Semiconductor Device Simulation

- motivation and target applications
  - compact model development under conditions relevant for circuit design
  - development of test structures and measurement methods
  - (fast) predicting device performance and compact model parameters of next generation Si/SiGe bipolar processes (for process development support)
- most important features of DEVICE
  - solves in one-, two-, three-dimensional (rectangular) structures
    - Poisson´s as well as continuity and transport equations for electrons and holes
    - combination of Poisson´s and majority continuity equation for fast simulation of electrical coupling between (lossy) device regions at high frequencies (no inductors yet)
  - conventional drift-diffusion model
    - material parameters: Si, SiGe
    - field dependent mobility, high-doping effects, dependence on lattice temperature
  - operation modes: DC, transient (time domain), small-signal frequency domain
  - circuit simulation capability (using modified nodal analysis)
    - numerical device can be embedded in a circuit $\rightarrow$ mixed-mode device/circuit simulation
  - contains compact models such as HICUM and serves as reference simulator for verification of HICUM implementation in commercial circuit simulators
  - produces output directly suitable for compact modeling (f_T, y-parameters, internal model variables)

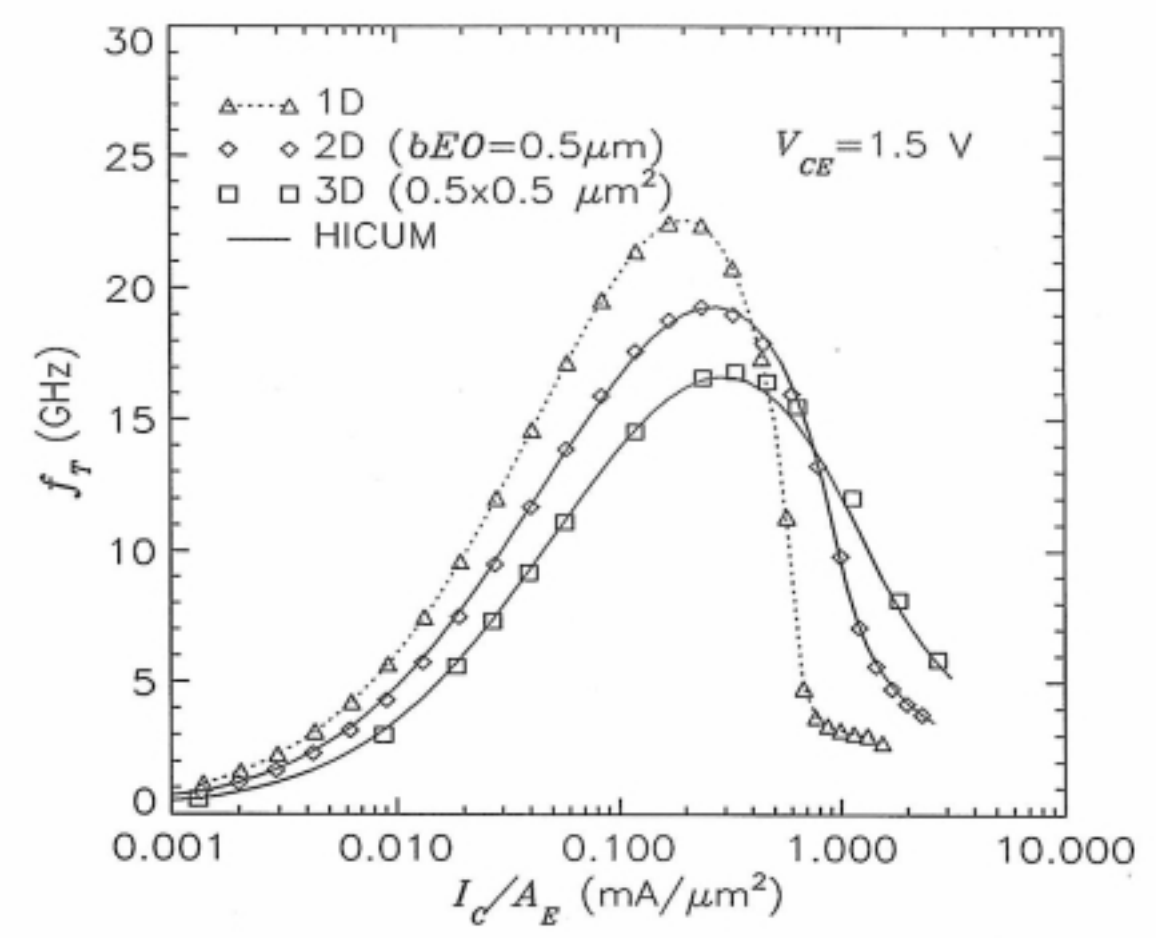
Scaling issues (1/4)

