Temperature dependence of the hard breakdown current of MOS capacitors

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Outline

- Introduction
- Measurements of the post breakdown I-V characteristics of MOS capacitors
- Simulation and calculation of the electron concentration in the substrate in accumulation and comparison with measured I-V characteristics
- Modelling the current density through a transparent barrier including temperature dependence
- Conclusions

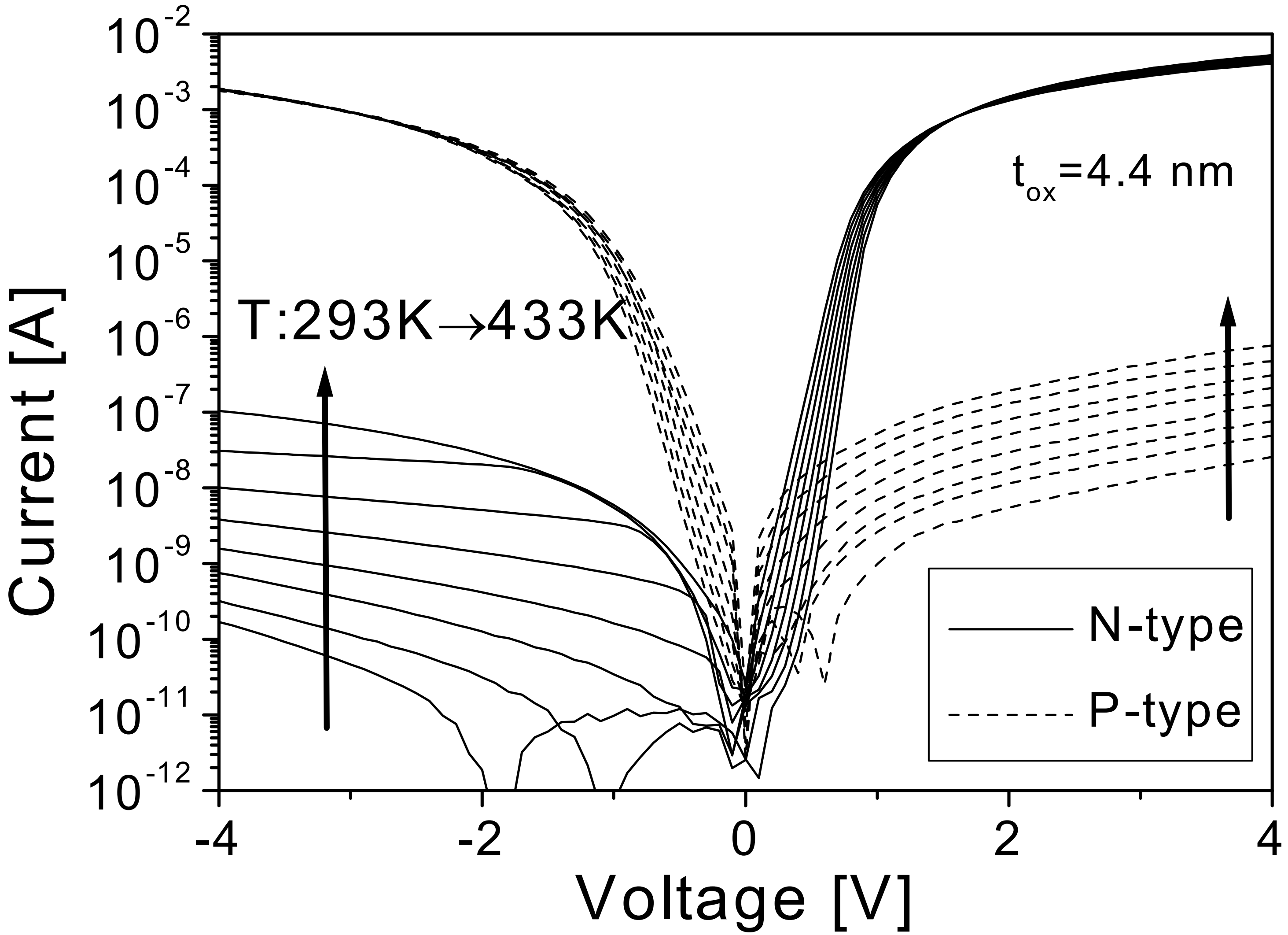
Introduction

- Continuous scaling of MOS devices leads to increased reliability concerns and maybe a higher oxide breakdown risk
- Models are necessary to predict circuit behaviour in the case of breakdown and develop failure-tolerant circuits
- Understanding the mechanisms involved leads to physical-based models that include voltage and temperature dependence

