Physics Based Fatigue Compact Model for Ferroelectric Capacitors

Elmar Gondro[1], Christian Kühn[1], Franz Schuler[2], and Oskar Kowarik[1]

[1]University of Bundeswehr, Institute of Electronics, ET 4, Neubiberg, Germany

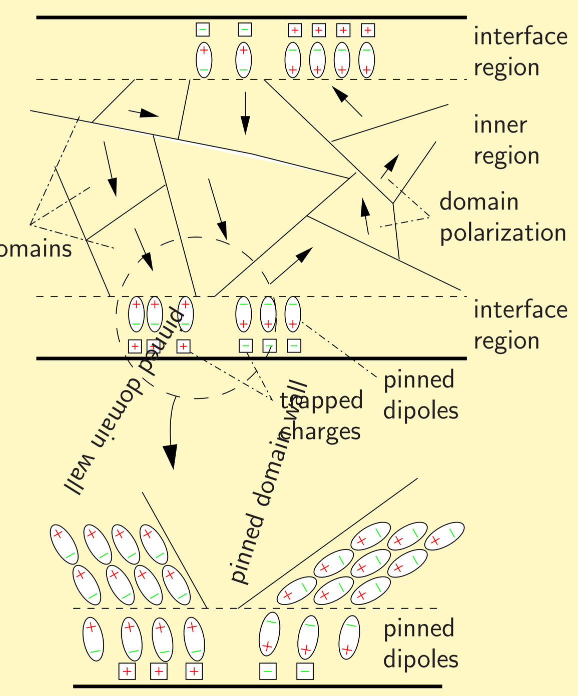
[2]Infineon Technologies AG, München, Germany

Fatigue and Physical Interpretation

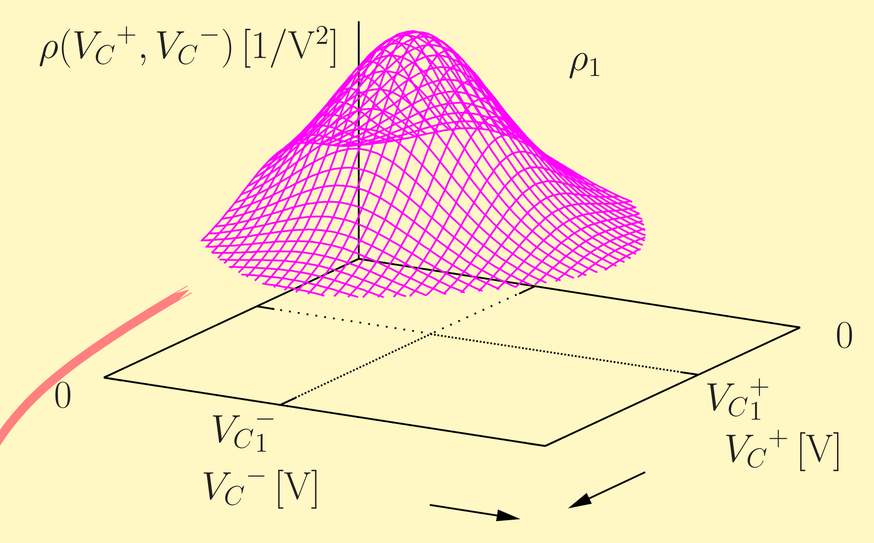
- Fatigue

  Gradual decrease of detectable polarization with increasing number of polarization cycles

