Study of a single dangling bond (P_{b0} center) at the SiO_2/Si interface in deep submicron MOS transistors

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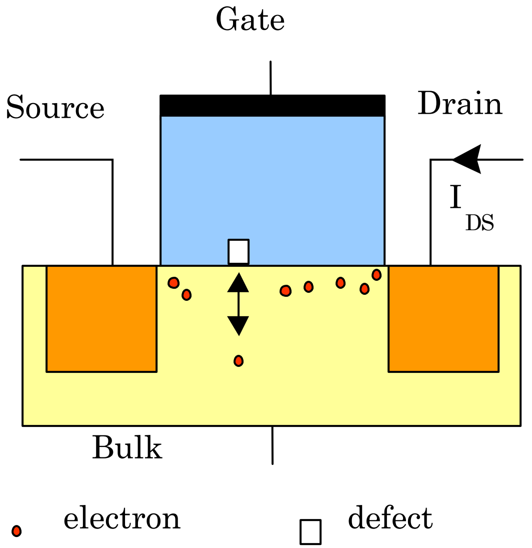
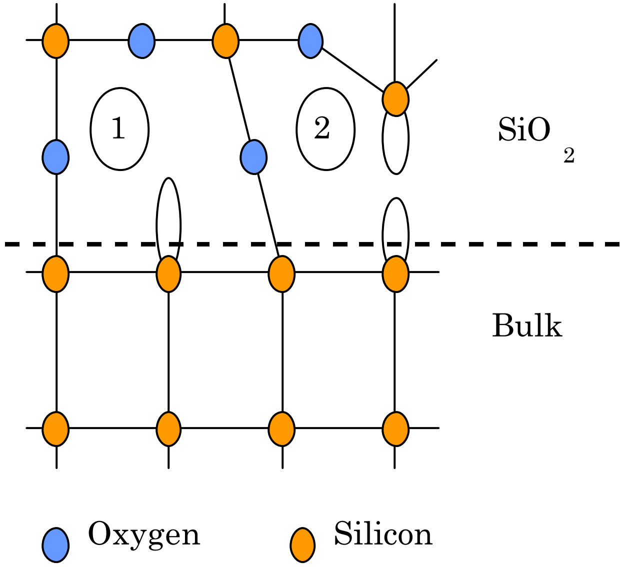
Motivation of the work

- Characterization of SiO_2/Si interface for deep sub-micron MOS transistors (50nm length)





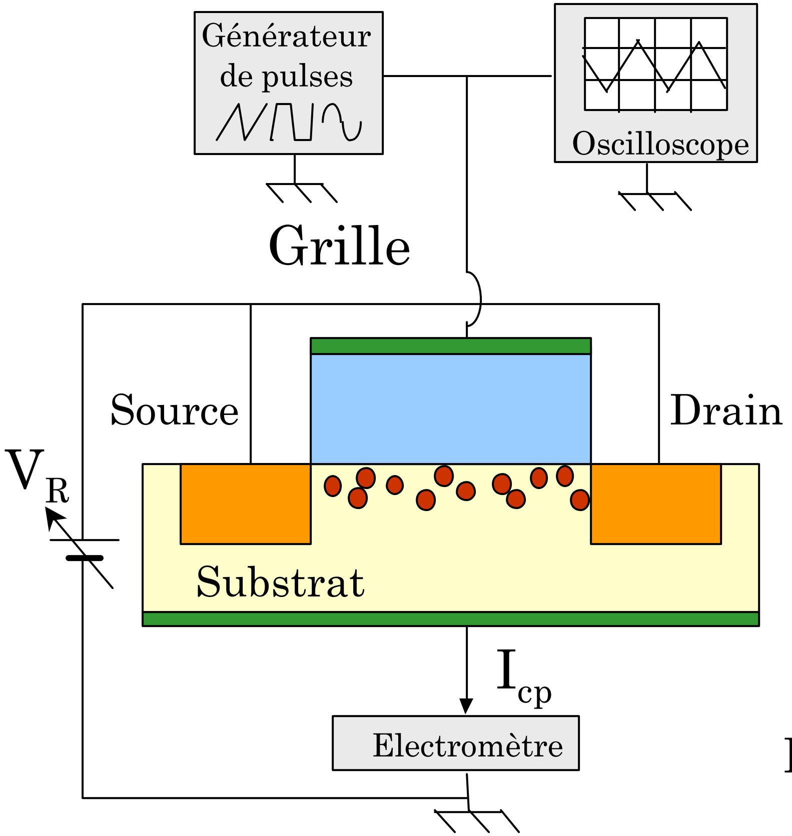
- Use of charge pumping measurement to determine :
  - the capture cross section ($\sigma_{n,p}$)
  - the energy position (E_t)

