

High Concentration of Interface Traps in MOS Transistor Modeling

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High Concentration of Interface Traps in MOS Transistor Modeling Outline

- Our Motivations.
- Theory of Recombination DCIV (R-DCIV) and CV Methodologies.
- Effects of high interface trap concentration at discrete energy levels on R-DCIV and CV line shapes.
- Effects of the paired-exponential distribution of neutral electron and hole interface traps on R-DCIV and CV line shapes.
- Summary

High Concentration of Interface Traps in MOS Transistor Modeling

- (1) **Chih-Tang Sah**, "Origin of Interface States and Oxide Charges Generated by Ionizing Radiation," Plenary IEEE Nuclear and Space Radiation Conference, San Diego, 1976; Tran. Nuclear Sciences NS23(6), 1563-1568, December 1976.
- (2) **Chih-Tang Sah**, "Interface traps on silicon surfaces, and on oxidized Si from electron spin resonance and X-ray photoemission spectroscopy," *Properties of Silicon*, Section 17.1, 17.2 and 17.3, pp.499-520. INSPEC, The Institution of Electrical Engineers, UK, 1988.
- (3) **Chih-Tang Sah**, Bin B. Jie and Zuhui Chen, "A History of Electronic Traps on Silicon Surfaces and Interfaces," Proceedings on CD's of this Conference..
- (4) **Chih-Tang Sah** and Bin B. Jie, "Generation-Recombination-Trapping at Interface Traps in Compact MOS Transistor Modeling," Proc. ICSICT-2006, 1206-1213, October 23-26, 2006. Shanghai, China. IEEE Catalog No. 06EX1294.
- (5) **Bin B. Jie** and Chih-Tang Sah, "Generation-Recombination-Trapping at Interface Traps in Short-Channel MOS Transistors," *ibid.* 1214-1219.
- (6) **Zuhui Chen**, Bin B Jie, and Chih-Tang Sah, "Effects of Energy Distribution of Interface Traps on Recombination DC Current-Voltage Lineshape," *J. Appl. Phys.* 100, 114511(2006)
- (7) **Chih-Tang Sah**, "Evolution of the MOS transistors, from conception to VLSI," *IEEE Proceedings*, 76(10), 1280-1326, October 1988. On SiO₂/Si interface traps, see sections III A to H, especially III-D and IV-A, C, D and H.

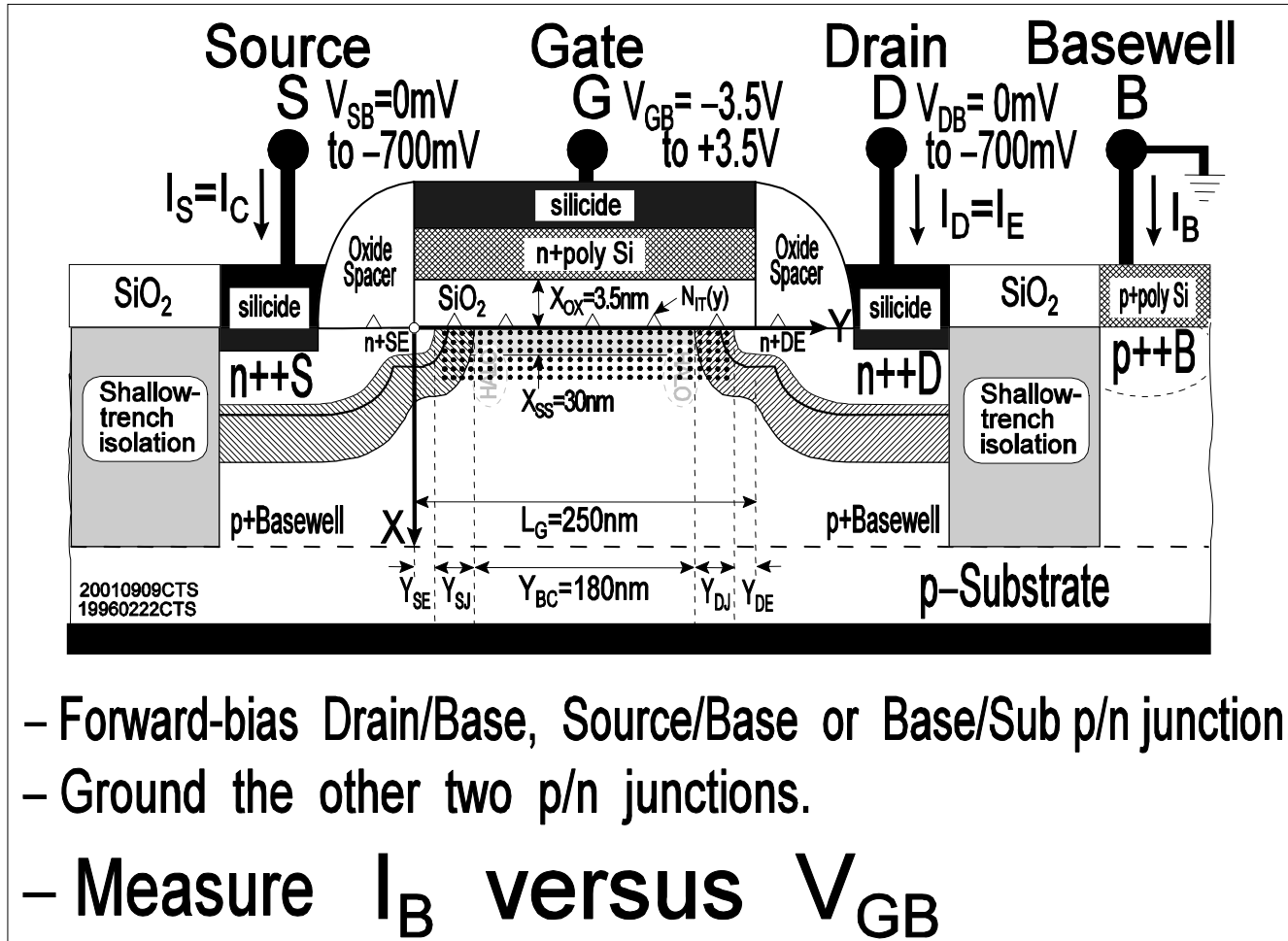
Plus many references cited in these five articles

Motivation

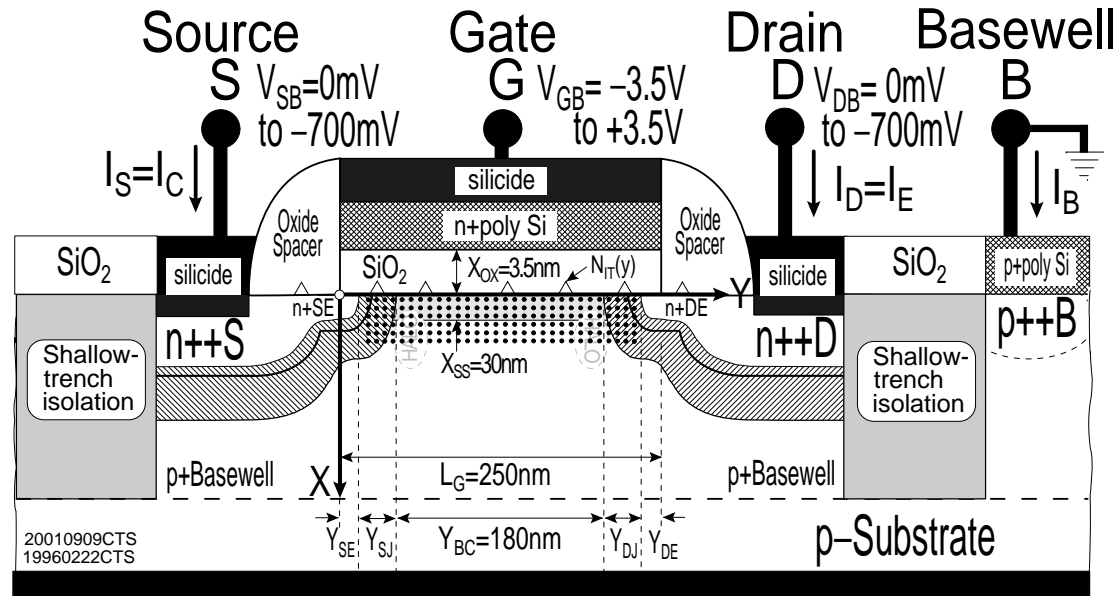
Reasons for investigating high concentration of interface traps in MOS transistors.