- circuit design, especially for high-speed and high-frequency applications, requires optimization via device sizing

→ requires availability of *many* different transistor configurations (E width and length; number of E, B, C fingers)

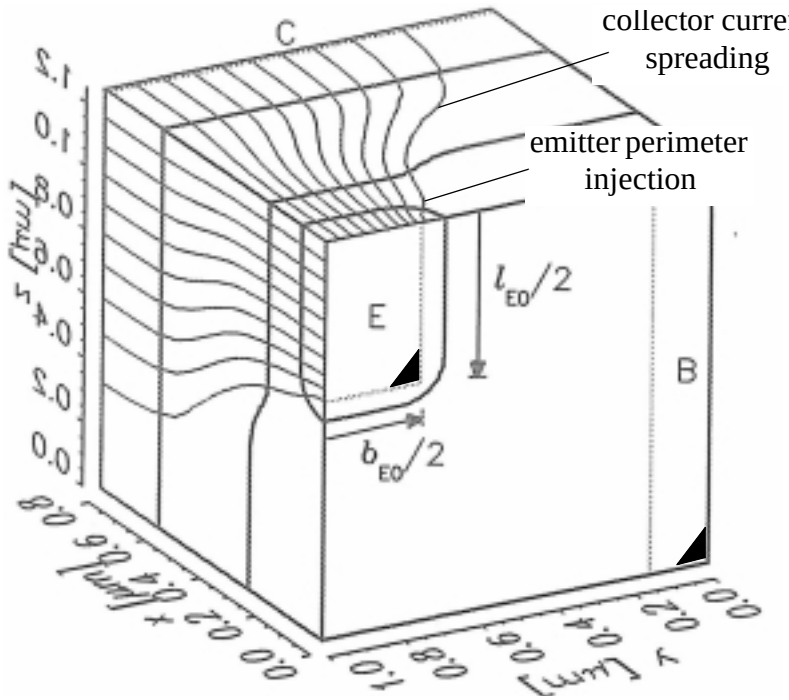
→ scalable compact models: equations for calculating each equivalent circuit element as a function of device geometry

- impact of emitter size on transit frequency:

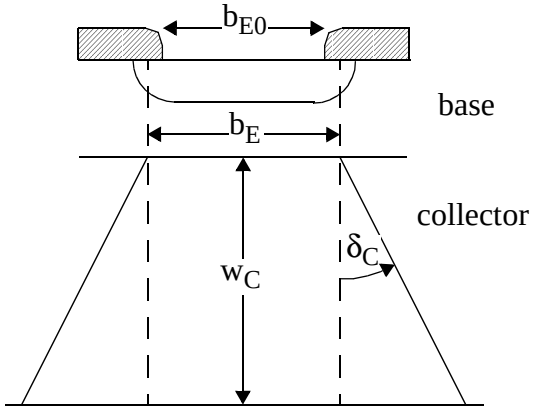


Scaling issues (2/4)

- use device simulation to investigate as a function of emitter size and for different processes
  - perimeter injection (current and charge)
  - collector current spreading



- compact model development
  - analytical equations for current and charge
  - appropriate equivalent circuit representation



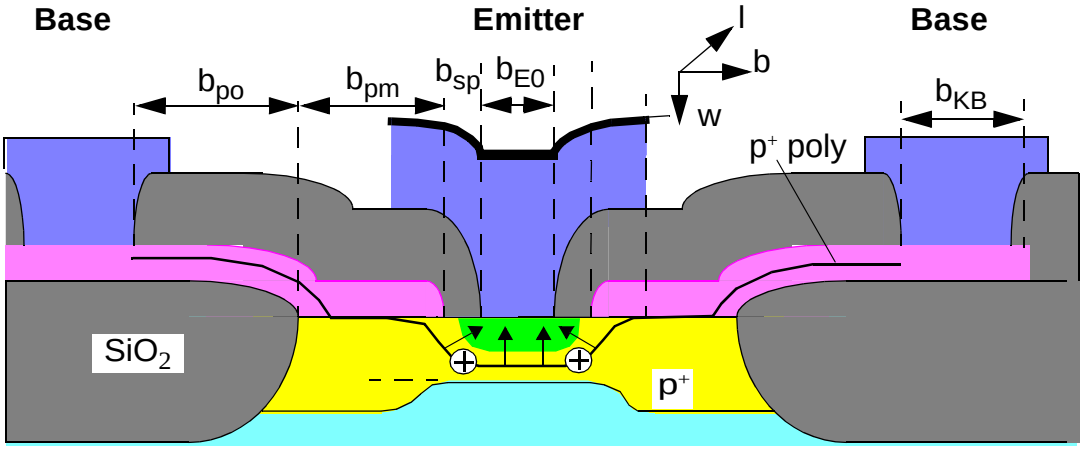
collector current spreading at high current densities