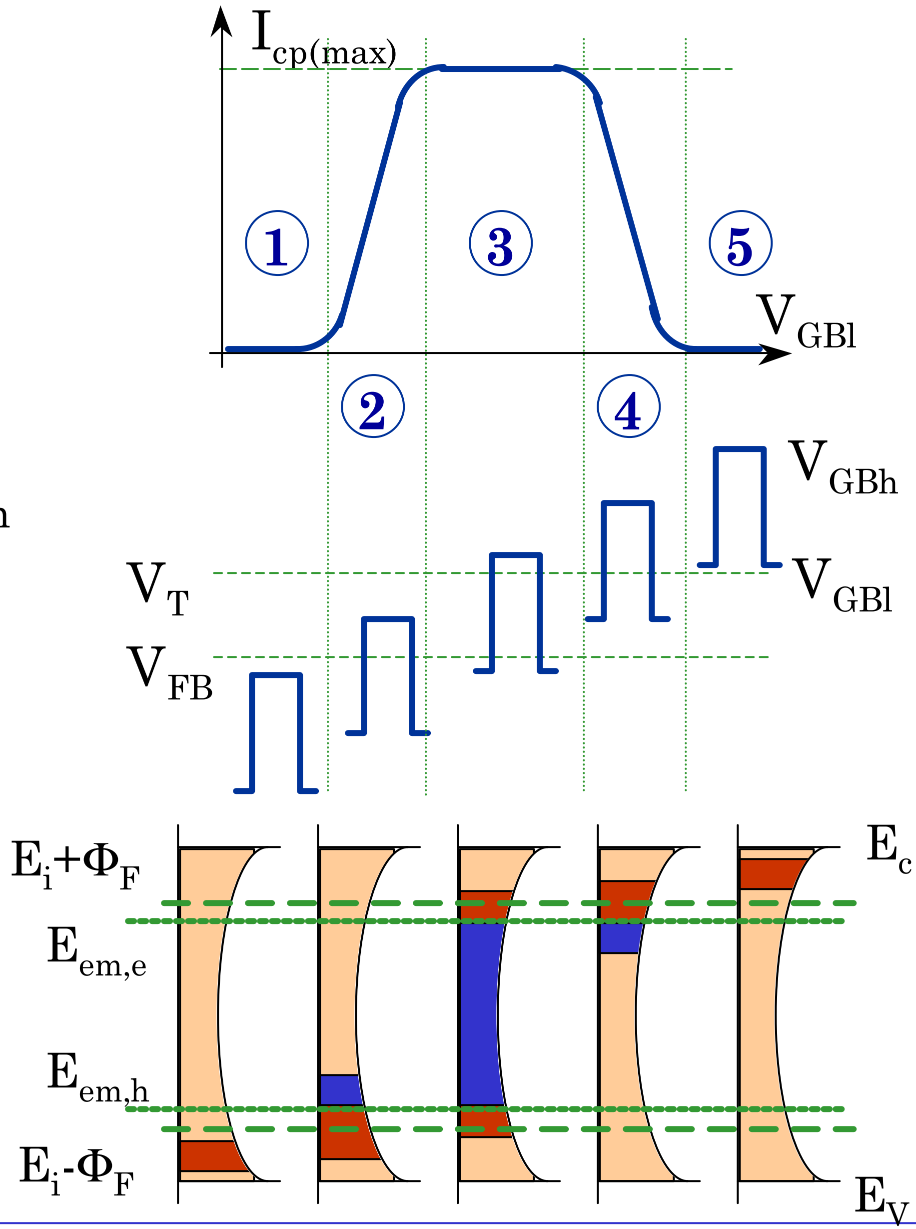
- Low current measurements done on a wafer probe station (4-400K)