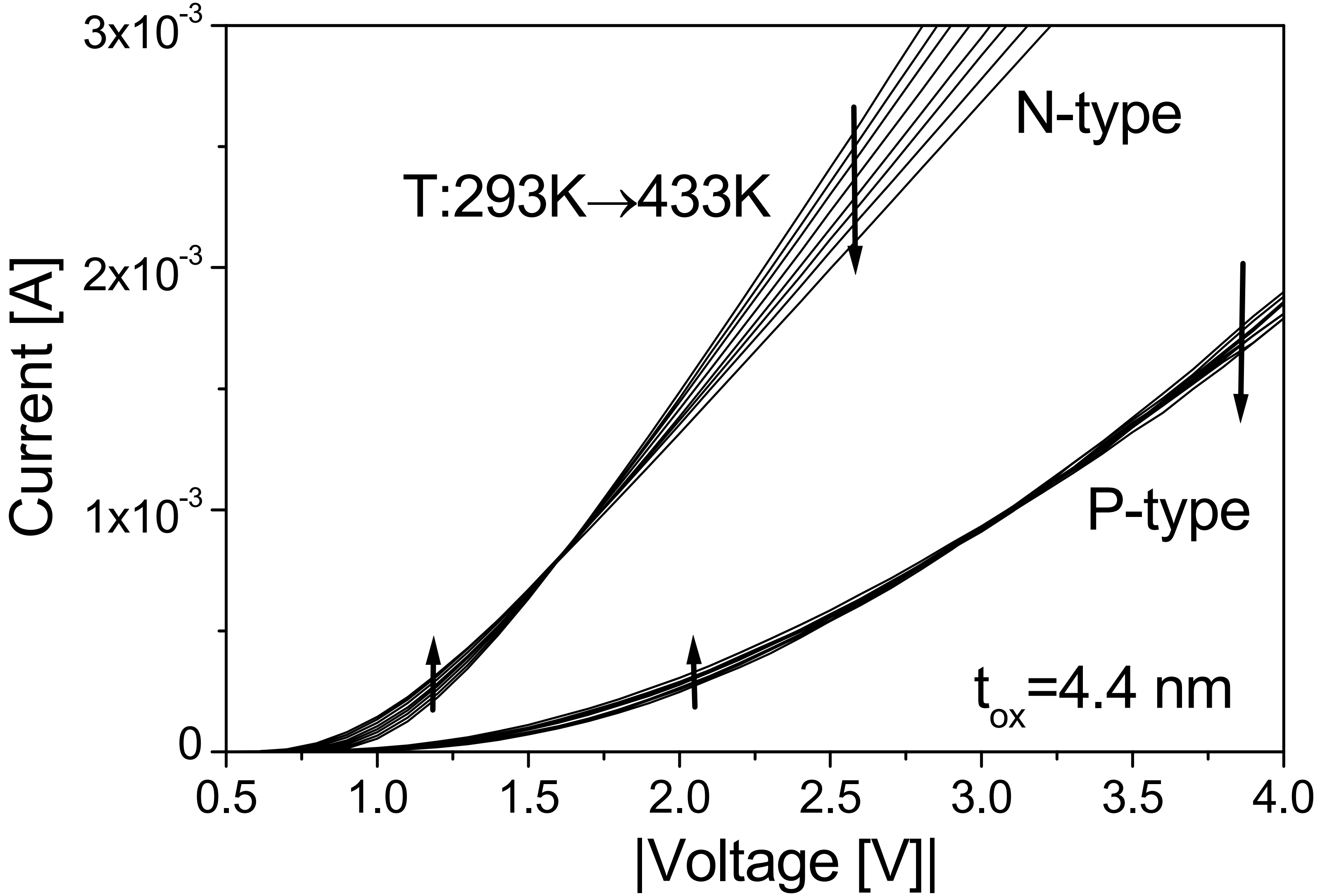
Experiments and simulations

- **Industry standard dual-gate 0.25µm technology**
- **n- and p-type MOS capacitors with an area between 0.1 and 0.3 mm^2**
- **t_{ox}=2.9 and 4.4nm (RTO)**
- **$N_{Substrate}=3x10^{17}cm^{-3}$, $N_{Poly}=7x10^{19}cm^{-3}$**
- **T=293→433K**
- **MINIMOS6.1 for simulations**

