COMPUTER HISTORY MUSEUM

First-Order Modeling of the IBM 1401 Loopy Transistors

The "Inversion Charge Dumping" Model

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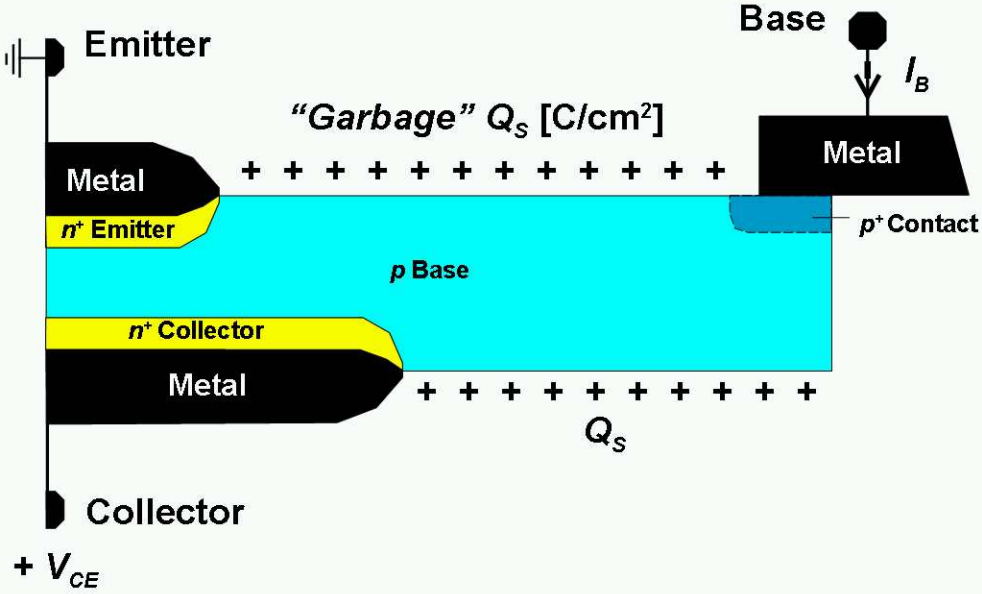
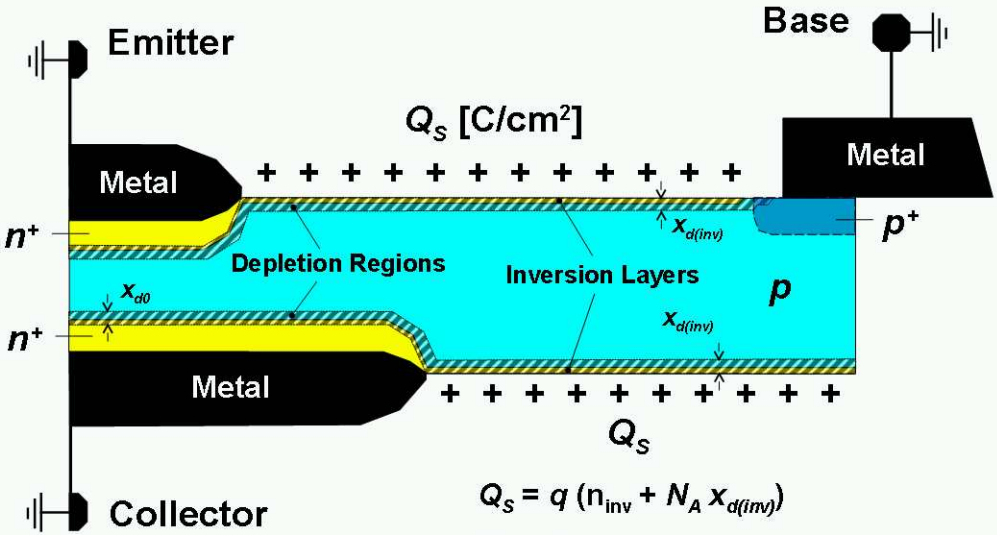
Assumptions

