The measurements of doping density in InAs by capacitance-voltage techniques with electrolyte barriers

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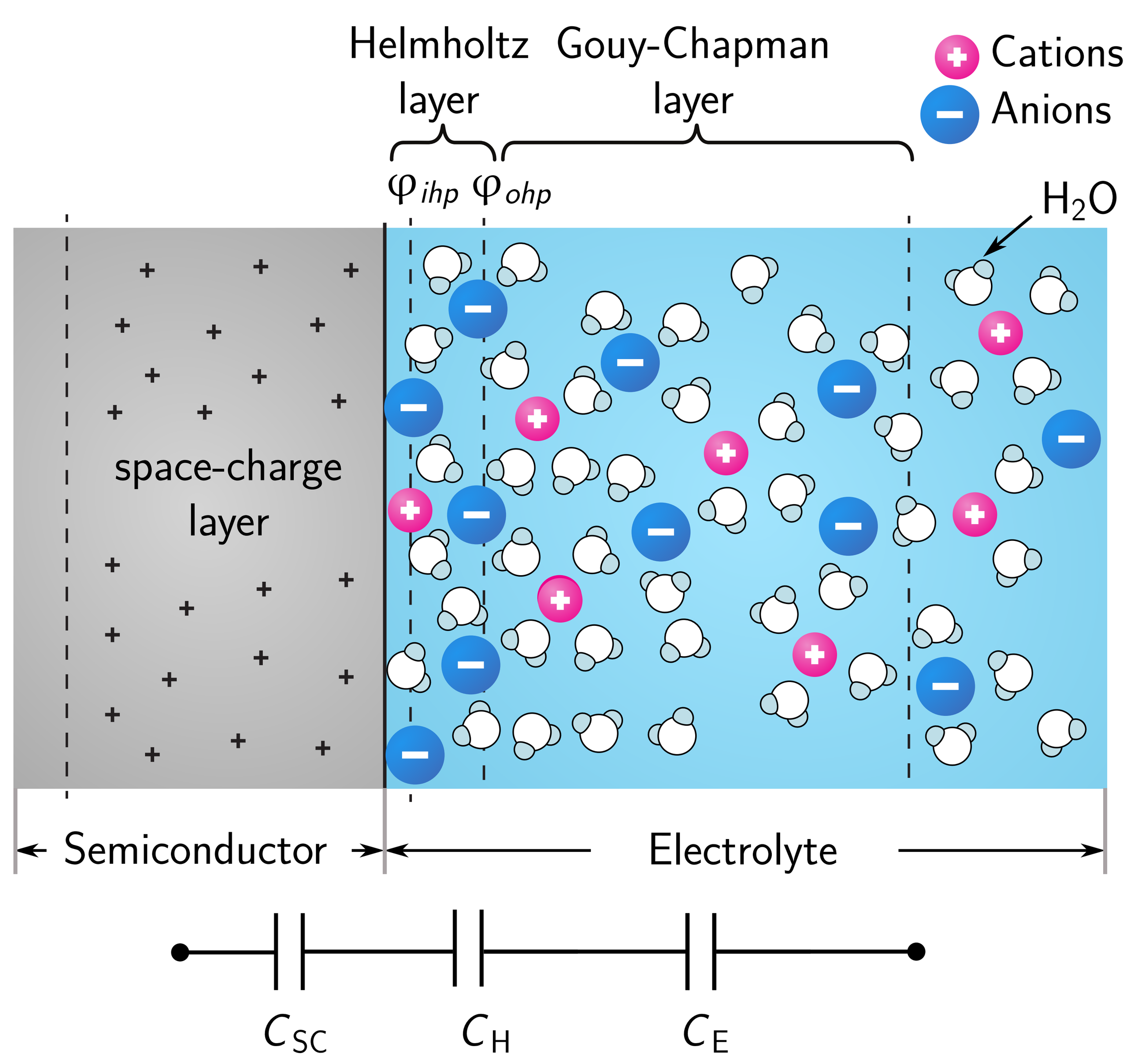
Motivation