- Concentration and spatial variation of interface traps along the silicon surface greatly affect digital, analog, RF and HF performance of MOS transistors and the endurance of the floating gate MOS transistors.
- High concentration of interface traps are generated in MOS transistors during radiation exposure and during operation of the floating-gate memory transistors.
- Theory and potential new applications.

Theory of recombination DCIV (R-DCIV) and CV Methods: **the R-DCIV**



Theory of recombination DCIV (R-DCIV) and CV Methods: Baseline of R-DCIV

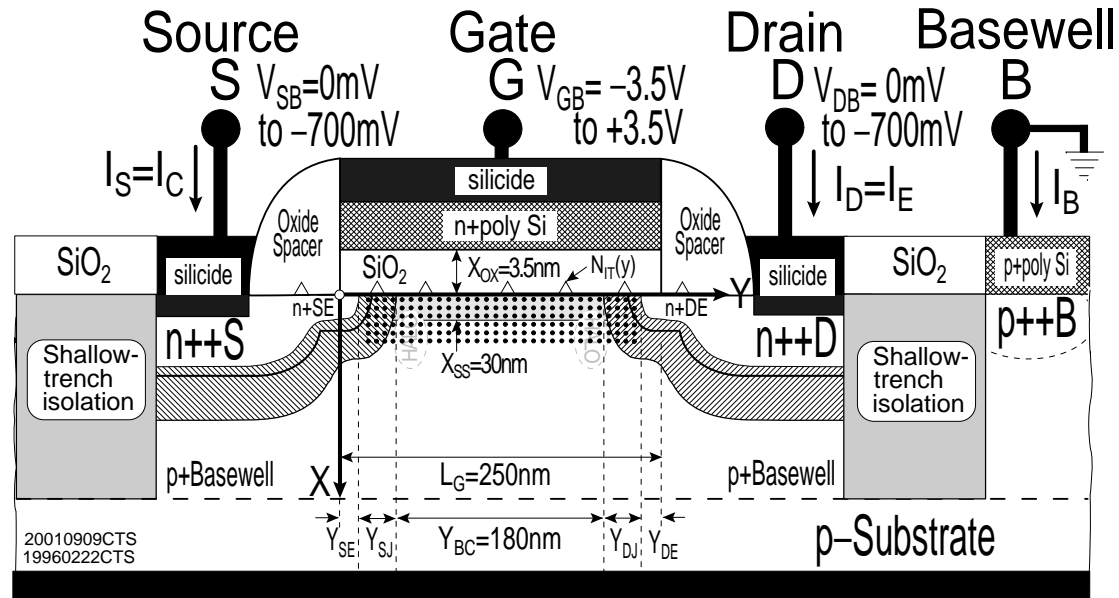


I_B versus V_{GB}

$$I_B = I_{\text{BaseLine}} + I_{\text{InterfaceTrap}}(V_{GB})$$

$$I_{IT}(V_{GB}) = I_{SE} + I_{SJ} + I_{BC} + I_{DJ} + I_{DE}$$

Theory of recombination DCIV (R-DCIV) and CV Methods: R-DCIV Formulas



I_B versus V_{GB}

$$I_B = I_{\text{BaseLine}} + I_{\text{InterfaceTrap}}(V_{GB})$$

$$I_{IT}(V_{GB}) = I_{SE} + I_{SJ} + I_{BC} + I_{DJ} + I_{DE}$$

Theory of recombination DCIV (R-DCIV) and CV Methods: R-DCIV Formulas

$$R_{SS} = \frac{c_{ns} c_{ps} N_S P_S - e_{ns} e_{ps}}{c_{ns} N_S + e_{ns} + c_{ps} P_S + e_{ps}} N_{IT}$$

$$= \frac{(c_{ns} c_{ps})^{1/2} n_i [\exp(U_{PN}) - 1] / 2}{\exp(U_{PN} / 2) \cosh(U_S^*) + \cosh(U_{TI}^*)} N_{IT}$$

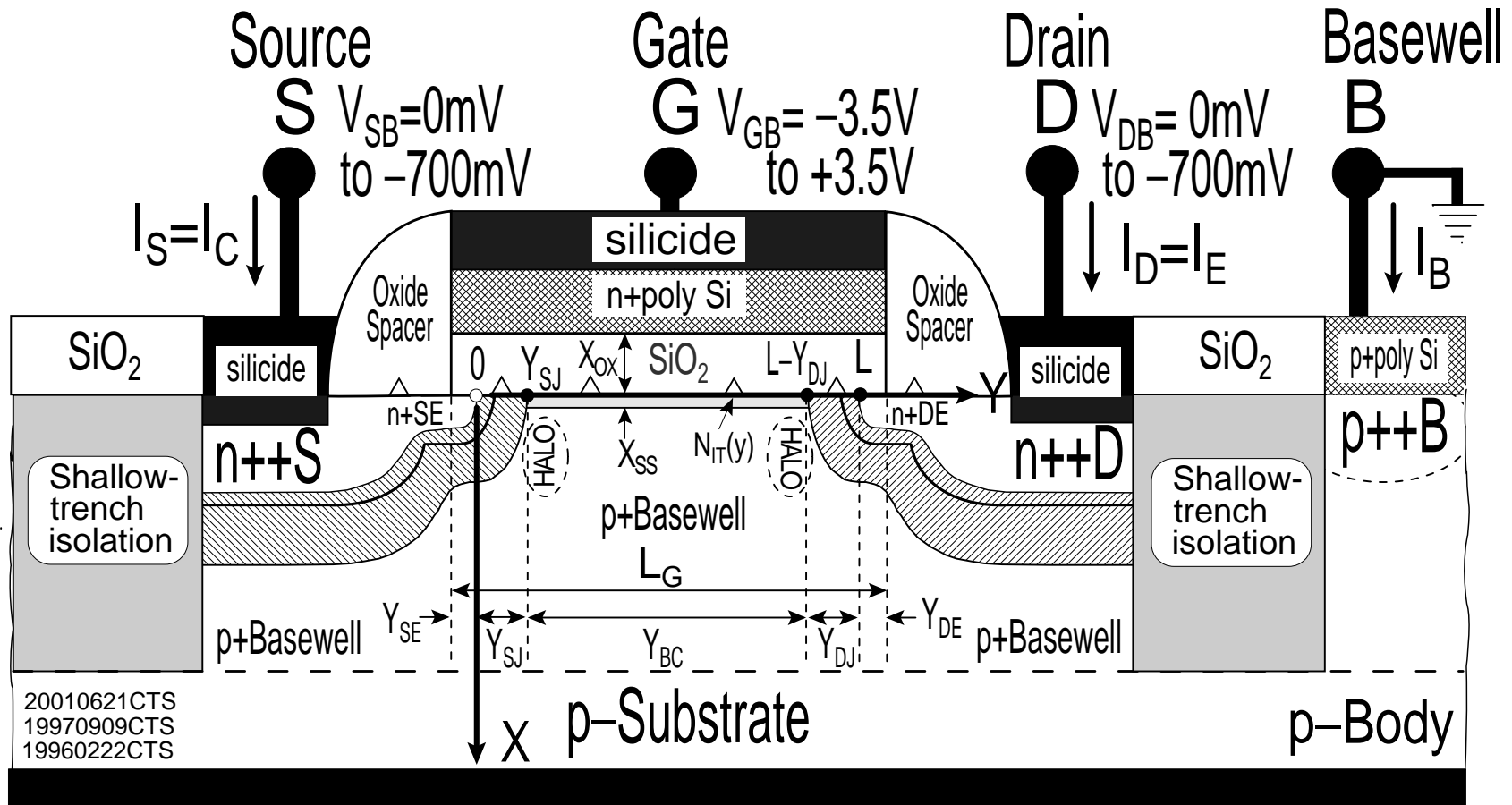
$$I_B(V_{GB}) = q \iiint R_{SS}(V_{GB}) N_{IT}(y, z) dy dz$$

$$= \frac{q (c_{ns} c_{ps})^{1/2} n_i W}{2} \iint \frac{[\exp(U_{PN}) - 1] N_{IT}(E_{TI})}{\exp(U_{PN} / 2) \cosh(U_S^*) + \cosh(U_{TI}^*)} dE_{TI} dy$$

$$U_S^* = U_S + \frac{1}{2} [\ln(c_{ns} / c_{ps}) - (U_P + U_N)]$$

$$U_{TI}^* = E_{TI} / k_B T = [(E_T - E_I) / k_B T + \frac{1}{2} [\ln(c_{ns} / c_{ps})]]$$