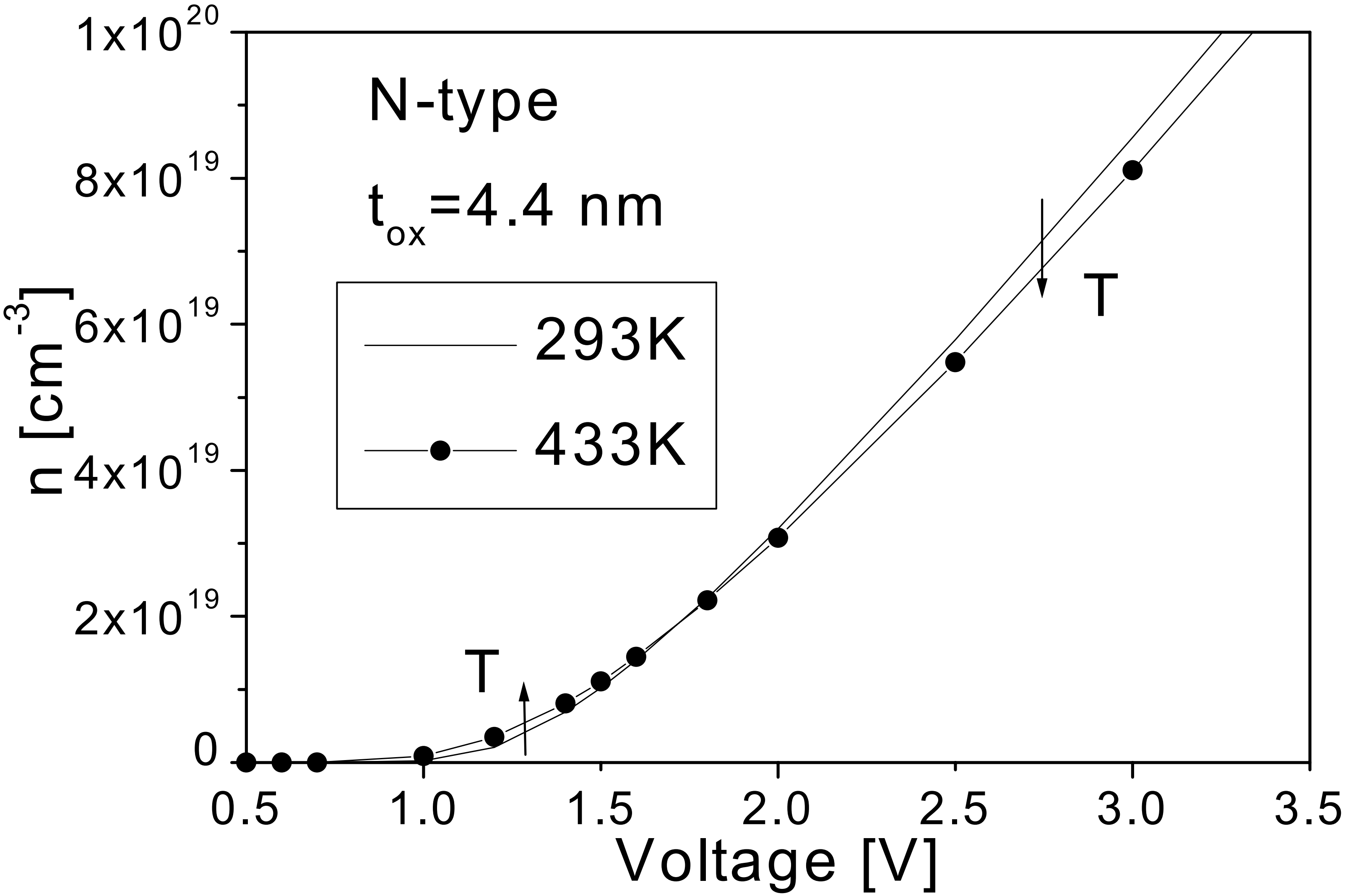
Hard breakdown currents



HBD currents in accumulation

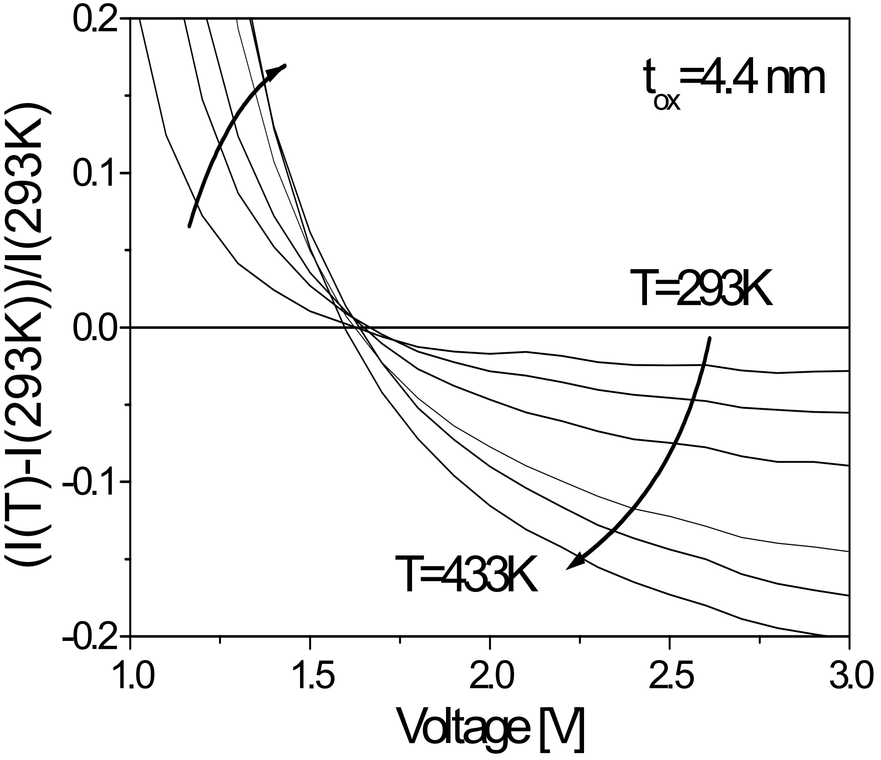


Simulated electron concentration

