Simulation study of ballistic spin-MOSFET devices with ferromagnetic channels based on Heusler and oxide compounds

Patrizio Graziosi [a] and Neophytos Neophytou [b]
[a] CNR – ISMN, Istituto per lo Studio dei Materiali Nanostrutturati, v. Gobetti 101, 40129, Bologna, Italy, patrizio.graziosi@gmail.com;
[b] School of Engineering, University of Warwick, Coventry CV4 7AL, United Kingdom.

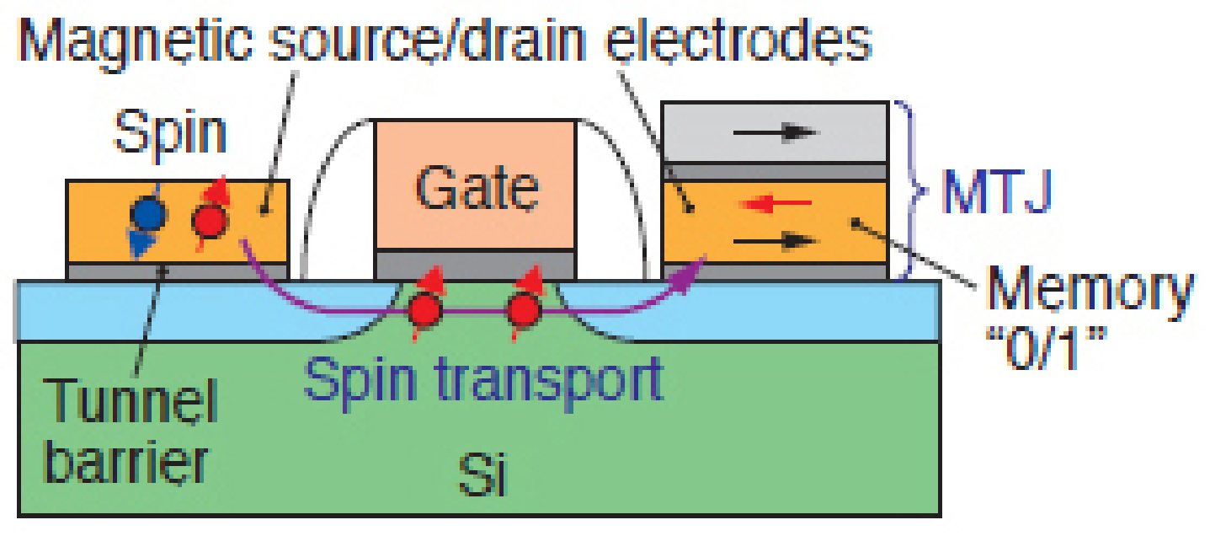
Newly emerged materials from the family of Heuslers and complex oxides exhibit finite bandgaps and ferromagnetic behavior with Curie temperatures much higher than even room temperature. Using the semiclassical top-of-the-barrier FET model, we explore the operation of a spin-MOSFET that utilizes such ferromagnetic semiconductors as channel materials, in addition to ferromagnetic source/drain contacts.