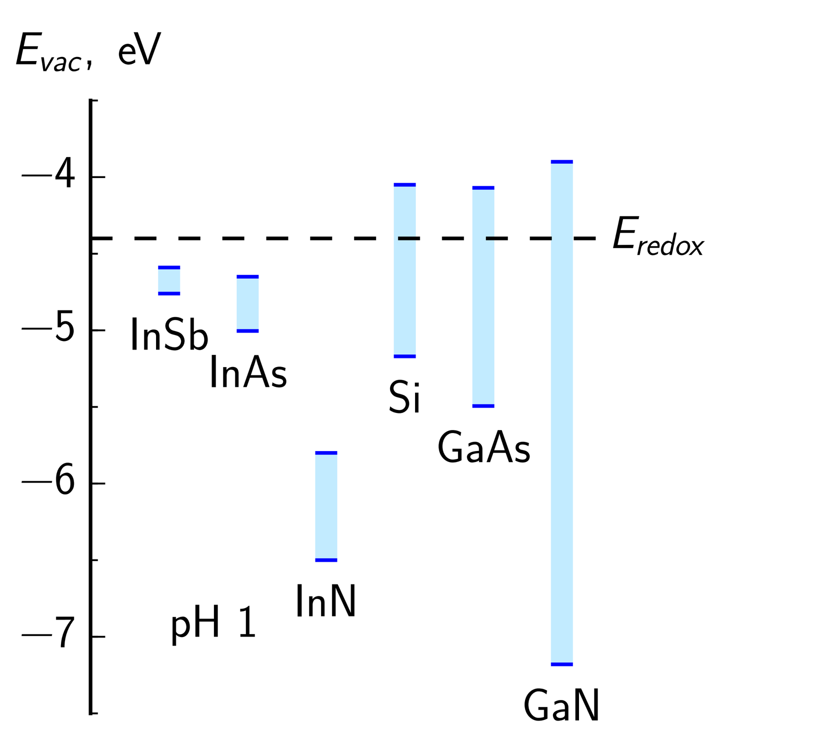
- Schottky contact is usually used in capacitance-voltage characterisation, but formation of reliable Schottky contact to InAs is difficult due to charge accumulation at the surface.
- Electrolyte can be used to form Schottky-like barrier junction to InAs, however, electrolyte based C-V measurements in n-InAs give overestimated impurity concentration.

The purpose of present work is to explain the mismatch between CV and Hall results and to determine the optimal parameters of CV measurements for doping density extraction in n-InAs.

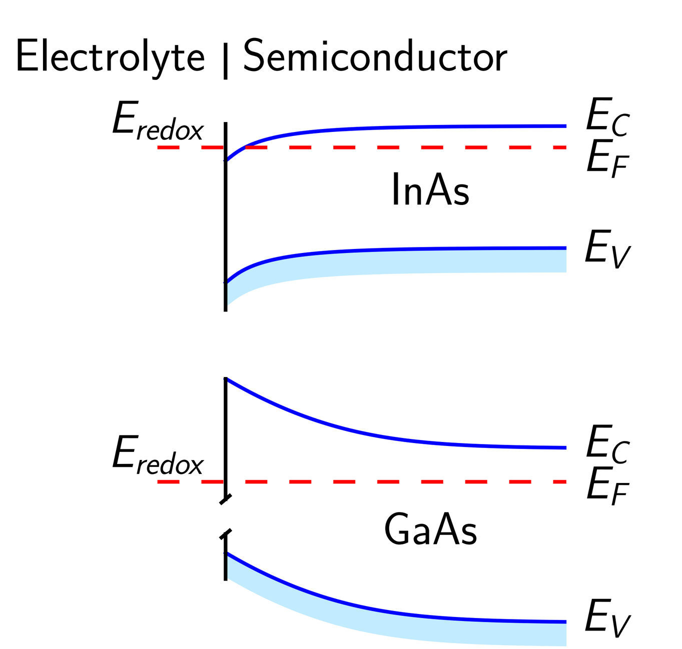
Semiconductor-electrolyte interface



The structure of semiconductor-electrolyte interface



Position of energy bands at the surface of various semiconductors in aqueous solution



Band diagrams of InAs and GaAs at equilibrium

Simulation

Poisson equation with modified Thomas-Fermi approximation (MTFA) was used to calculate CV characteristics.