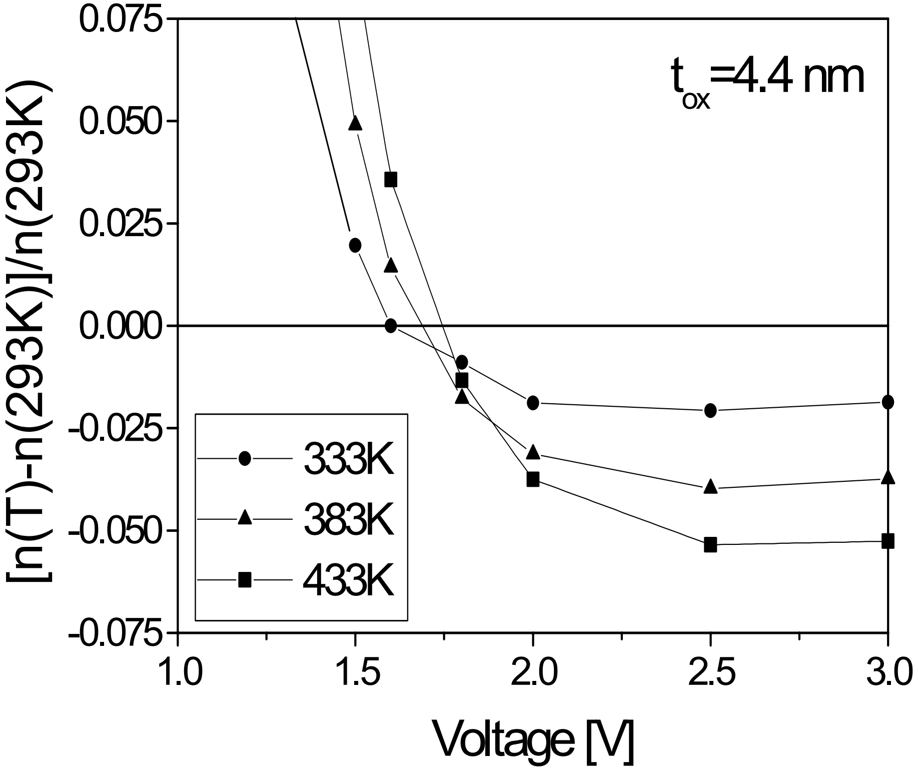


Detailed behaviour of current and charge at the interface

Experiment



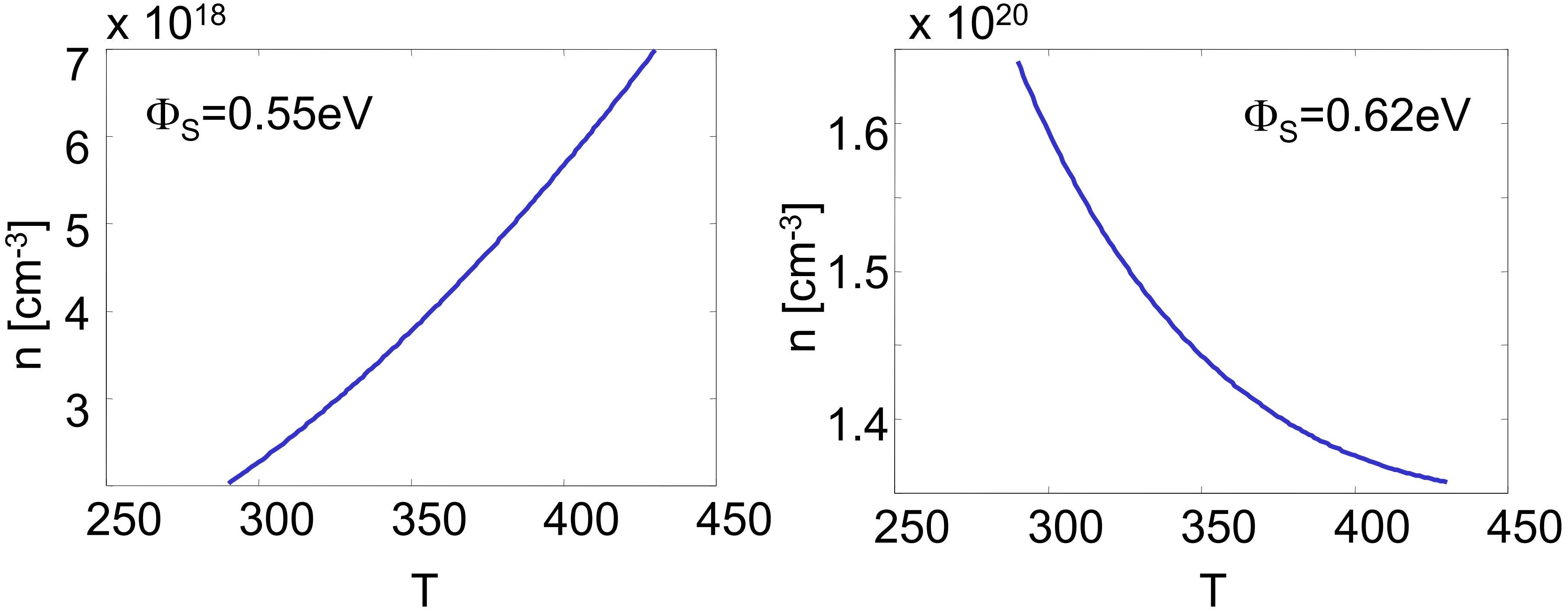
Simulation



N-type substrate

Calculated electron concentration of a non-degenerate semiconductor

$$n = 3.02 \cdot 10^{15} cm^{-3} K^{-3/2} \cdot \mathrm{T}^{3/2} \cdot \exp\left((\Phi_s - \frac{E_g}{2}) \frac{1}{kT} \right)$$