Theory of recombination DCIV (R-DCIV) and CV Methods: CV Formulas



Theory of recombination DCIV (R-DCIV) and CV Methods: CV Formulas

$$(1) V_{GB} = V_S + V_{FB} - Q_{IT} / C_{OX} + \epsilon_S E_S / C_{OX}$$

$$(2) Q_{IT} = -qN_{IT} \times F_{IT} = -qN_{IT} \frac{c_{ns} N_S + e_{ps}}{c_{ns} N_S + e_{ns} + c_{ps} P_S + e_{ps}}$$

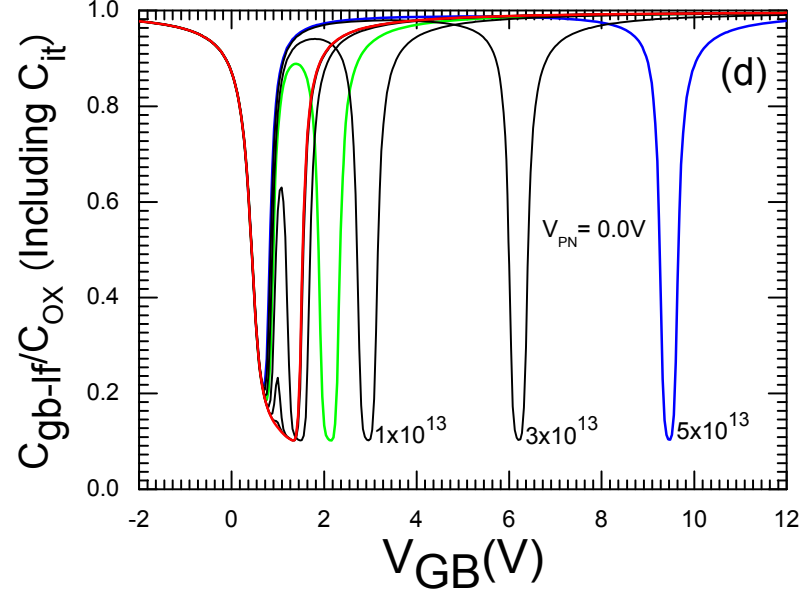
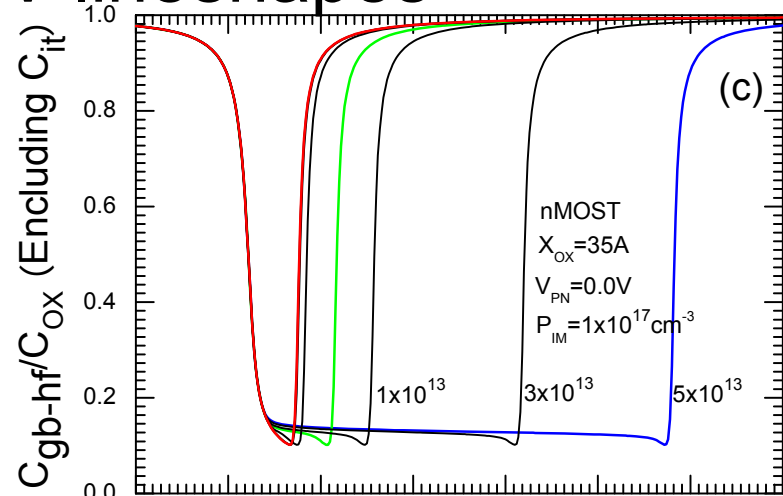
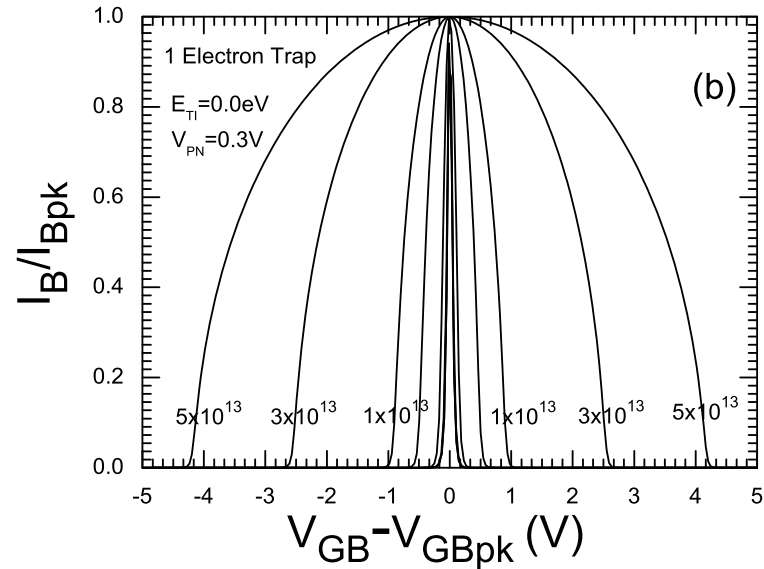
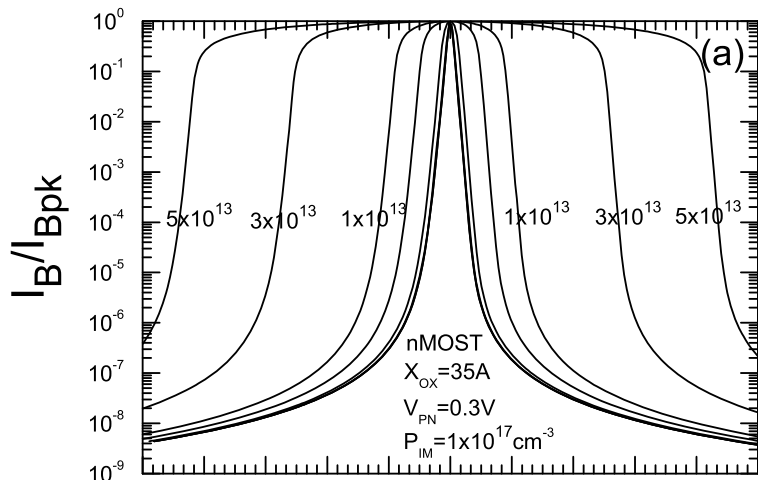
$$(3) C_{gb-hf} = C_S \times C_{OX} / (C_S + C_{OX})$$