Poisson equation

$$\frac{d^2\varphi}{dz^2} = -\frac{q}{\varepsilon\varepsilon_0}\left[N_D^+ - N_A^- - n(z) + p(z)\right]$$

with electron concentration:

$$n(z) = \int_0^\infty \rho_c(z,E) f_{FD}(E) f_{MTFA}(z,E)\, dE$$

and DOS for non-parabolic conduction band:

$$\rho(z,E) = \frac{1}{2\pi^2}\left(\frac{2m_e}{\hbar^2}\right)^{3/2}\sqrt{E}\cdot\sqrt{1+\alpha E}\cdot(1+2\alpha E)$$

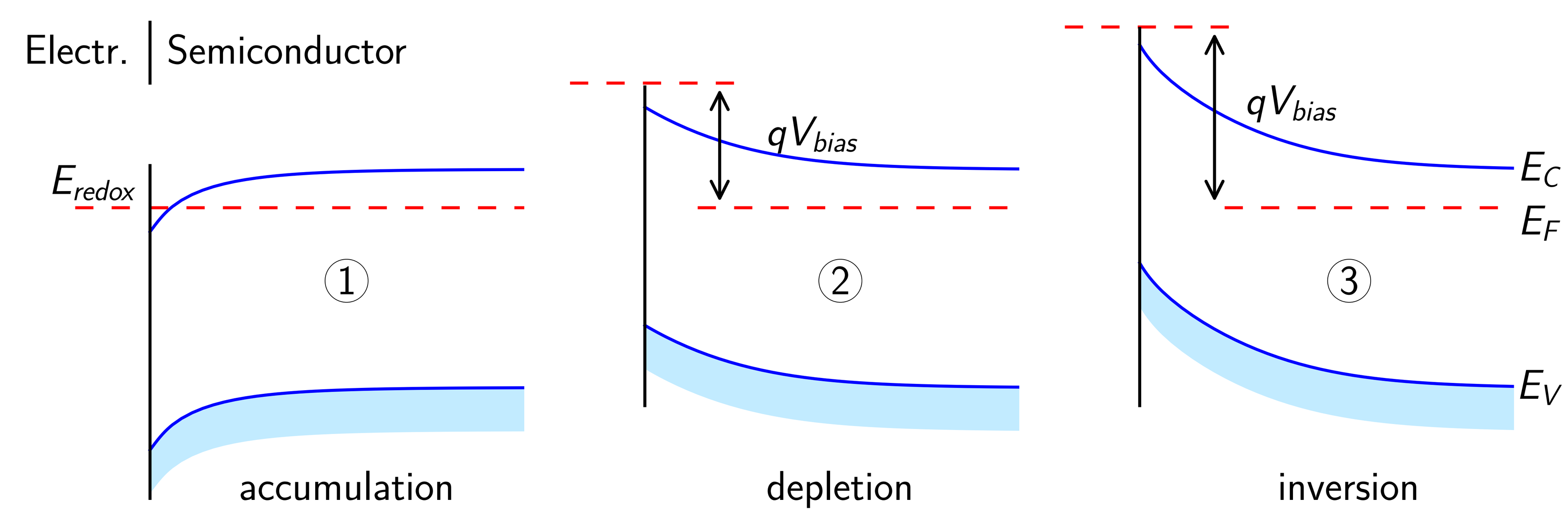
Modified Thomas-Fermi approximation

MTFA used to take into account boundary condition for wave function during accumulation.

$$f_{MTFA}(z,E) = 1 - sinc\left(\frac{2z}{L}\left(\frac{E}{k_B T}\right)^{1/2}(1+\alpha E)^{1/2}\right)$$