Outline

- Theory of single trap charge pumping
- Experimental results
- Interpretations
- Conclusions

Charge pumping technique





$$I_{cp} = qA_{eff}F_PD_{it}(E_{em,h} - E_{em,e})$$

Single trap

❑ Charge pumping current

$$I_{CP} = \frac{\int_0^T q\left[e_p(1-f_t) - c_p f_t\right]dt}{T}$$

➢ The amplitude of I_{cp} is depending on $(f_{tmax}-f_{tmin})$ $I_{cp\,max} = q \times F$

❑ Trap filling probability

$$\frac{df_t(t,E_t)}{dt} = c_n(1-f_t) - e_n f_t + e_p(1-f_t) - c_p f_t$$

➢ Depend on capture cross section and energy position

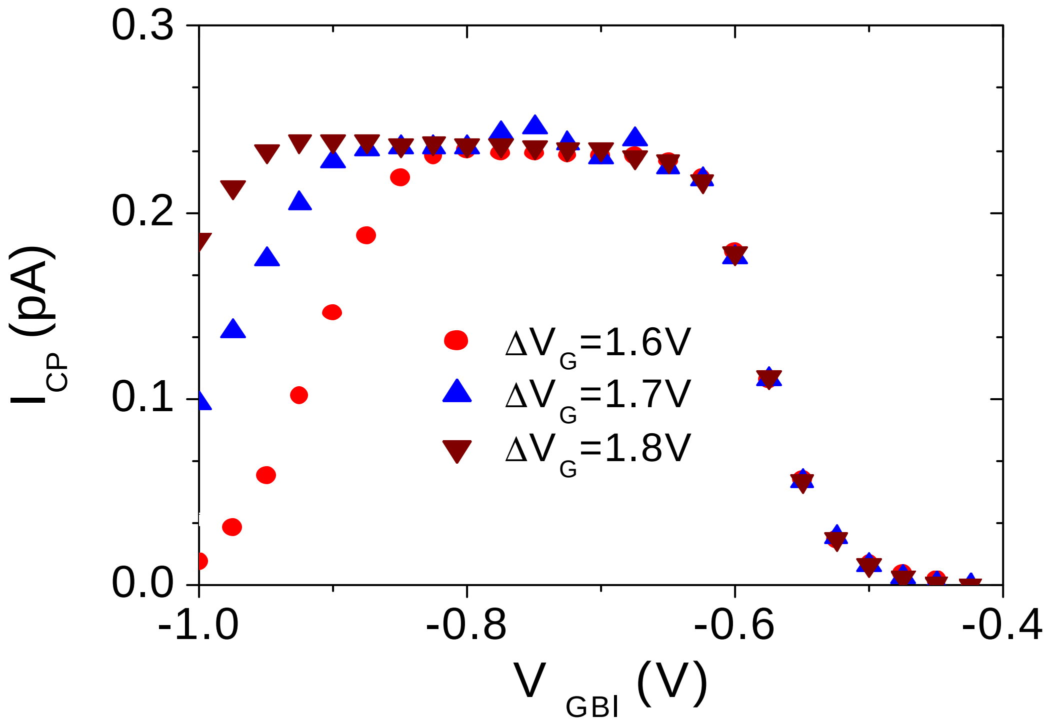
➢ Can be varied by changing
- the gate signal shape
- the temperature

Experimental results (T=298K)

❑ Single trap detection

➢MOSFET's characteristics :