$$(4) C_{gb-lf} = (C_S + C_{it}) \times C_{OX} / [(C_S + C_{it}) + C_{OX}]$$

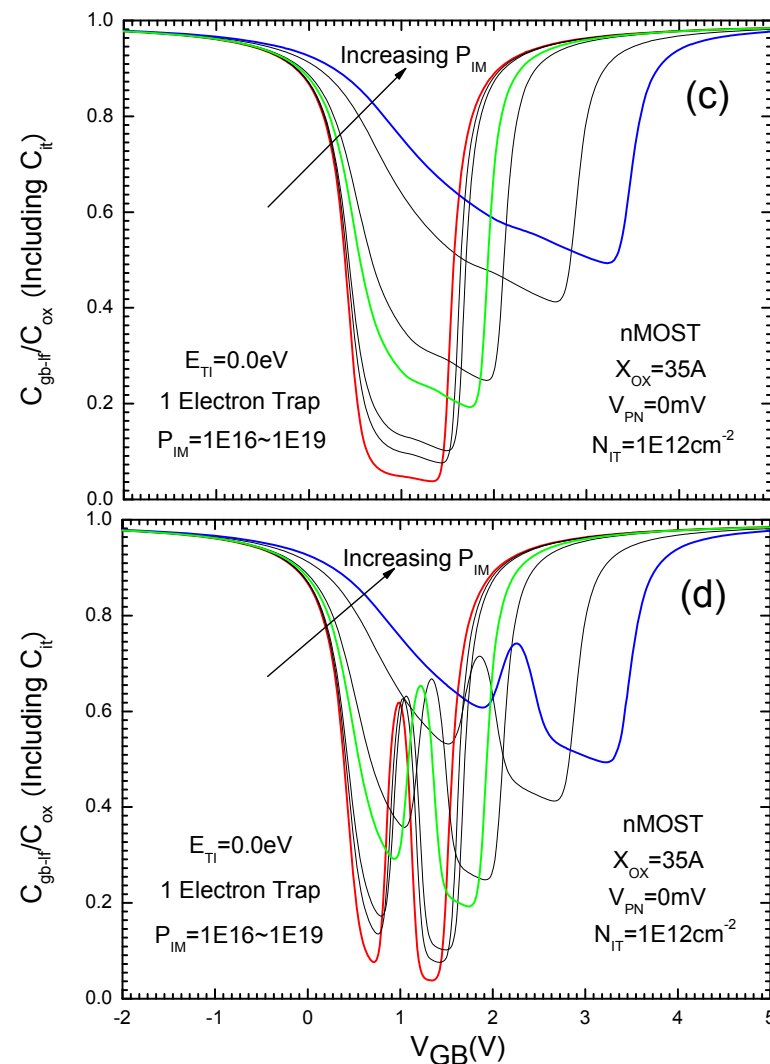
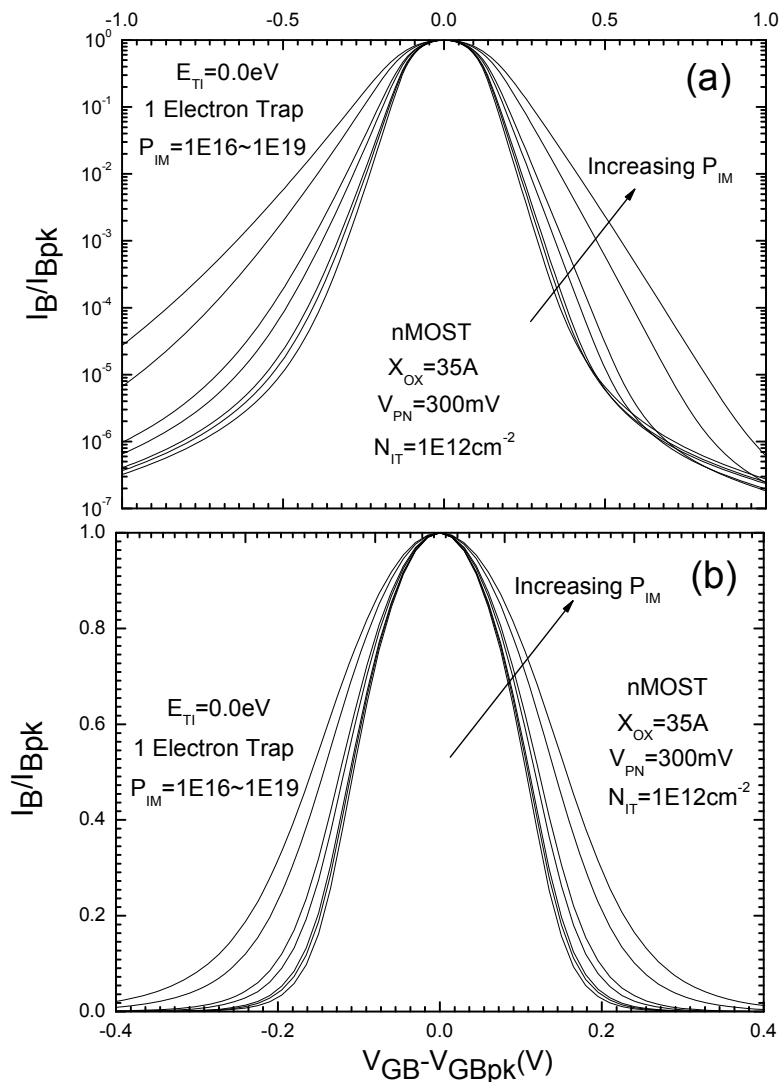
$$(5) C_{it} = \frac{q^2 N_{IT} (c_{ns} N_S + e_{ps}) \times (c_{ps} P_S + e_{ns})}{kT (c_{ns} N_S + e_{ns} + c_{ps} P_S + e_{ps})^2}$$

$$(6) C_S = \frac{q}{E_S} \{ -N_V \exp(-U_S - U_V + U_F) + N_C \exp(U_S + U_C - U_F + U_{PN}) \\ + P_{IM} / [1 + g_A \exp(U_F - U_A - U_S)] \}$$

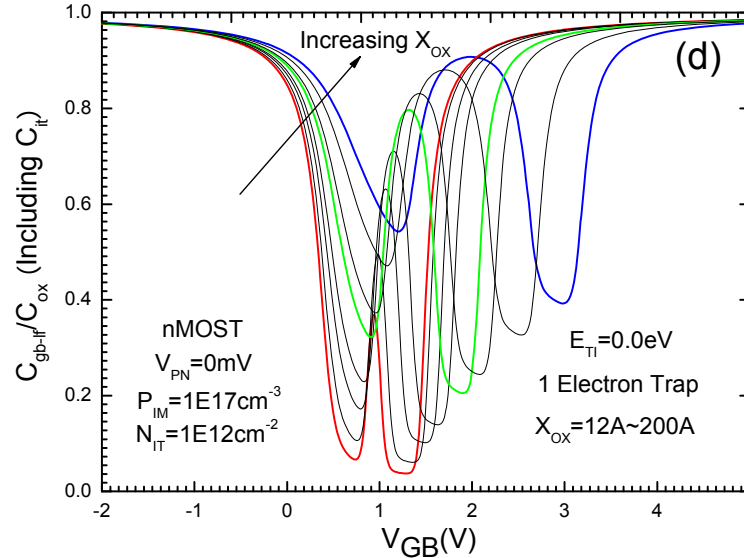
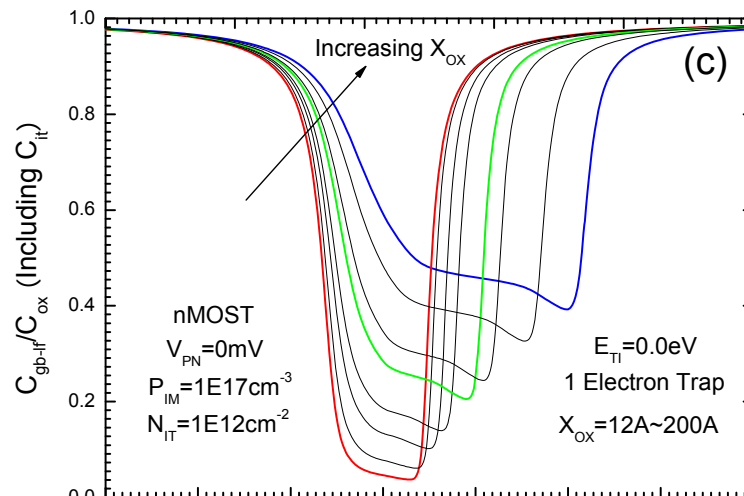
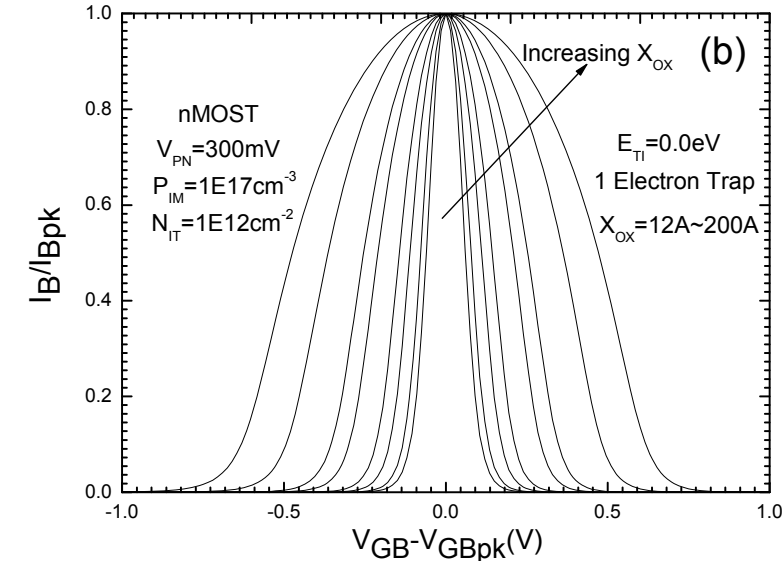
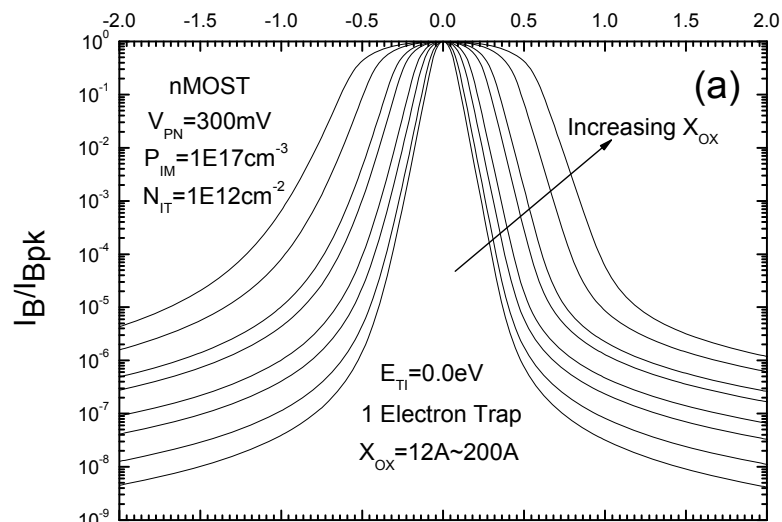
Effect of interface trap concentration on R-DCIV and CV lineshapes