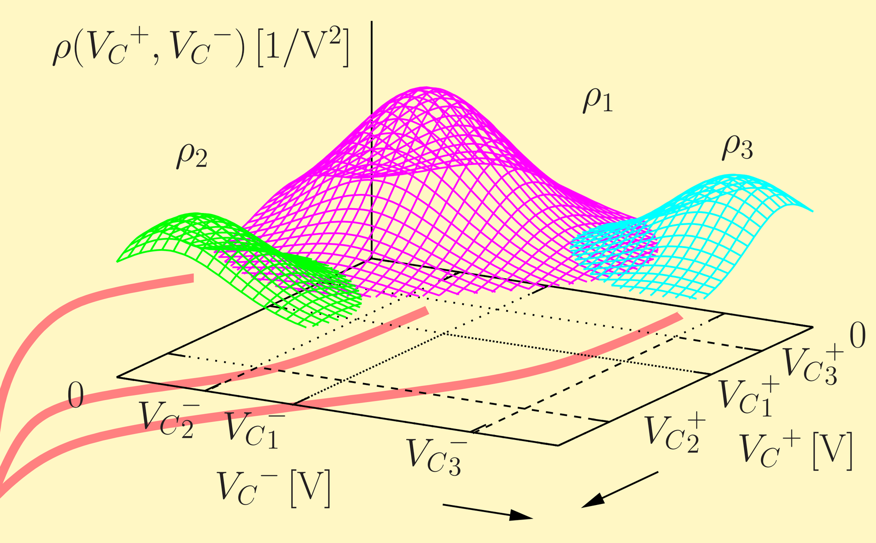
- Physical Interpretation
  - Large-scale defect migration
  - Domain pinning by defects
  - Domain pinning by grain boundaries
  - Screening at electrode interface



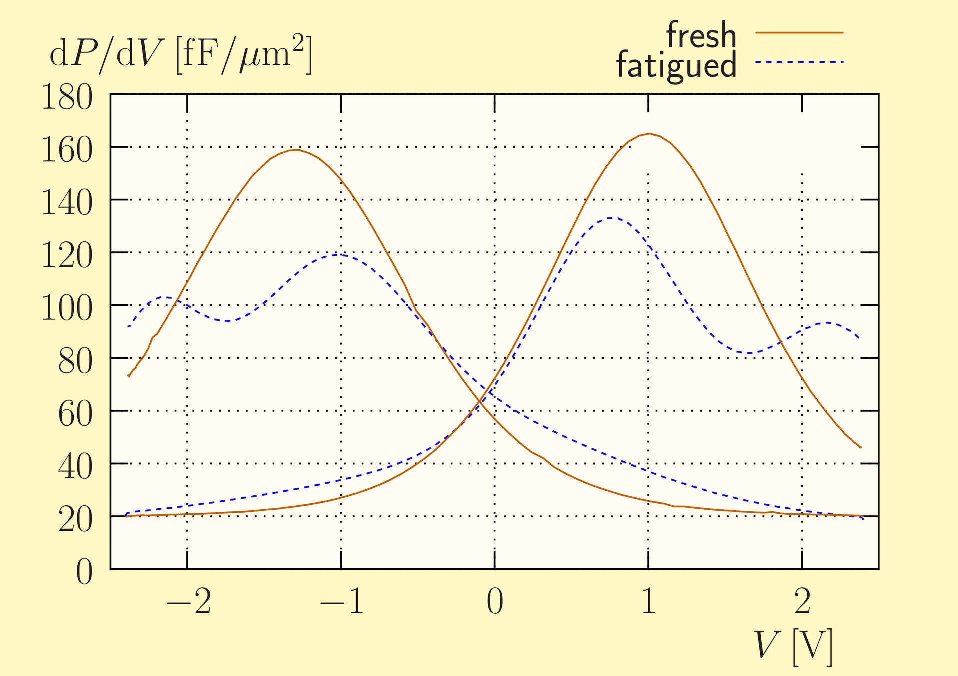
Probability Density Function before Fatigue