- $t_{ox=}$ 2.3nm
- E-beam photolithography
- W/L= 0.25µm/0.05µm.
- n type



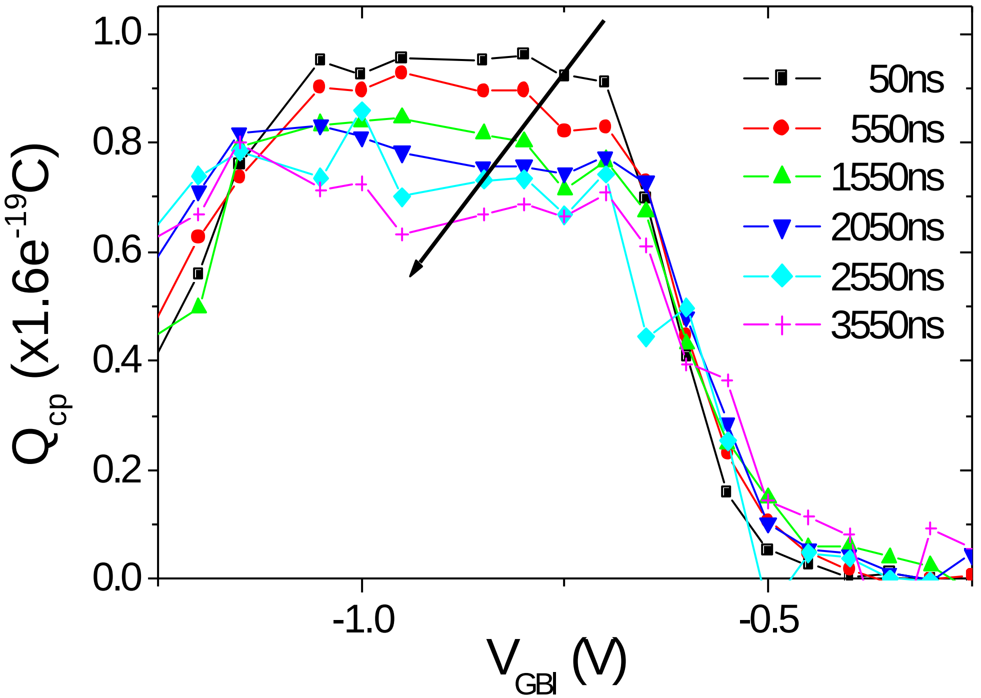
F=1.5MHz

$I_{cp\ max}$ = qxF

Experimental results (T=298K)

❑ Trap response vs. rise time

➢ The rise time influences the amplitude of I_{CP} : t_{rise} ↗ ➡ I_{CP} ↘



➢CP current affected by the accumulation/inversion transition time :

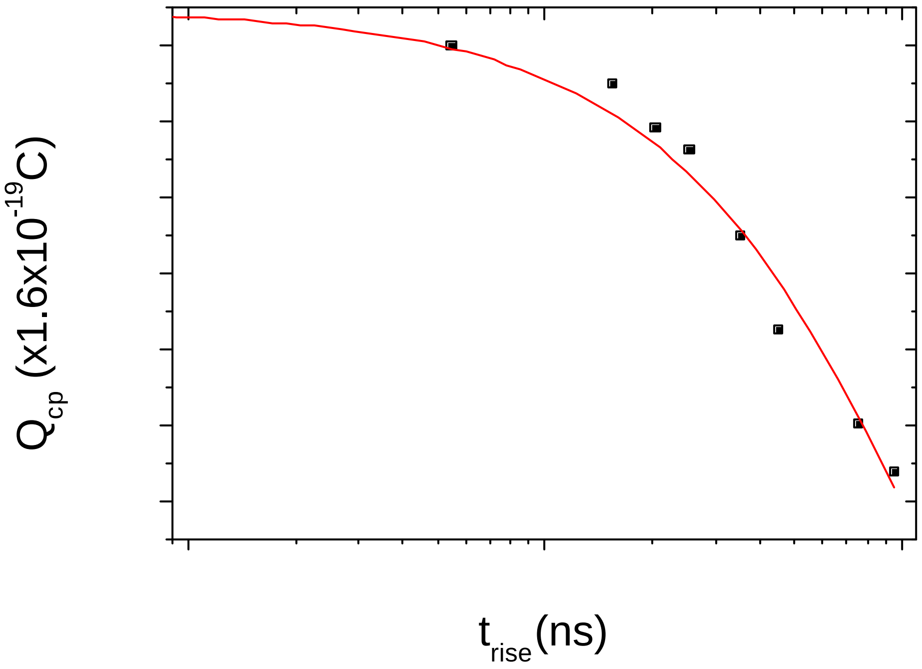
$$t_e = \frac{V_{Th} - V_{FB}}{\Delta V_G} t_{rise} = t_{rise}$$