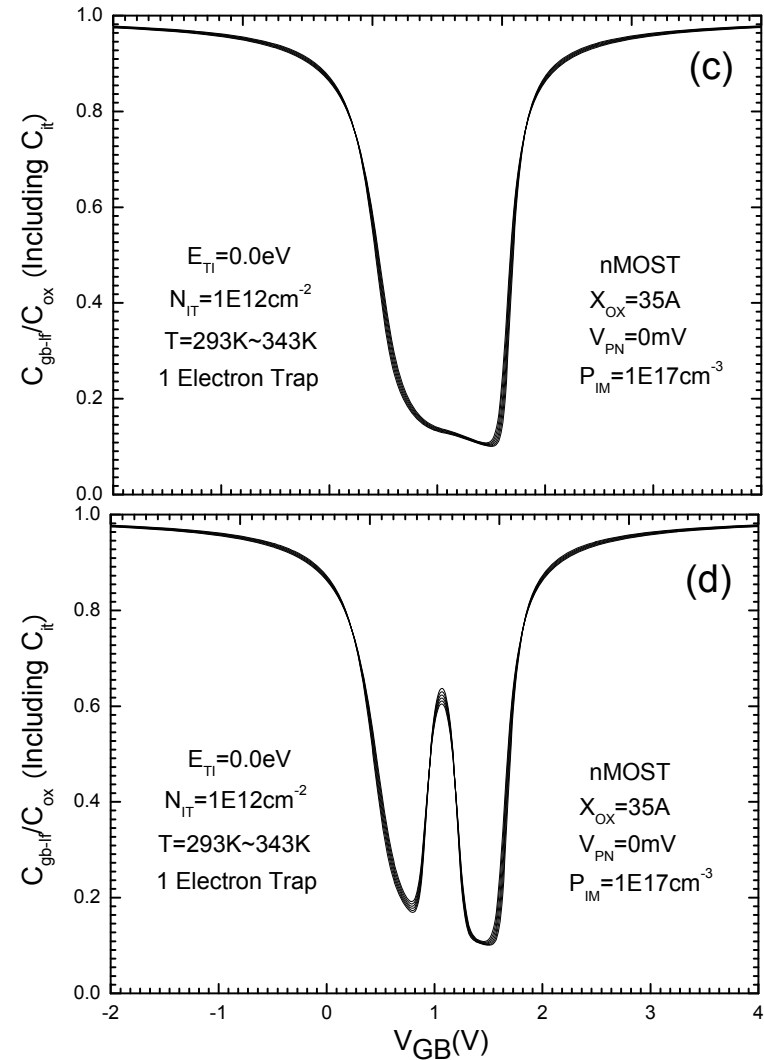
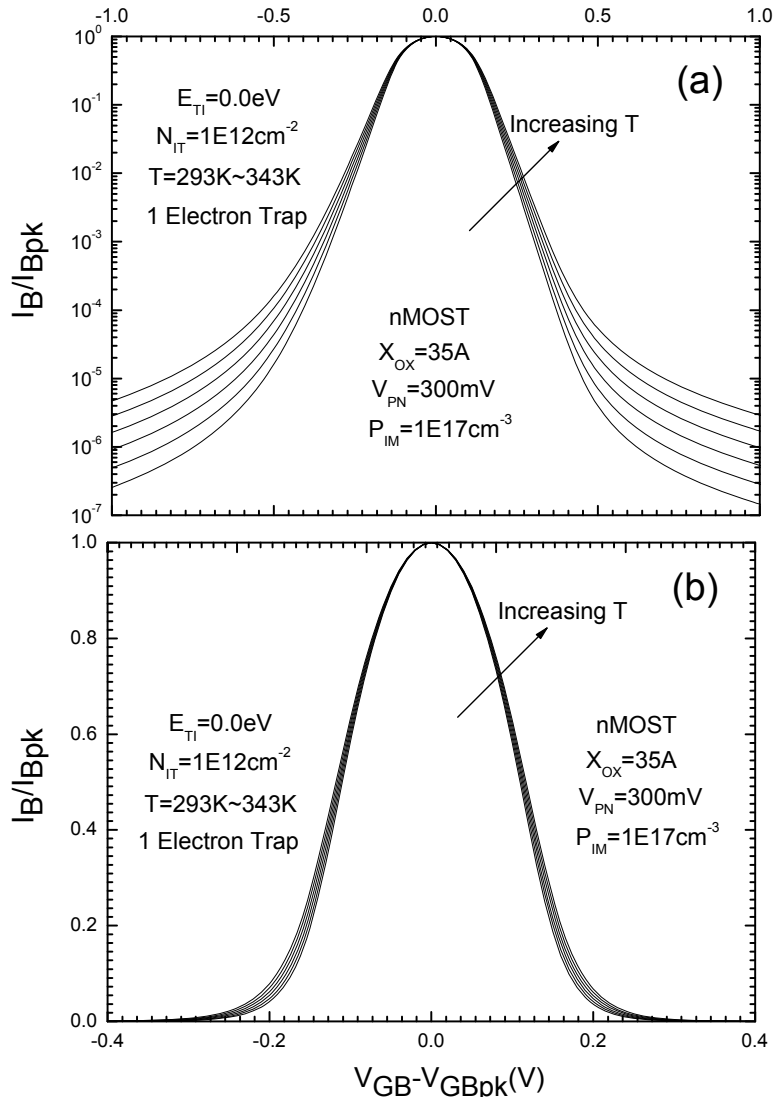
Effect of dopant impurity concentration on R-DCIV and CV lineshapes



