can use advantageously a transistor with its source and drain shorted together, their common connection serving as terminal C.