Unidirectional current density through a transparent barrier

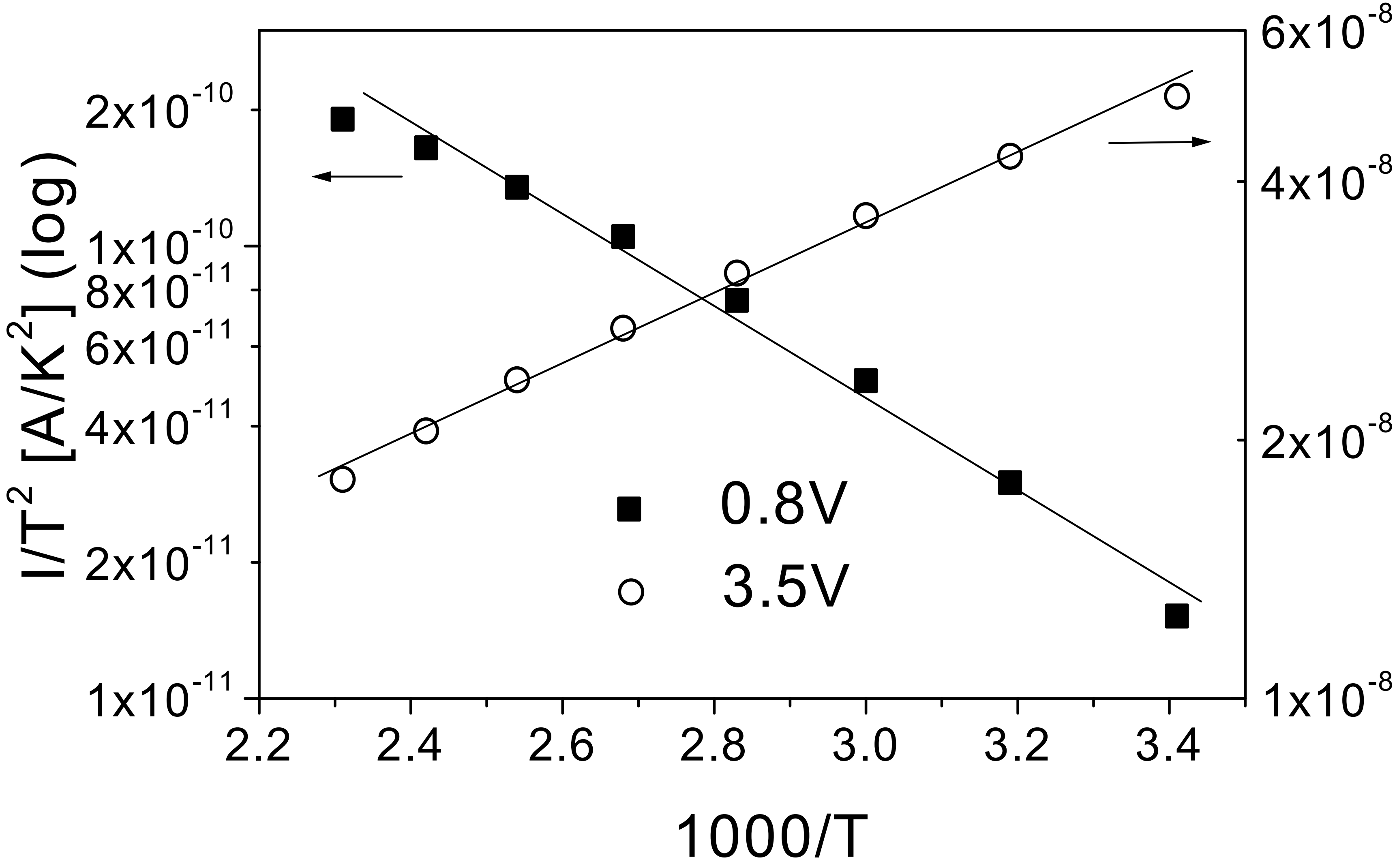
$$J = \frac{4\pi\, q\, m}{h^3} \int_{E_C}^{\infty} \underbrace{F\left(E - E_{FC}\right)}_{\substack{\textit{Fermi-distribution}\\ (\textit{Boltzmann approximation})}} \int_{0}^{E-E_C} \underbrace{D\left(E - E_t\right)}_{\substack{\textit{Transmission}\\ \textit{coefficient}\ (=1)}} dE_t\, dE$$