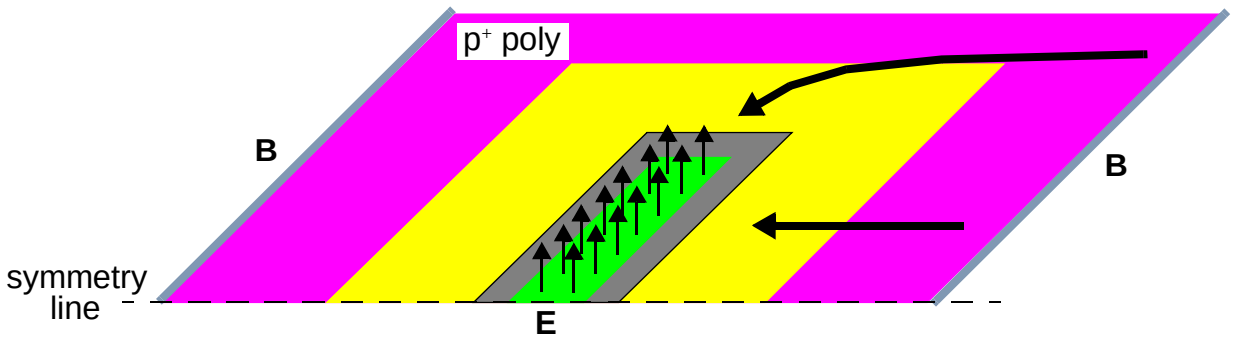
Scaling issues (2/4)

base resistance as a function of "geometry"

- theory exists for
  - 2D geometry = long emitter stripe with one or two base contacts in parallel
  - circular emitter
  - rectangular emitter (approximate solution)
- needed: continuously scalable compact equations for *realistic* transistor geometries used for *integrated* circuit design
- issue: no suitable measurement method for r_B

schematic cross-section of relevant transistor region
and projection of hole current path into 2D plane