Interpretation (T=298K)

❑ Trap response vs. rise time

Accumulation – inversion : trap filled by hole emission / electron capture

Inversion – accumulation : trap emptied by electron emission / hole capture



$$Q_{cp} = qe^{-t_{rise}/\tau}$$

$\tau \sim 12\mu s$

➢ Trap located in the lower part of the silicon bandgap : hole emission induces a reduction of I_{CPmax}

Interpretation (T=298K)

❑Shockley-Read-Hall Statistics

$$t = \frac{1}{s_p v_{th} n_i \exp\left(\frac{E_t - E_i}{kT}\right)}$$

- At a constant temperature: t =function (s_p, $\mathbf{E_t}$)

- Solutions

  1/ 3CP measurements at constant temperature

  - determination of E_t

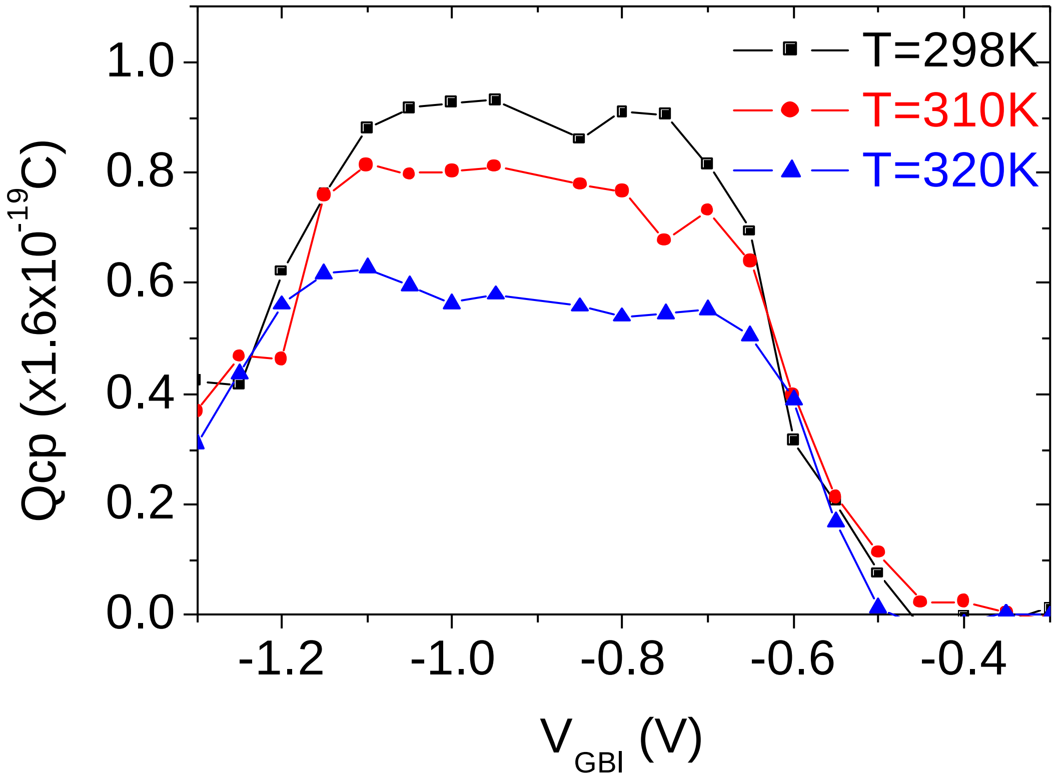
  (L.Militaru et al, IEEE EDL 2002, 23, p.94)