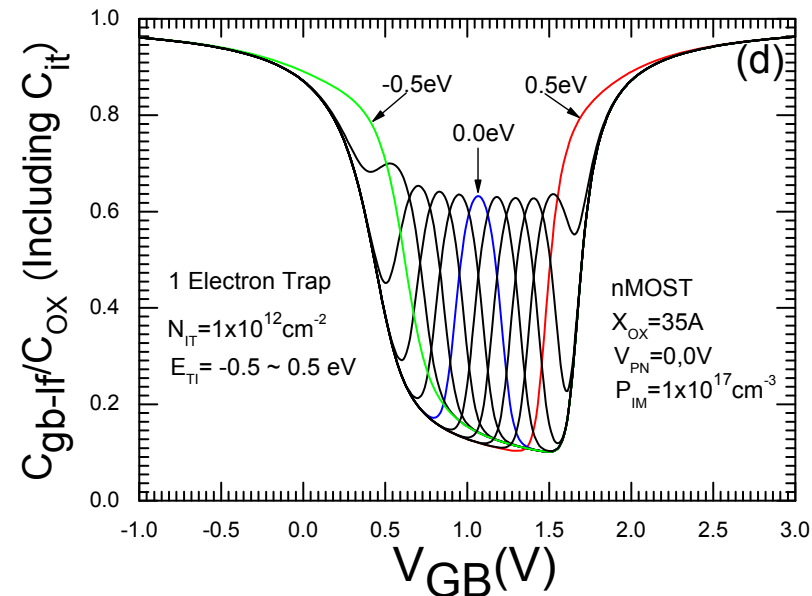
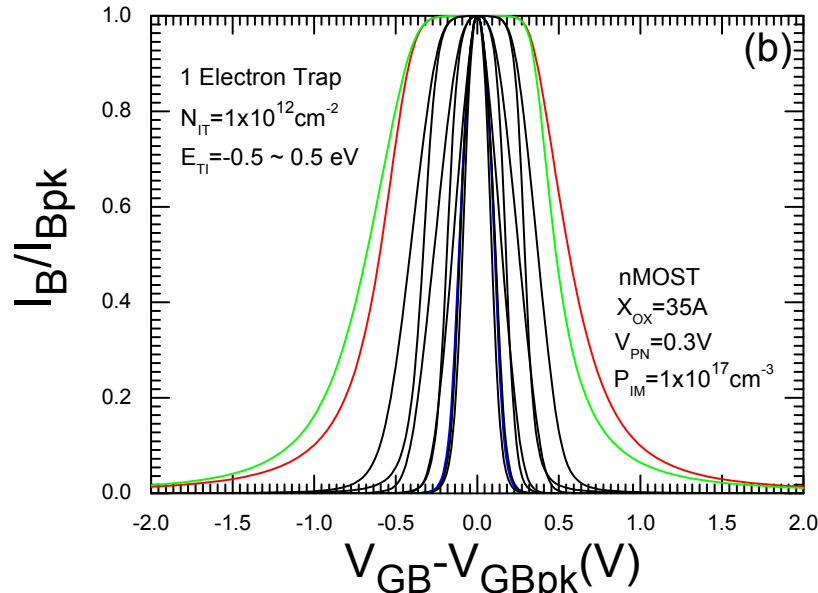
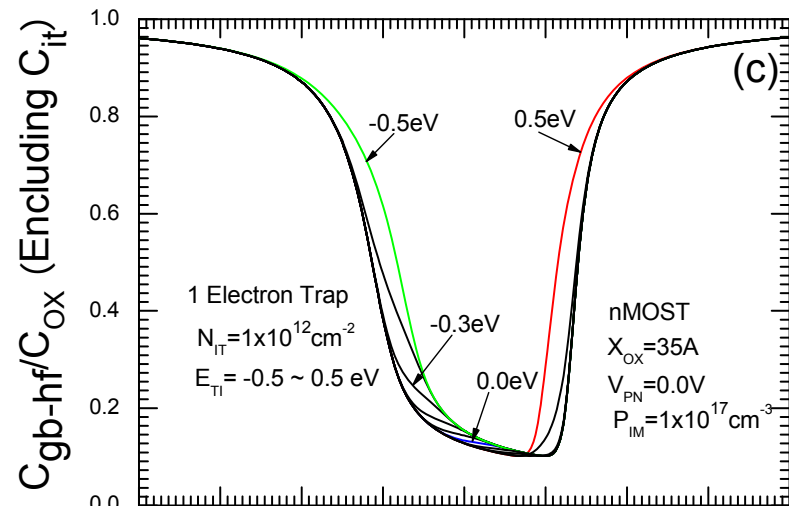
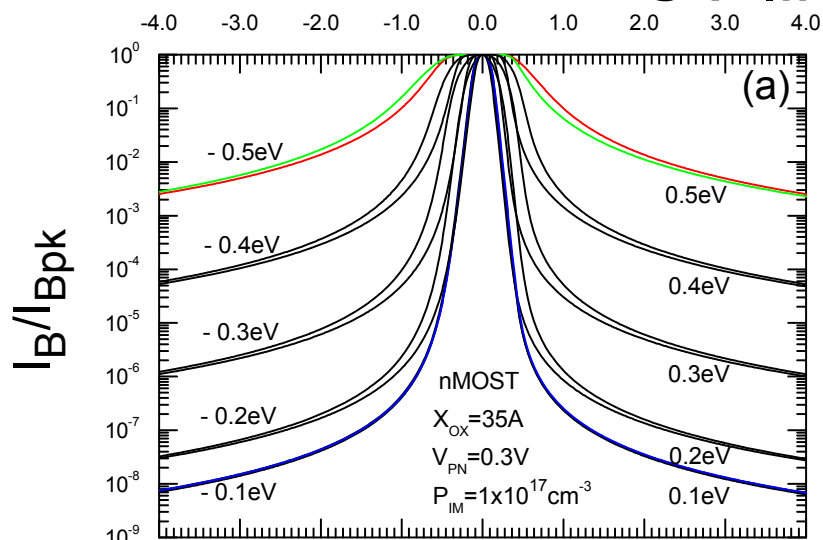
Effect of oxide thickness on R-DCIV and CV lineshapes