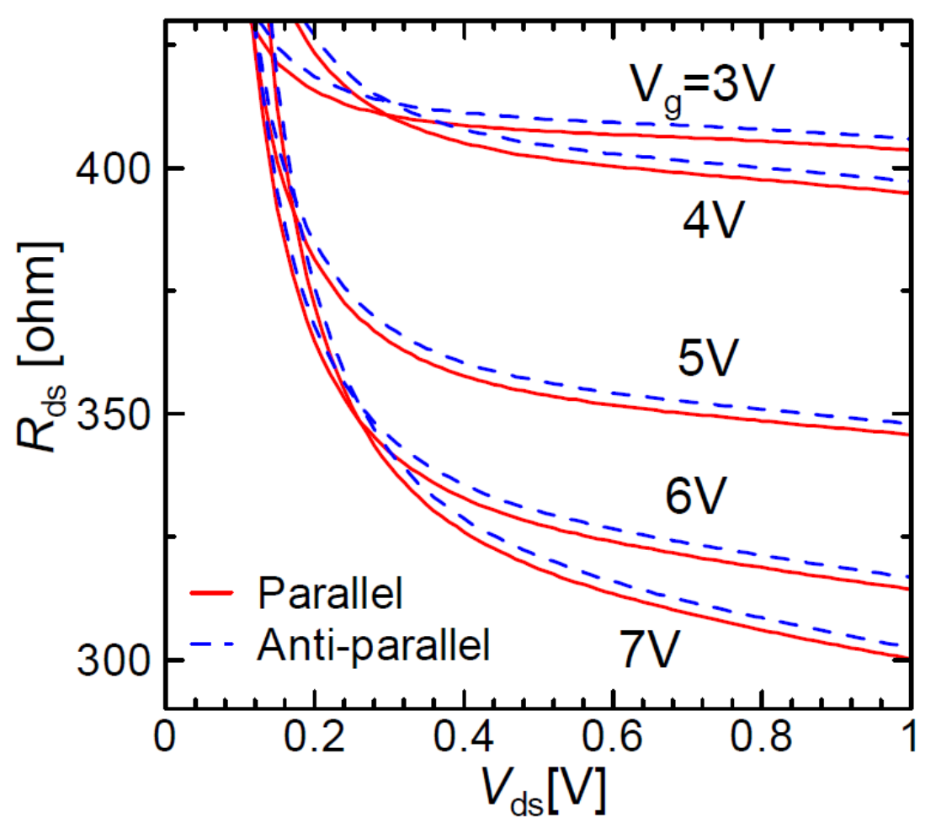
Such a device could retain the spin polarization of injected electrons in the channel, the loss of which limits the operation of traditional spin transistors with non-ferromagnetic channels.

Although the investigated compounds are Mn_2CoAl, CrVZrAl, CoVZrAl, and $NiFe_2O_4$, we expect that the insight we provide is relevant to other classes of such materials as well. **Ref.** *P. Graziosi and N. Neophytou*, J. Appl. Phys. **123**, 084503 (2018).

Toshiba's spin MOSFET

Sufficient operation only at low T
Possible loss of Spin Polarization in the Si channel