$$\textit{with}\ E_C - E_{FC} = -\Phi_s + \tfrac{1}{2} E_g$$

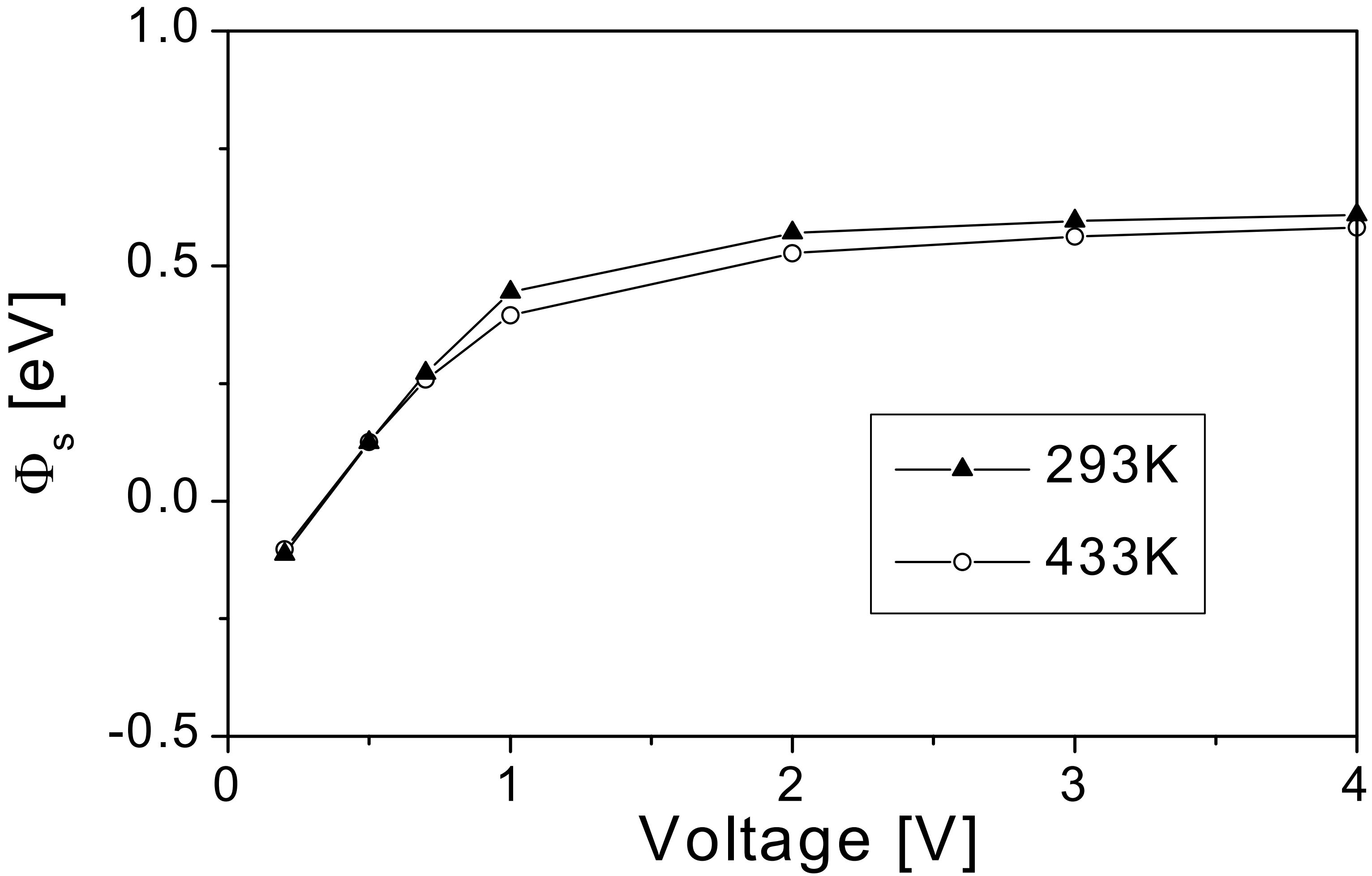
↓

$$J = \frac{4\pi\, q\, m}{h^3} \left(kT\right)^2 \exp\left(\left(\Phi_s - \frac{E_g}{2}\right)\frac{1}{kT}\right)$$