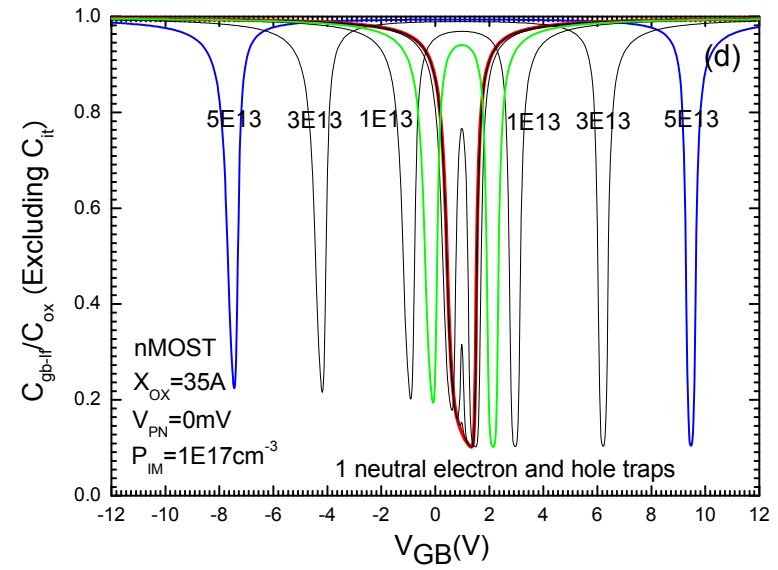
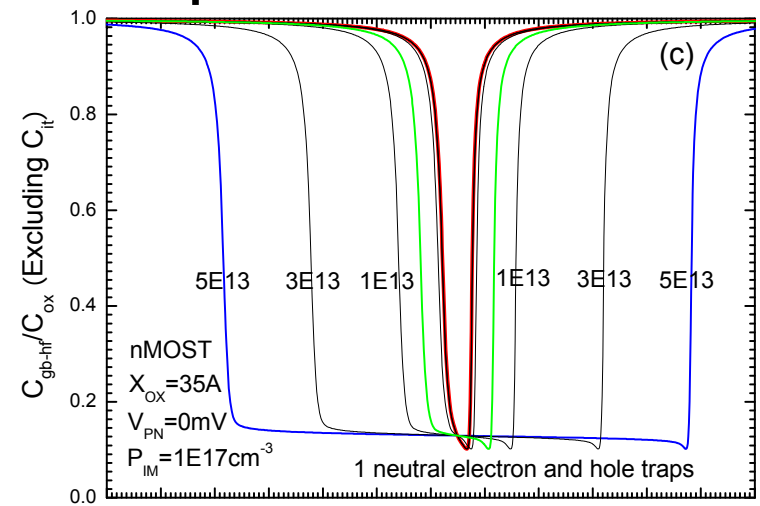
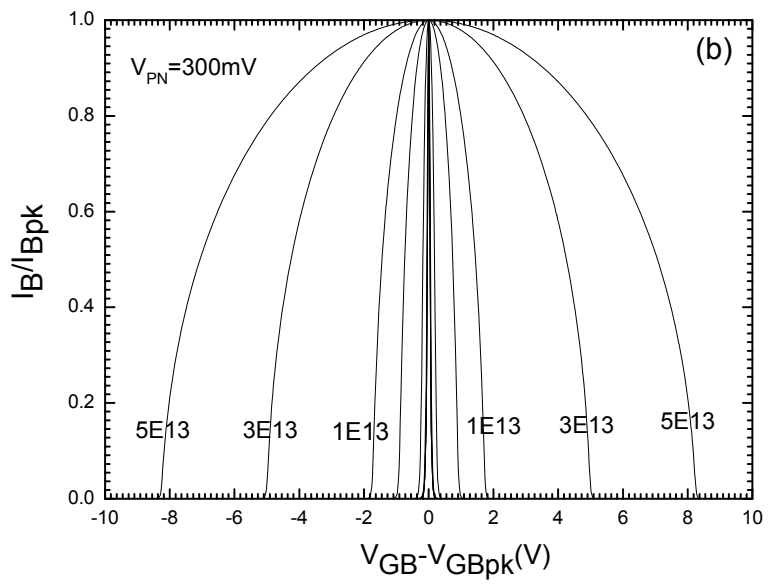
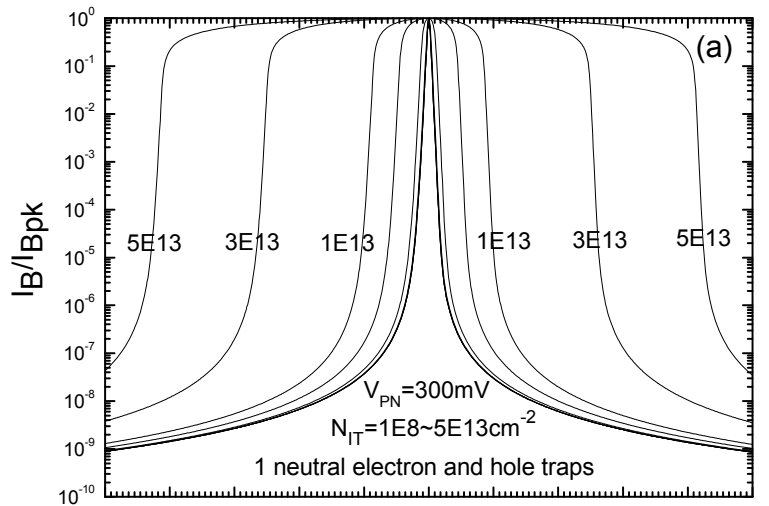
Effect of temperature on R-DCIV and CV lineshapes



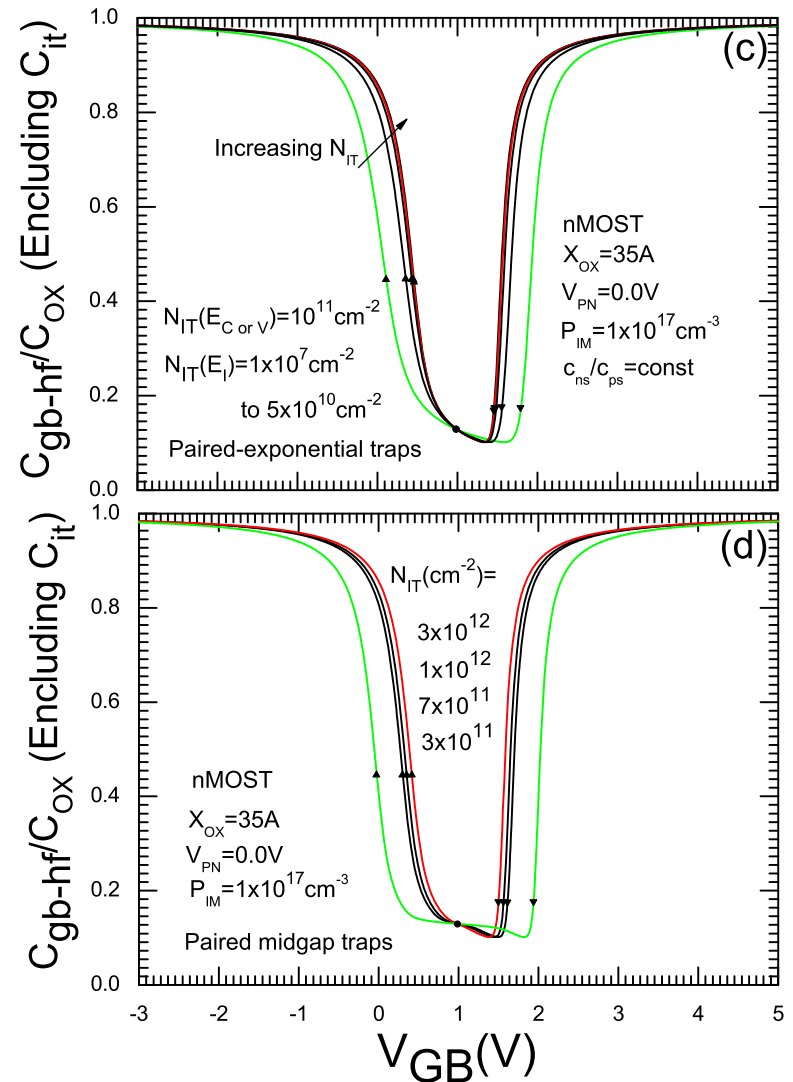
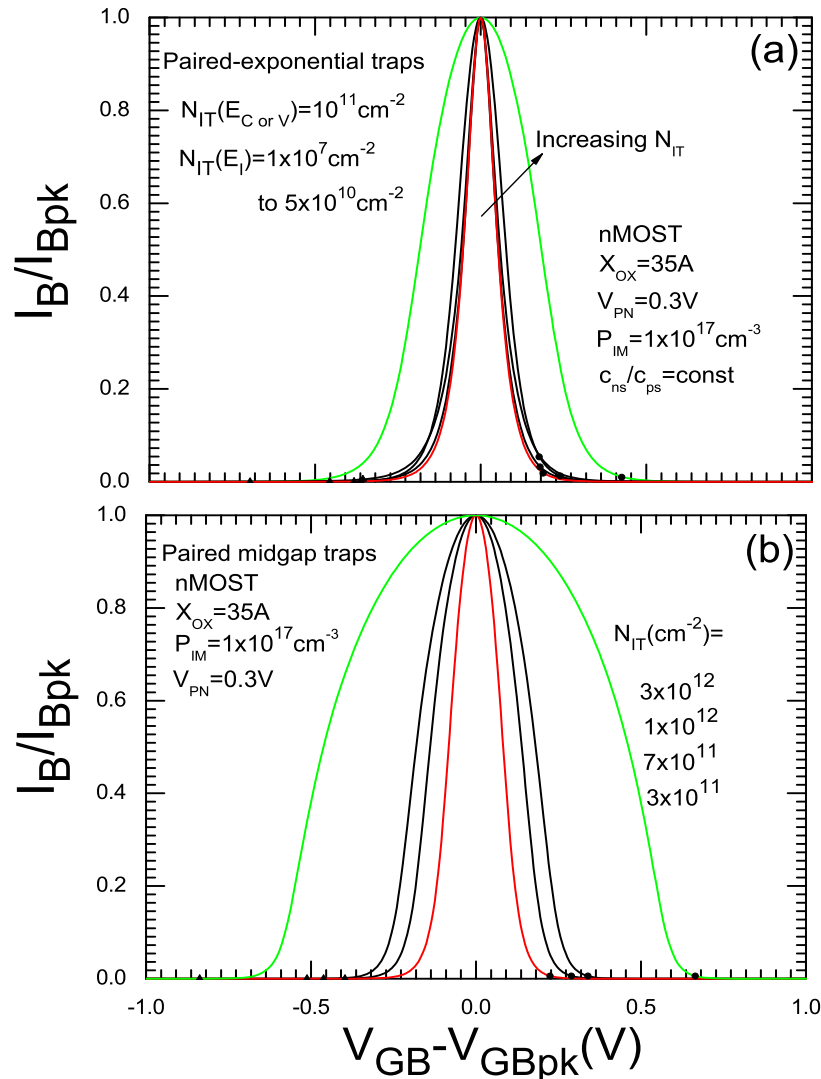
Effect of discrete trap energy level on R-DCIV and CV line shapes