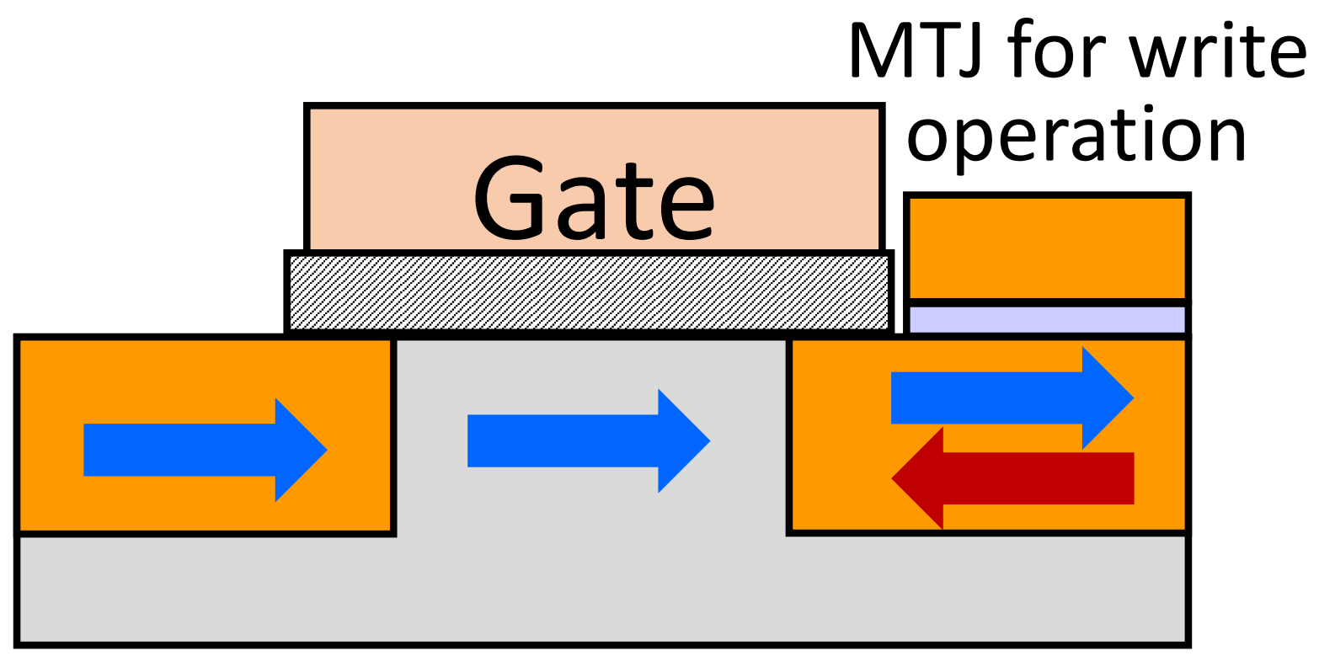


www.toshiba.co.jp/rdc/rd/fields/10_e08_e.htm

- *2009 IEEE International Electron Devices Meeting (IEDM)* (2009), pp. 1–4
- J. Electrochem. Soc. **158**, H1068 (2011)

Our Proposal
spin-MOSFET with ferromagnetic channel

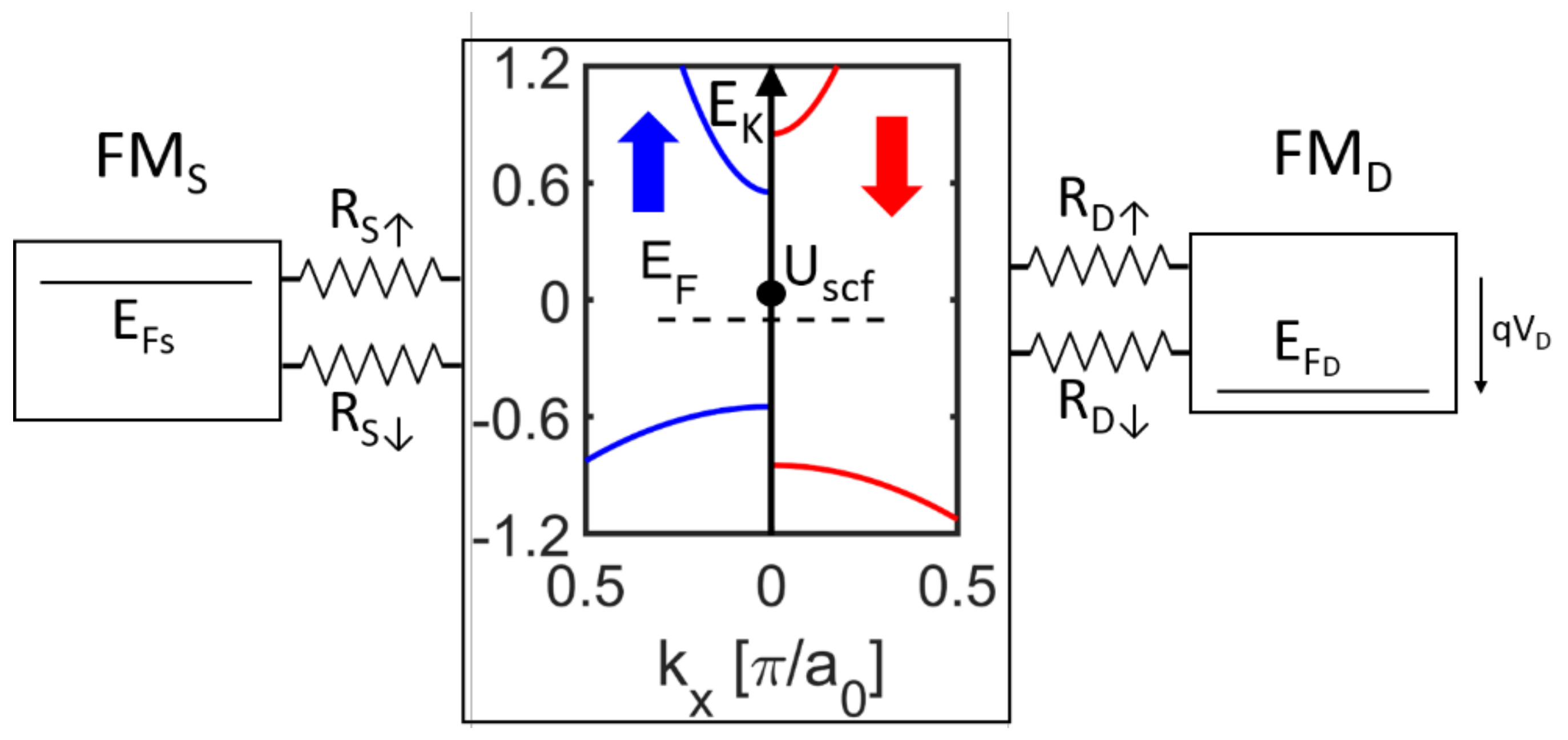
Ferromagnetic semiconductor channel to retain the Spin Polarization of the injected current