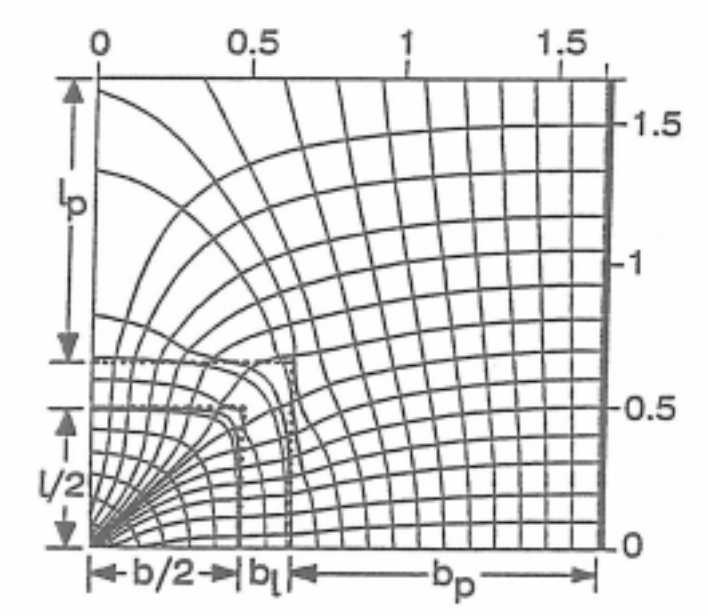




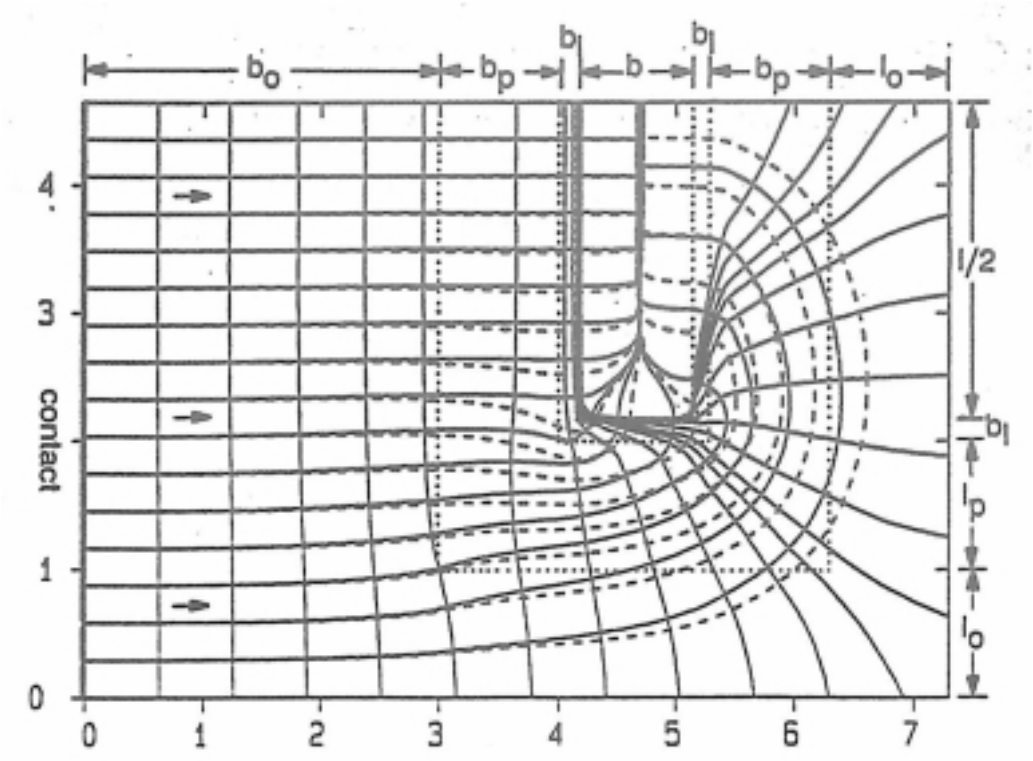
Scaling issues (2/4)

current low lines and equipotential lines

square-emitter structure



single-base rectangular structure with 1:5 aspect ratio

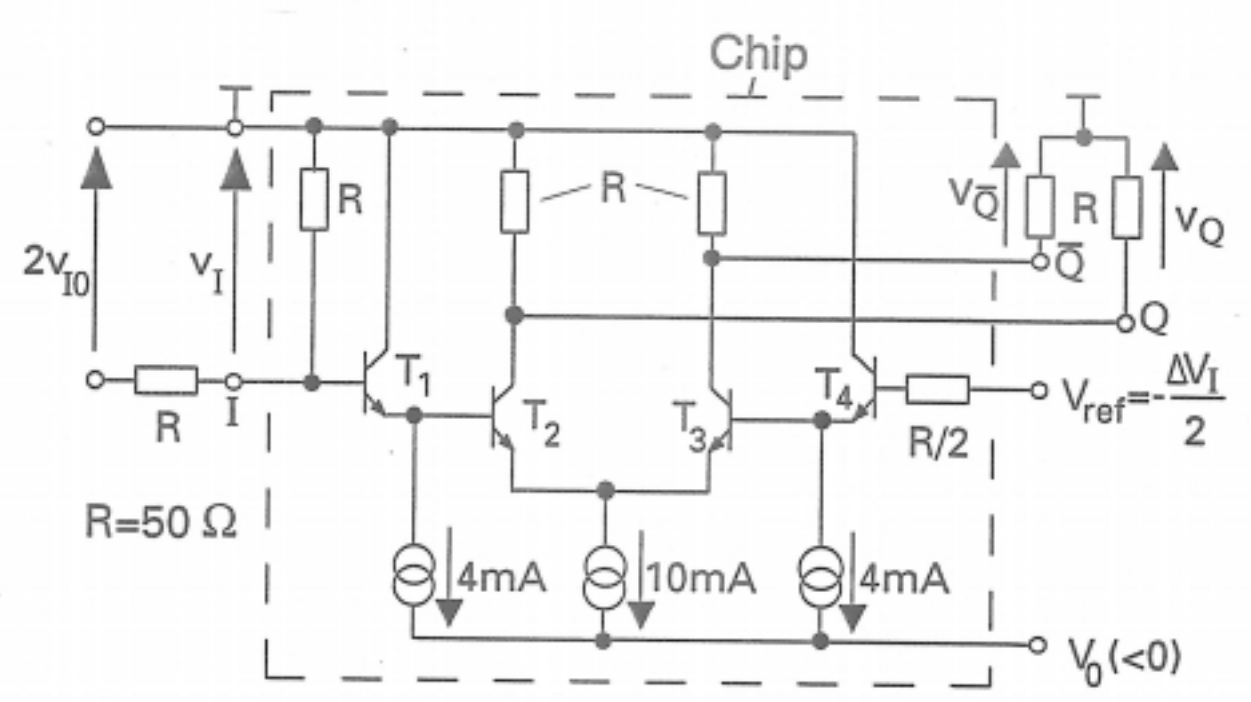


Mixed-Mode Simulation (1/2)