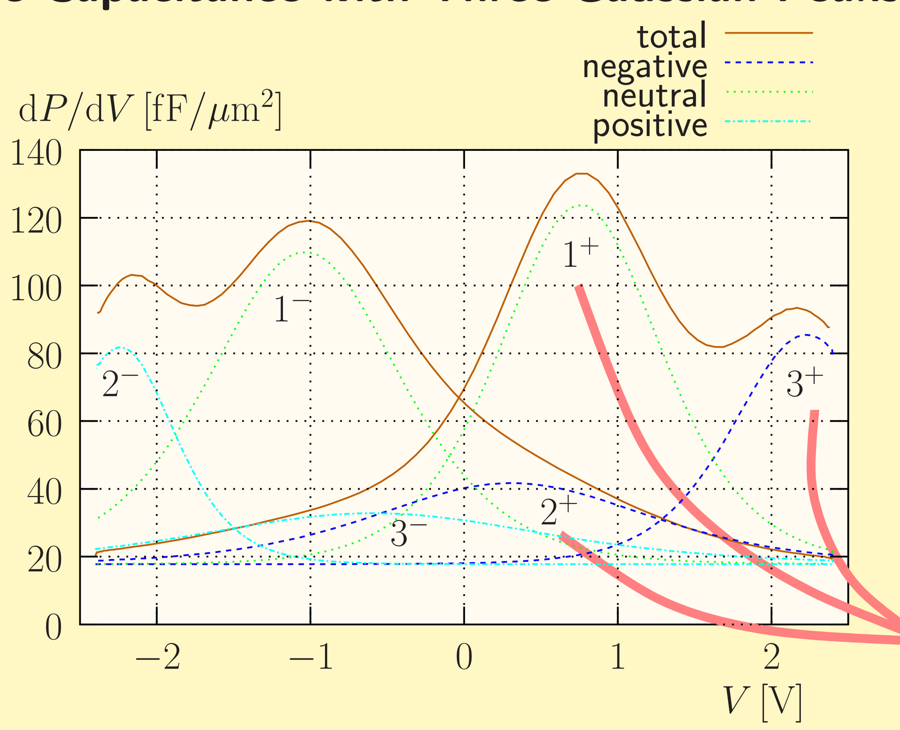
Probability Density Function after Fatigue



Fatigue Behavior of Capacitance Characteristic



Fatigue Capacitance with Three Gaussian Peaks



Standard Preisach Model

$$P(V, V_1, V_2, \ldots) = \int_{v_c^+}\int_{v_c^-}\rho(v_c^+, v_c^-)D(V, V_1, V_2, \ldots)p\,\mathrm{d}v_c^-\,\mathrm{d}v_c^+$$

$$P(V_{ext}) = F \cdot P_{sat} \cdot \tanh[a(V_{ext} \mp V_C^{\pm})]$$

$$\mathrm{d}P/\mathrm{d}V(V_{ext}) = F \cdot P_{sat} \cdot a/\cosh^2[a(V_{ext} \mp V_C^{\pm})]$$

New Fatigue Model ($\rho \longrightarrow \rho_1, \rho_2, \rho_3$)

$$P(V_{ext}) = \sum_{i=1}^{3} F_i \cdot P_{sat\,i} \cdot \tanh[a_i(V_{ext} \mp V_{C\,i}^{\pm})]$$

$$\mathrm{d}P/\mathrm{d}V_{ext} = \sum_{i=1}^{3} F_i^{\pm} \cdot P_{sat\,i} \cdot a_i^{\pm}/\cosh^2[a_i^{\pm}(V_{ext} - V_{C\,i}^{\pm})]$$