- **Alloyed Germanium *npn* Transistors**
- **Lowly doped base**
- **Fixed positive charge on the surface of p-type Ge, Q_s [C/cm^2], strong enough to invert surface**
  - To be distinguished from Grove's interface charge, Q_{ss}.
- **The Grove-Deal-Snow theory on the MOS system, fully proven for Silicon, applies identically to Germanium**
  - Polarities of voltages and region types are important: the npn and pnp modeling stories will be different!
- **General "Surface States" language avoided unless clearly defined**

Physical Structure (Half Cross-Section)



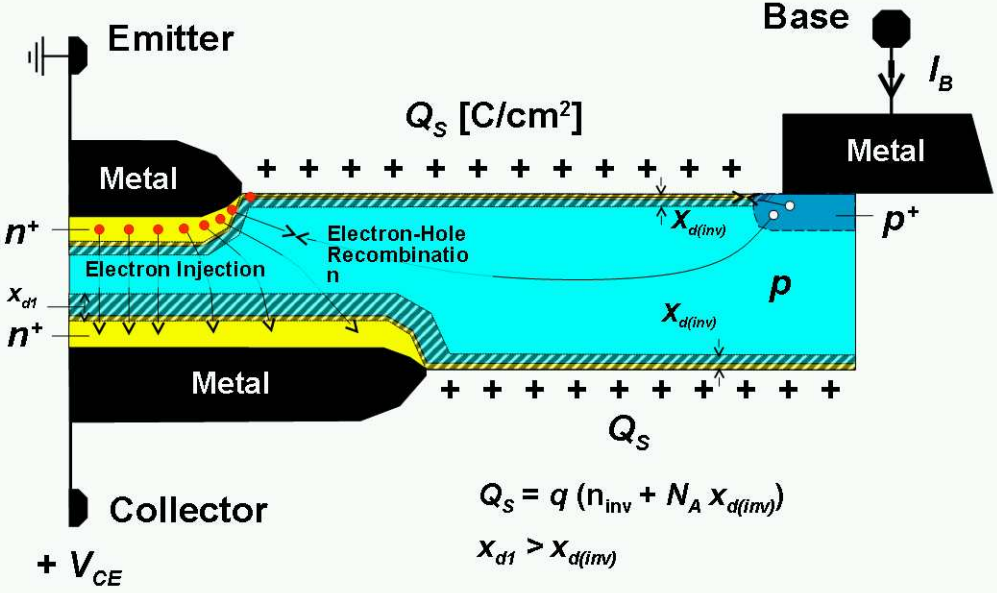
Thermal Equilibrium Situation



$$Q_S = q\,(n_{inv} + N_A\, x_{d(inv)})$$

$$x_{d0} \sim x_{d(inv)}$$

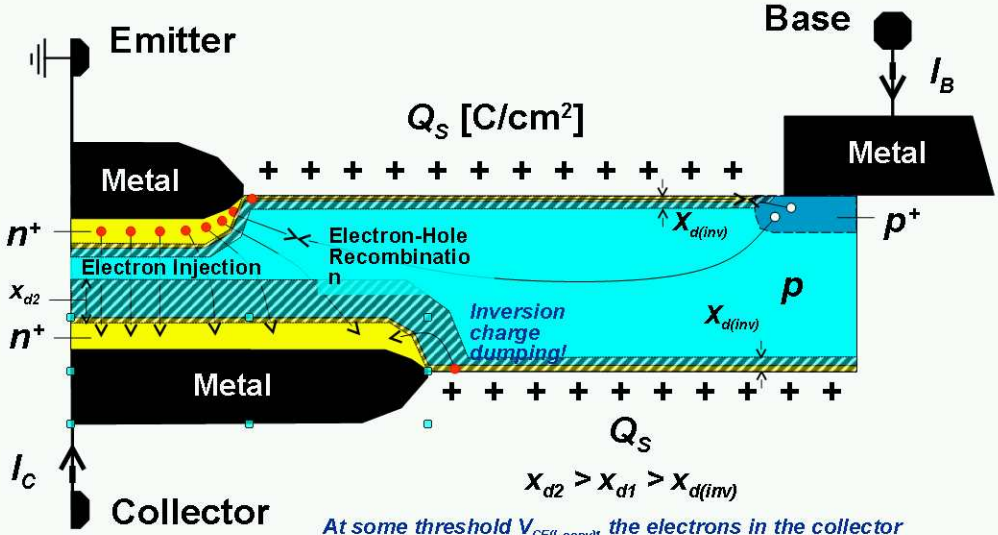
Low-V_{CE} Electronic Activities



$$Q_S = q\,(n_{inv} + N_A\, x_{d(inv)})$$

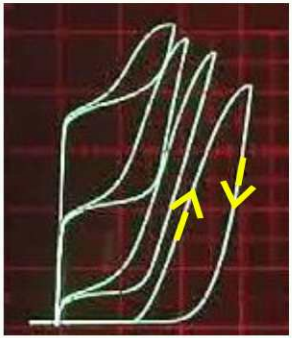
$$x_{d1} > x_{d(inv)}$$

Higher-V_{CE} Electronic Activities



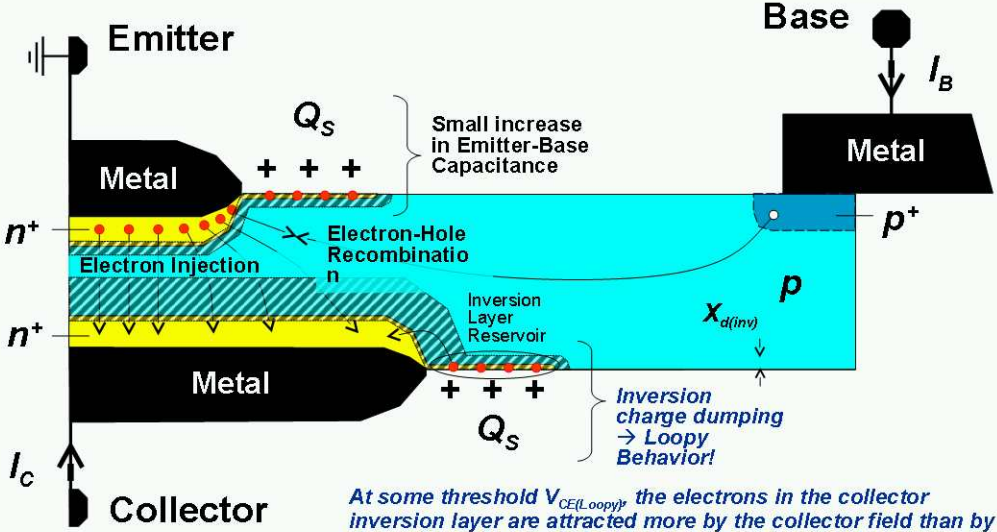
At some threshold $V_{CE(Loopy)}$, the electrons in the collector inversion layer are attracted more by the collector field than by the surface charge → the charge in the inversion layer reservoir is dumped into collector creating a surge in I_C!

Discussion…



- Uniform Q_S is not actually needed in this model: localized surface charge around E-B and C-B junctions works better
  - Eliminates E-B leakage (channel-limited forward diode current, perhaps not seen).
- Inversion Charge Dumping expected to saturate as rate of charge dumping exceeds rate of inversion layer rebuilding by pair generation
- When collector voltage sweeps back down…
  - Electric field that created Inversion Charge Dumping reduces, reducing the rate of charge dumping.
  - Inversion charge generation is a slow process → the supply of charge to be dumped diminishes → faster recovery to normal drain current → ***loopy behavior!***
  - Field structure involving fixed and mobile charges expected to be too complex for qualitative speculations → TCAD needed.

"Final" Model for Today, $V_{CE} > V_{CE(Loopy)}$



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Thanks for your attention!