P. Graziosi and N. Neophytou, J. Appl. Phys. **123**, 084503 (2018).

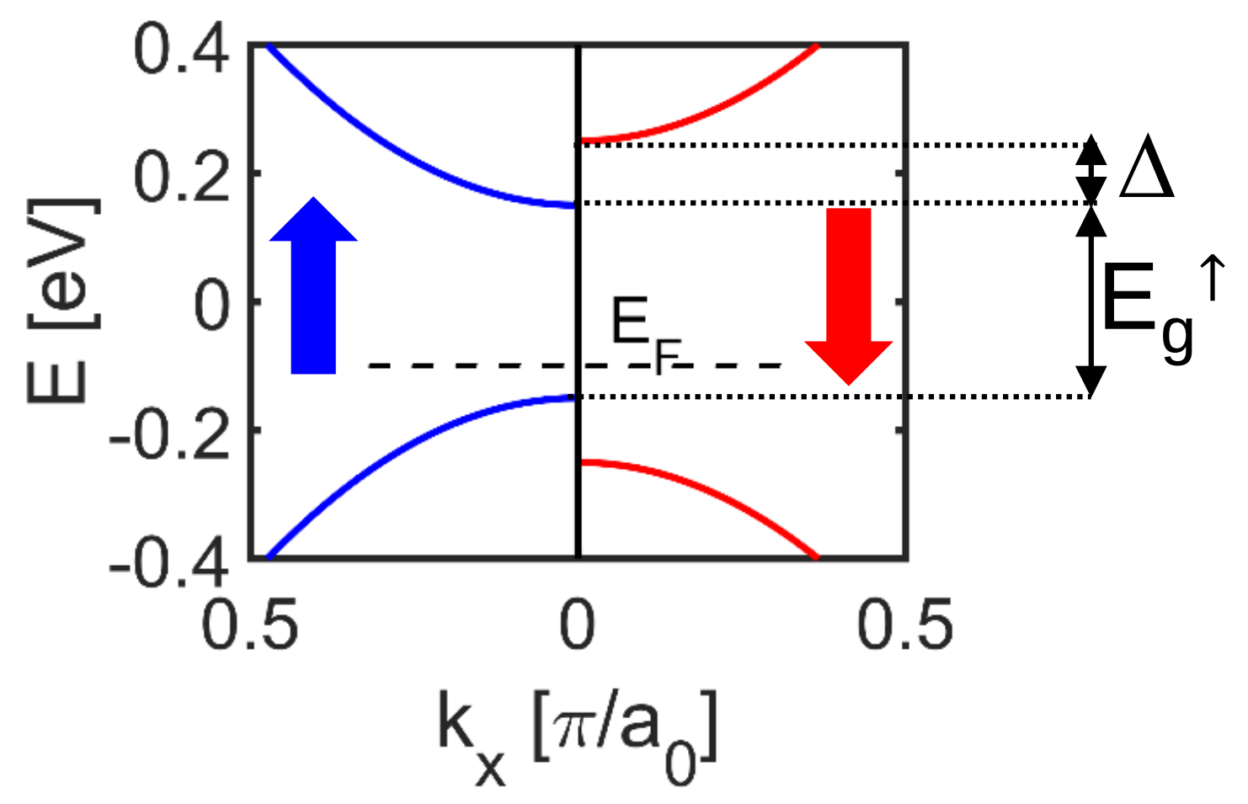
A somewhat similar Schottky Barrier MOSFET has been proposed in 2005 (*JAP* ***97**, 10D503*) but here we consider Ohmic contacts and parameters from real material band structures.