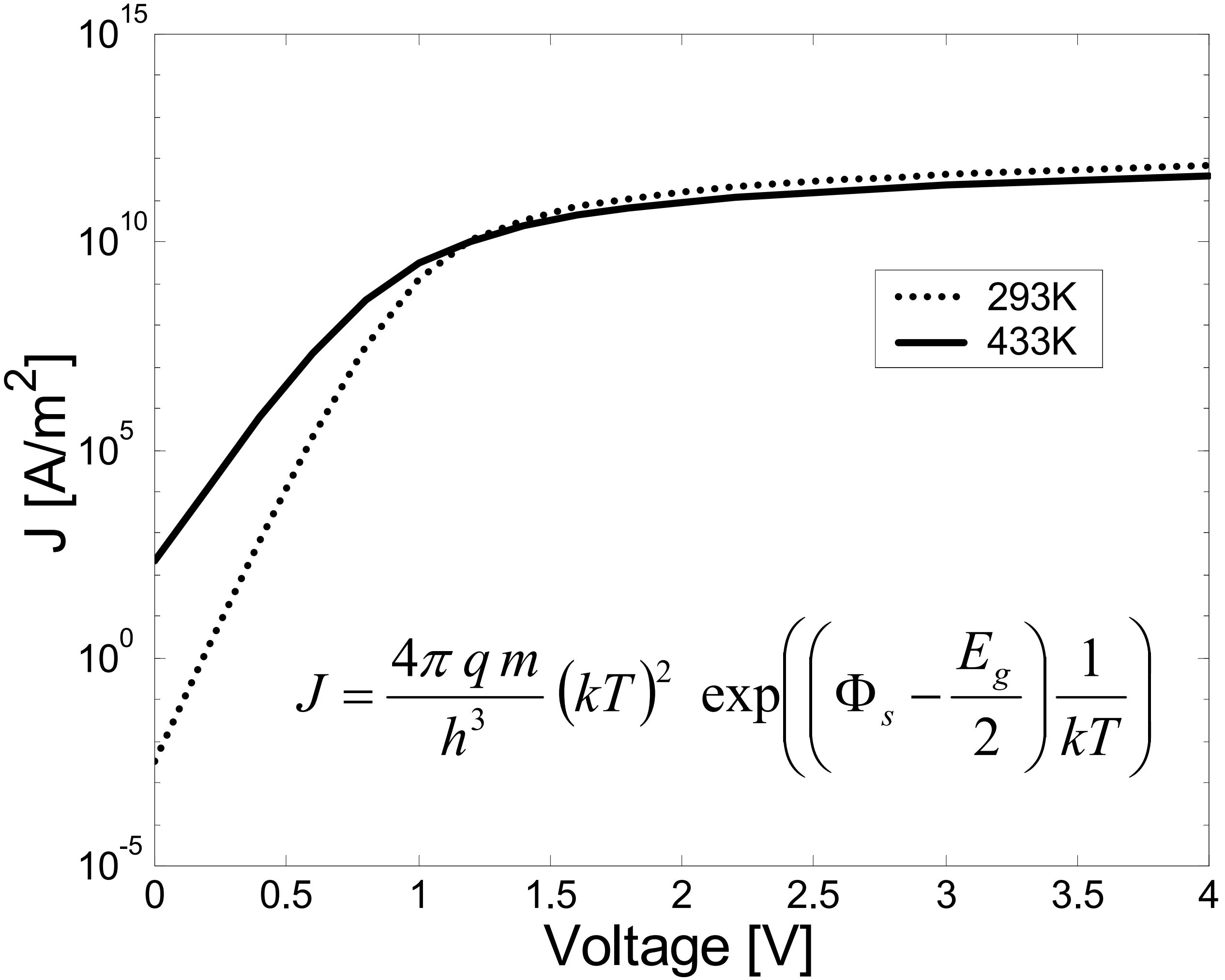
Measured temperature dependence at low and high bias



Simulated surface potential



Calculated current density



$$J = \frac{4\pi\, q\, m}{h^3}(kT)^2\ \exp\left(\left(\Phi_s - \frac{E_g}{2}\right)\frac{1}{kT}\right)$$

Conclusions

- **Similar dependence of the temperature behaviour was found for n- and p-type MOS structures after hard breakdown**
- **A crossover of the temperature dependence was observed that could be linked to the available charge for conduction**
- **An analytic expression for the current density was derived that reproduces all the features of the measurements**
- **The I-V-characteristic after breakdown is governed by the electrodes and not by the breakdown spot, which only affects the overall current magnitude through its size**
- **Recent research showed that the behaviour in accumulation and inversion is more readily explained by regarding the touching electrodes as a pn-junction which further emphasises that the current is strictly electrode-driven and even MOS physics plays a secondary role**