Results

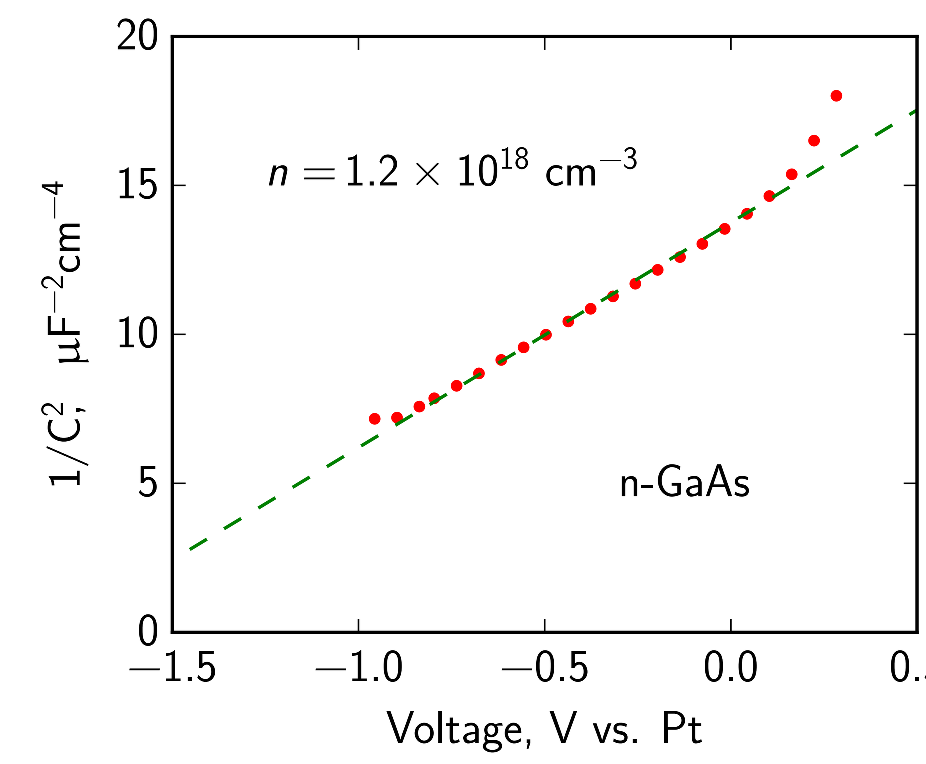
Energy band diagrams



Typical Mott-Schottky plot

- Linear fitting of C^{-2} *vs.* V plot gives doping concentration.
- Deep depletion can occur.
- Deviation from linear behavior due to grows of parasitic conductance.

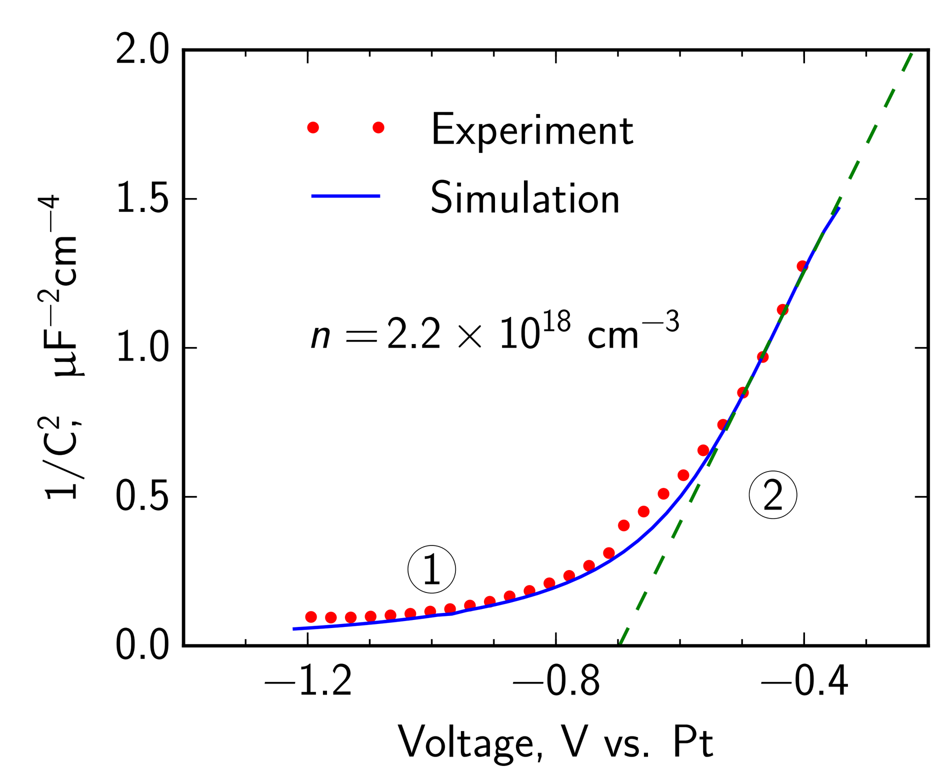
$$\frac{1}{C^2} = \frac{2}{q\varepsilon\varepsilon_0 N_D}\left(V - V_{FB}\right)$$