The Model
Ballistic MOSFET with spin dependent contact resistances



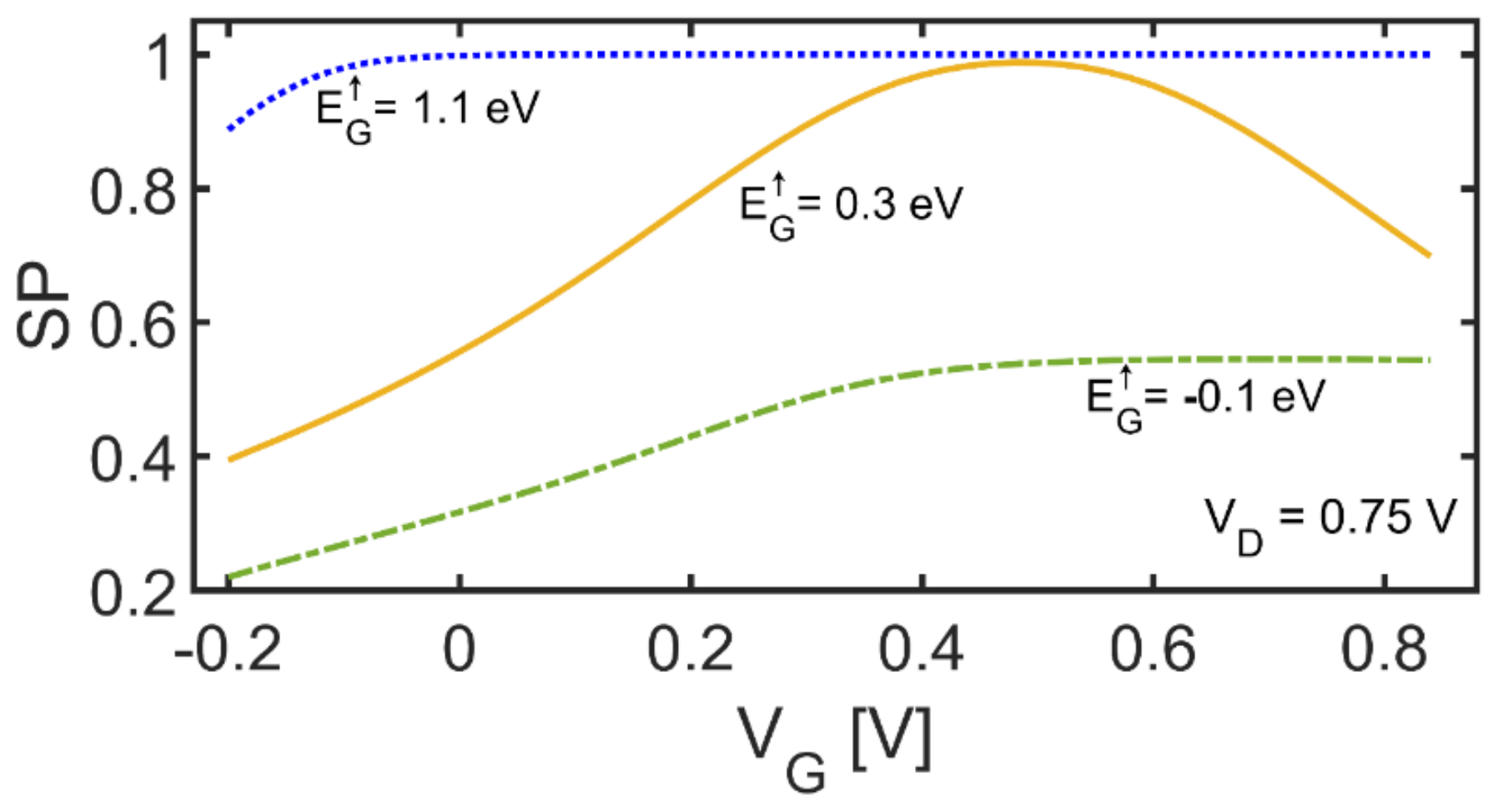
- $R_\downarrow/R_\uparrow$ = 2.5 or 10 , symmetric device
- $R_{S\uparrow}$ ~ $10^5\,\Omega$, extending the model in *PRB 48, 7099 (1993)*
- Series resistances added in a post-processing step using a bi-dimensional linear interpolation scheme