High-speed switching

- verification of compact model in realistic circuit environment
  - fast switching processes are extremely difficult to measure and require expensive equipment
- simple inverter
  - charge storage modeling
  - hard-saturation
  - ...
- (basic) circuit building blocks
  - impact of transistor operation in extreme regimes on circuit behavior

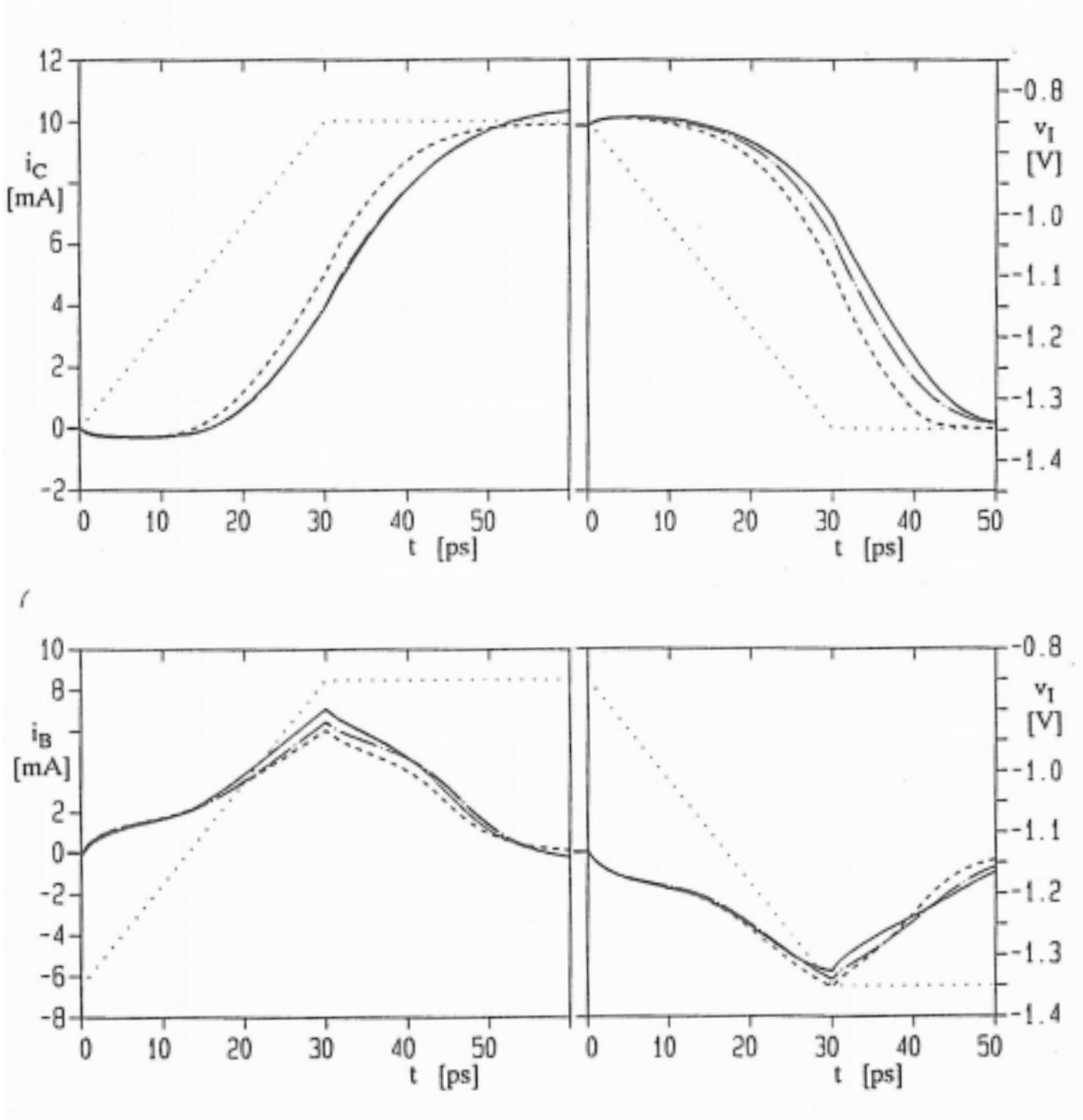
ECL gate



Mixed-Mode Simulation (2/2)

high-speed transients in a current switch:
time dependence of collector and base current

comparison: numerical transistor (solid lines), HICUM (dashed lines)



(on-state collector current = 1mA/μm^2)