Mott-Schotky plot of n-GaAs

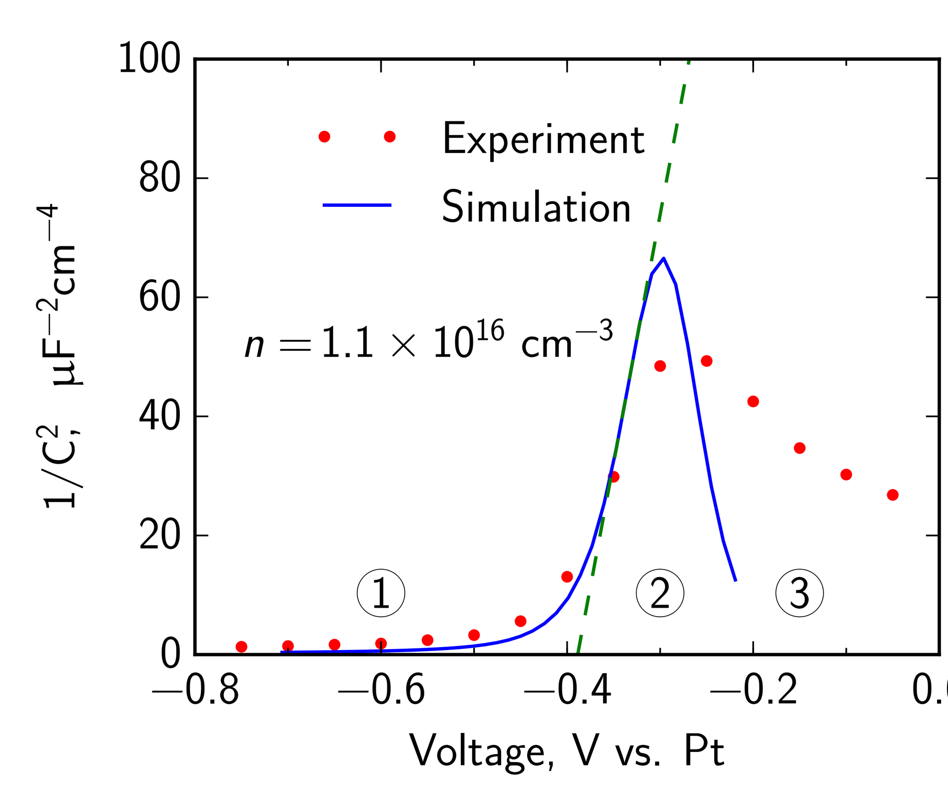
Mott-Schottky plots for n-InAs/electrolyte

- $N_D = 2\times10^{18}$ cm^{-3} from Hall measurements. Same value used in simulation.
- Capacitance measurements frequency: $f_m = 2$ kHz.
- Accumulation occurs at low positive slope.
- Depletion at linear region.



Mott-Schotky plot of n^+-InAs

- $N_D = 1\times10^{15}$ cm^{-3}
- $f_m = 1$ MHz.
- Depletion voltage span is very small.
- Fermi level shifts toward the center of forbidden energy gap, and the inversion starts earlier.



Mott-Schotky plot of epi-InAs

Summary

- The behavior of semiconductor-electrolyte interface depends on relative position of band edges to electrochemical potential in electrolyte. This cause formation of accumulation layer in low doped InAs at equilibrium.
- In heavily doped n-InAs ($N_D > 10^{18}$ cm^{-3}) the depletion approximation gives true doping density with 10 % accuracy.
- At the lower doping levels a simulation of capacitance-voltage characteristics should be used to estimate doping density.