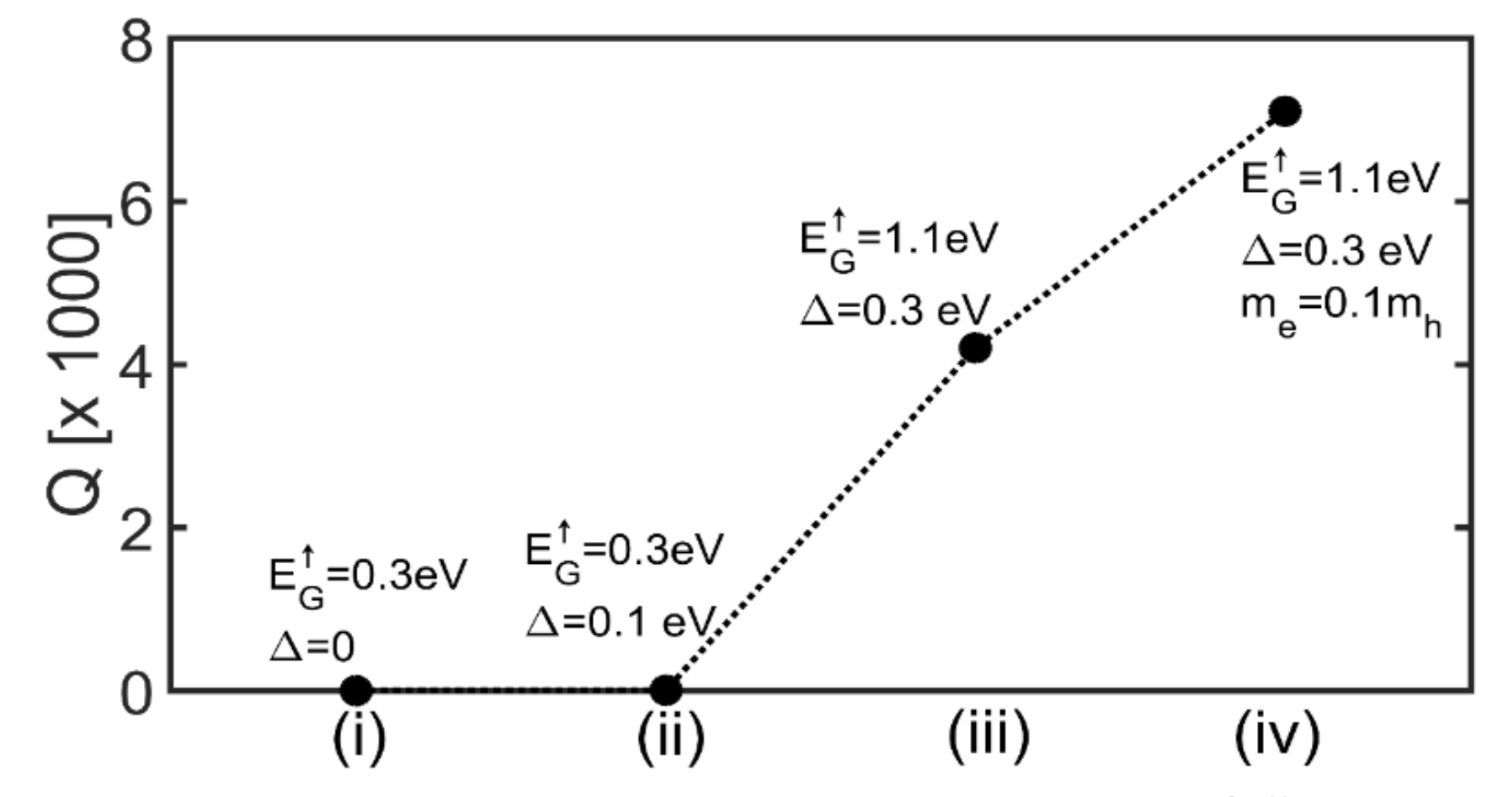
Generic band structure



Parameters are chosen to be close to the typical DFT band structures of ferromagnetic semiconducting Heulser (Mn_2CoAl, CrVZrAl, CoVZrAl …) m^{eff} = m_0 for the early evaluations, then from DFT calculations