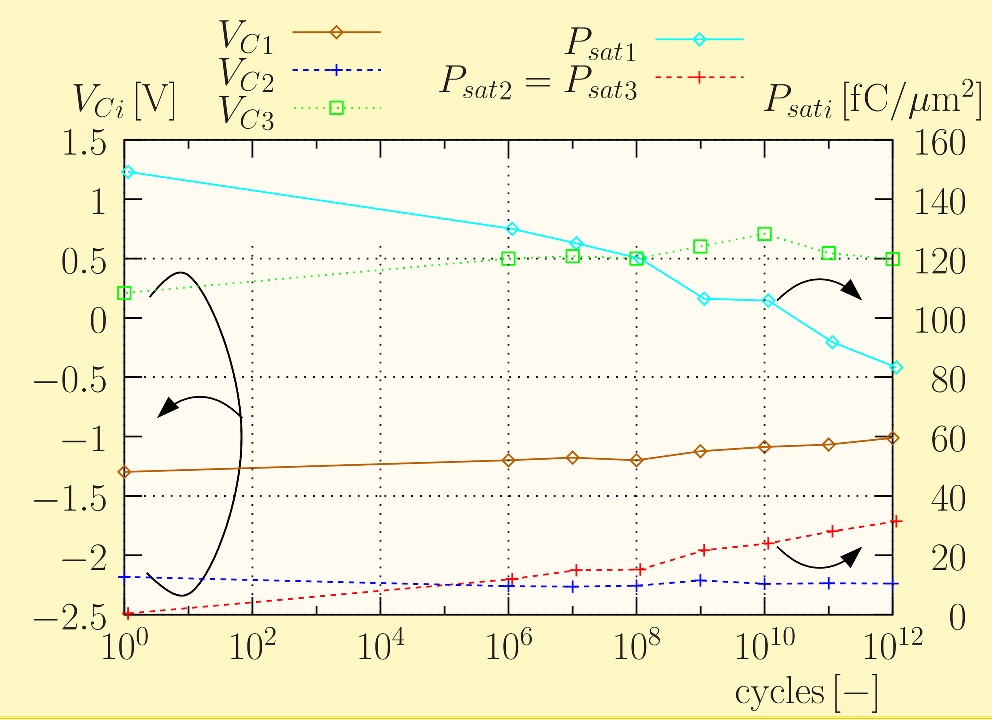
Measurement and Parameter Extraction

- Measurement of low-field fatigue of PZT
- Measurement curves not in saturation
  - low-field fatigue; $2.5\,\mathrm{V}$, $4000\,\mathrm{Å}$, PZT [Moazzami, 1995]
- Extracted parameters are corrected by factors

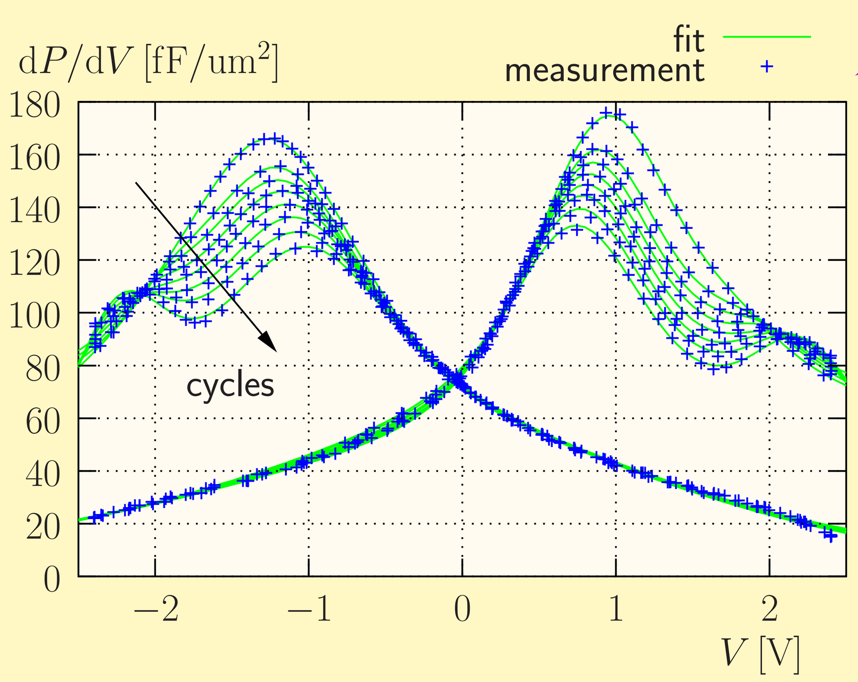
  $F_2^+ = \{1 - \tanh[a_2^- \cdot (V_{min} - V_{C2}^-)]\}/2$

  $F_3^- = \{1 + \tanh[a_3^- \cdot (V_{max} - V_{C3}^+)]\}/2$
- Good agreement between measurement and simulation