  2/ 2CP measurements at several temperatures

  - evolution of τ as a function of the temperature

Experimental results (T variable)

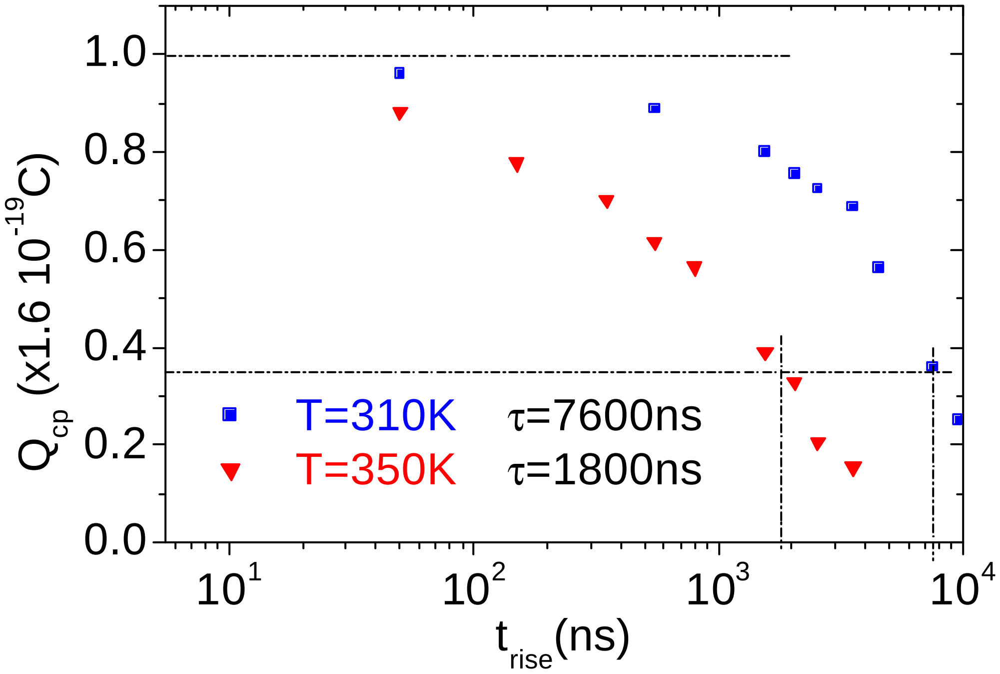
❑ Trap response vs. temperature



➢ Variation of the amplitude of charge pumping current : T ↗ ➡ I_{CP} ↘

Experimental results (T variable)

❑ Determination of the emission time constant



T(K)	298	310	320	330	340	350	360	370	380
t(μs)	12	7.6	4.8	3.1	2.3	1.8	1.3	0.7	0.3