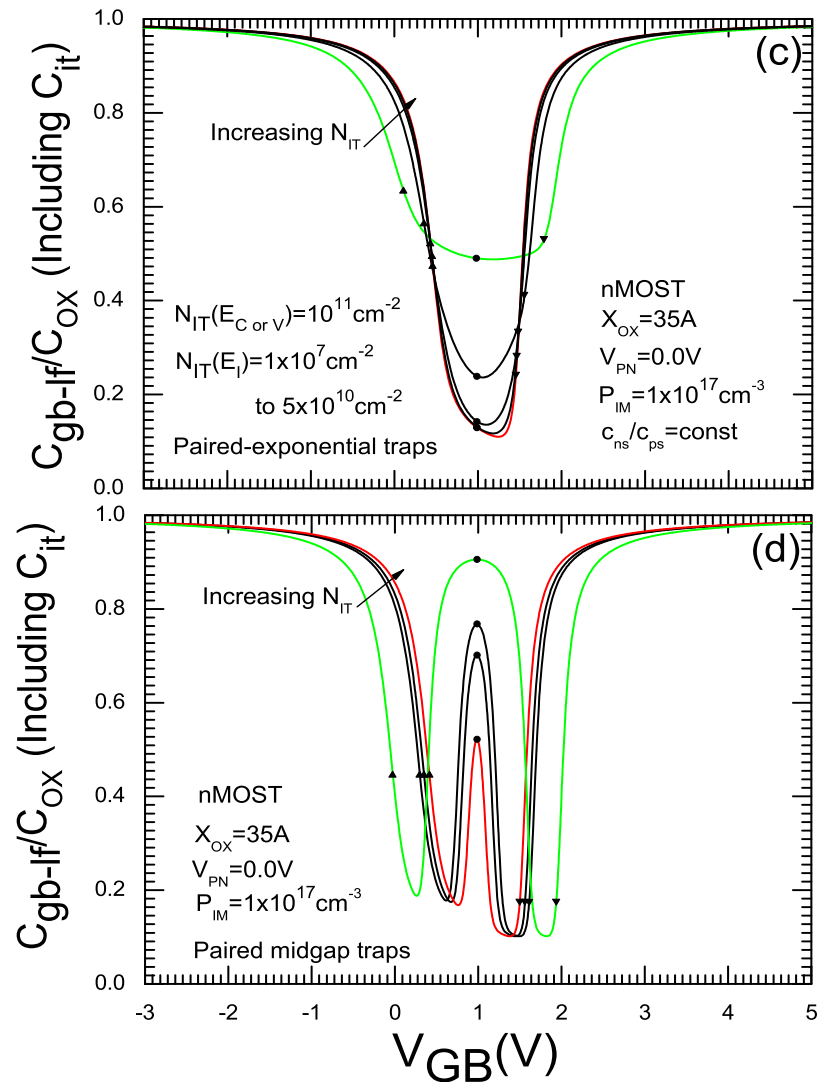
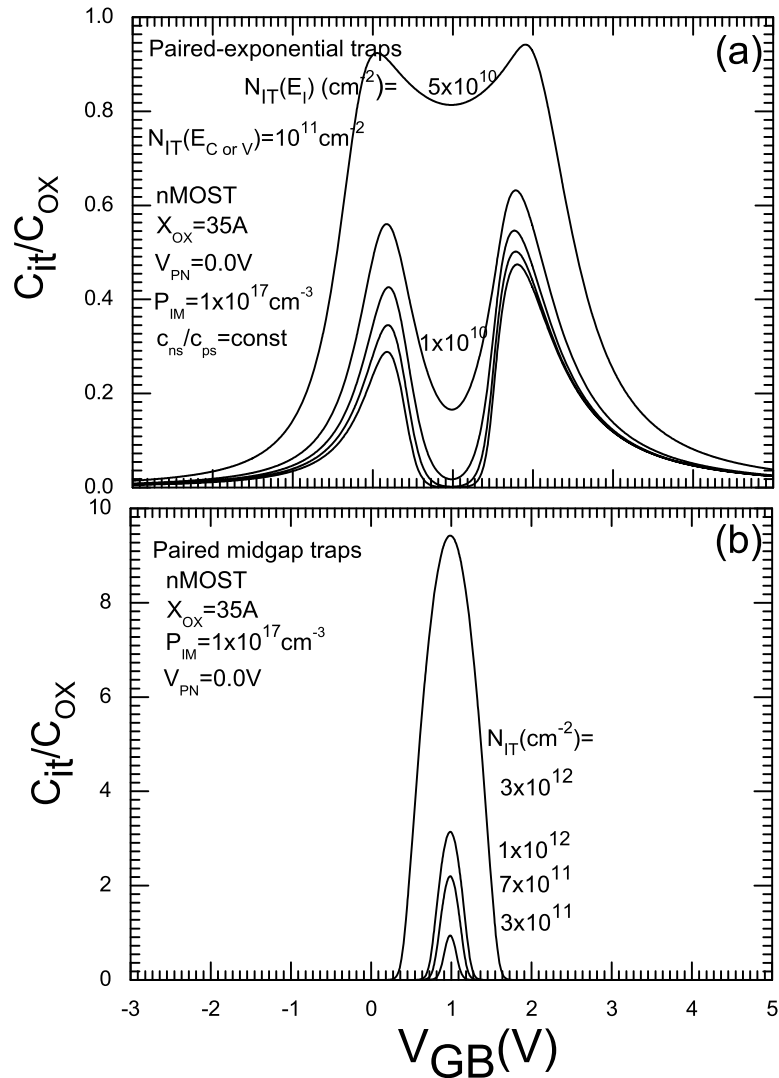
Effect of interface trap concentration on R-DCIV and CV line shapes



Effect of paired exponential distribution of interface traps on R-DCIV and CV line shapes



Effect of paired exponential distribution of interface traps on R-DCIV and CV line shapes



Summary

- The line shapes of the $CV(V_{PN}=0)$ and R-DCIV curves are increasingly distorted as increasing concentration of the interface trap concentration, due to the V_{GB} dependence of the trapped-charge Q_{IT} from trapped electrons at the neutral electron traps and trapped holes at the neutral hole traps.
- At high concentrations of interface traps, the low-frequency and high-frequency CV characteristics show extreme distortions, with even two minima, actually one maximum in the Low-Frequency CV valley.
- Increasing dopant impurity concentrations and broadening energy distribution of interface traps give characteristic recombination DCIV and HF and LF CV due to the presence of midgap-1-pair and distributed-55-pair interface traps.

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Acknowledgments

**Thank You Very Much
for your attention.**

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