Extracted Parameters

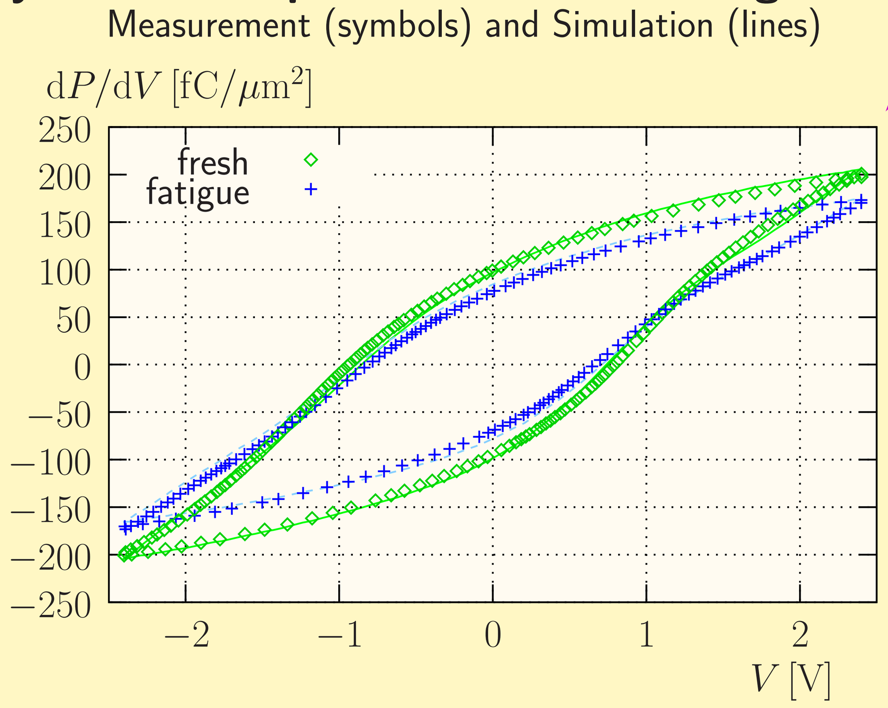


Fatigue Behavior of Capacitance Characteristic

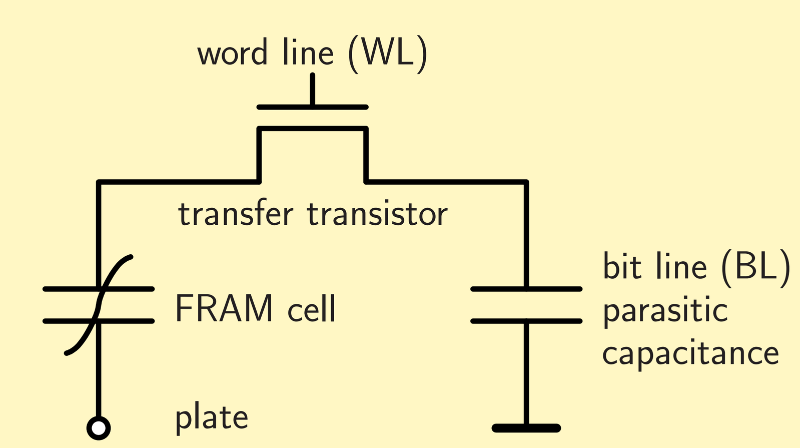


Hysteresis Loop for a Fresh and Fatigued Cell

Measurement (symbols) and Simulation (lines)



Read Equivalent Circuit for a Memory Cell



After 10^9 cycles the signal-to-noise-ratio decreases by $33\,\%$.

Conclusion

- Low-field fatigue of PZT modeled
- Starting point: Preisach model
- New fatigue model: three ferroelectric capacitors
- New extraction method for low-field fatigue
- Simulation of FRAM cells: read signal reduction of $33\,\%$ after 10^9 cycles
- Model easily adaptable to changed fatigue characteristics