Interpretation

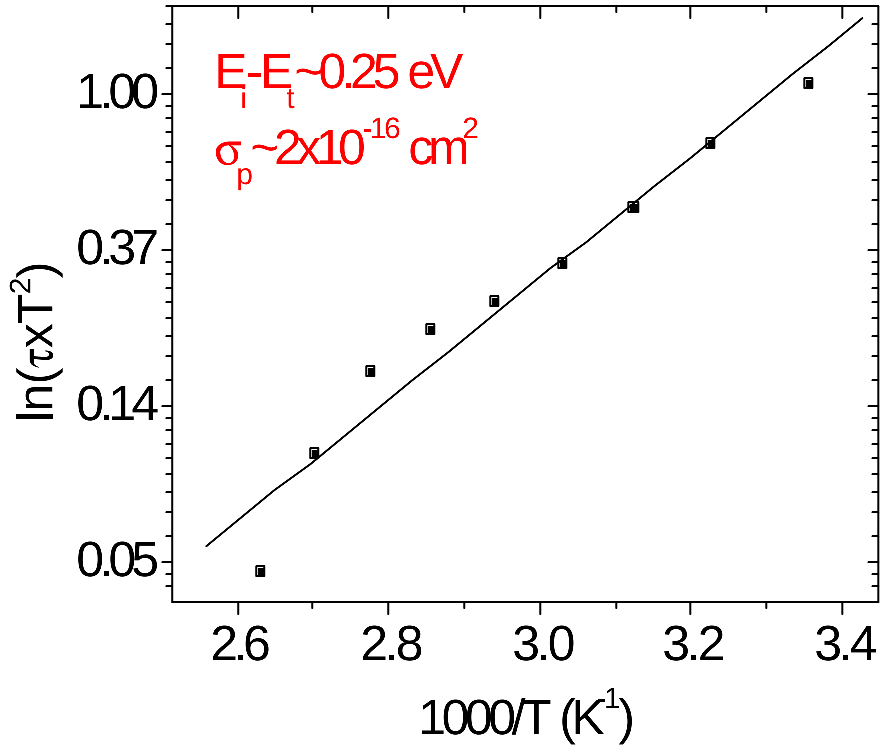
❑ Trap signature

$$t = \frac{1}{s_p v_{th} n_i \exp\left(\frac{E_t - E_i}{kT}\right)}$$

$$v_{th} \sim T^{1/2}$$

$$n_i \sim T^{3/2}$$

Activation energy of n_i = 0.56eV



➢ Literature : *P_{b0}* donor center

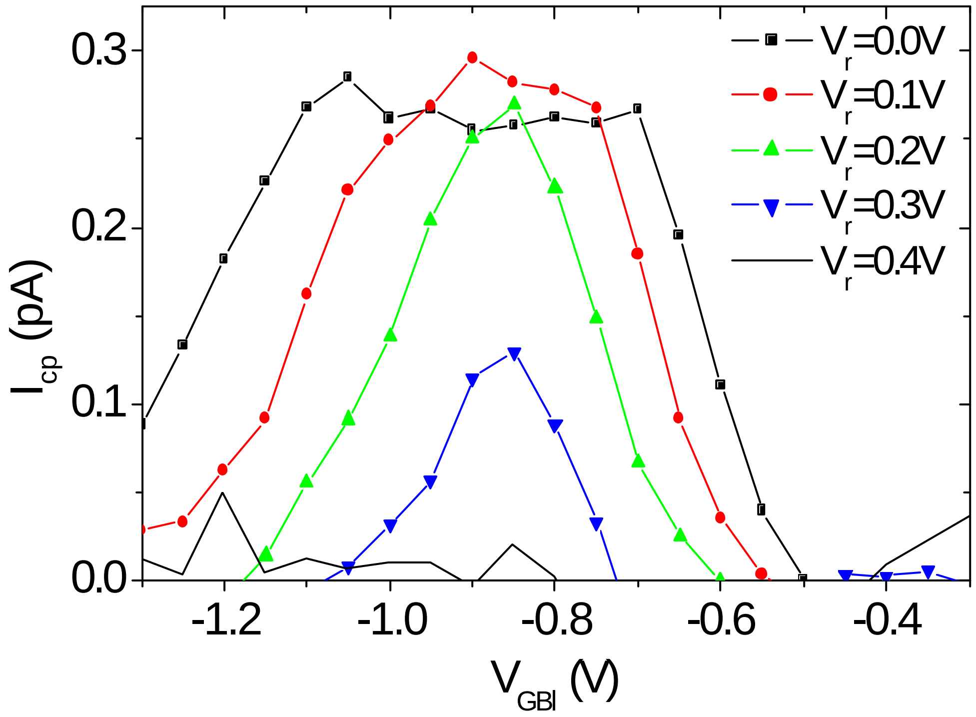
E_t~E_v+0.31eV

σ_p~10^{16} cm^2

Experimental results (T=298K)

❑ Trap position along the channel

➢ Trap activity extinction if V_r>0.4V



➢ Trap located close to the S/D regions

Conclusions

- Confirmation of the validity of the SRH statistics for a single trap

- Type of trap (donor or acceptor)

- Measurement of the time constant (τ) related to the hole emission from the trap, as a function of the temperature

- Trap characteristics (2CP)
    - Energy position within the Si bandgap
    - Capture cross section for holes
    - Localization of the trap position along the transistor channel (V_r)