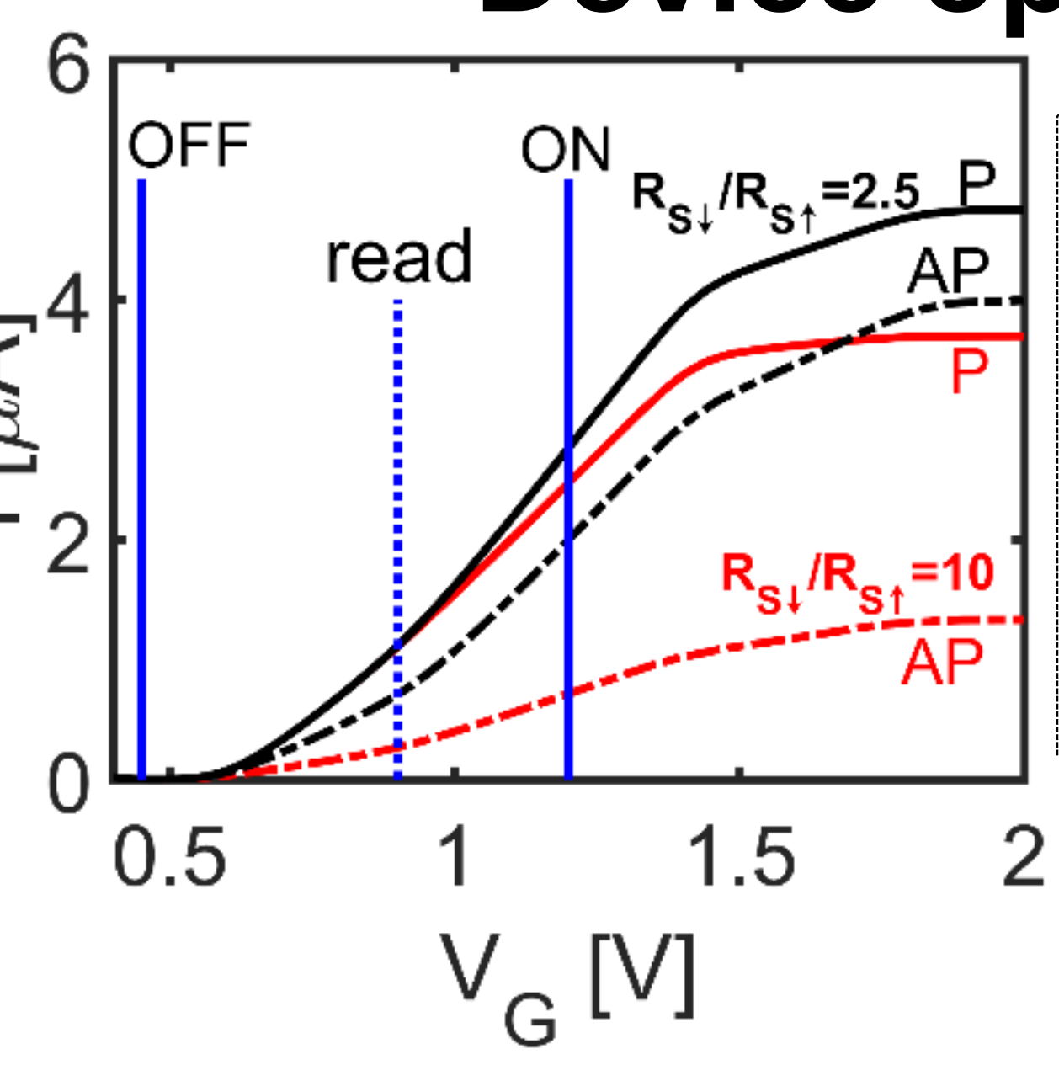
Parabolic bands





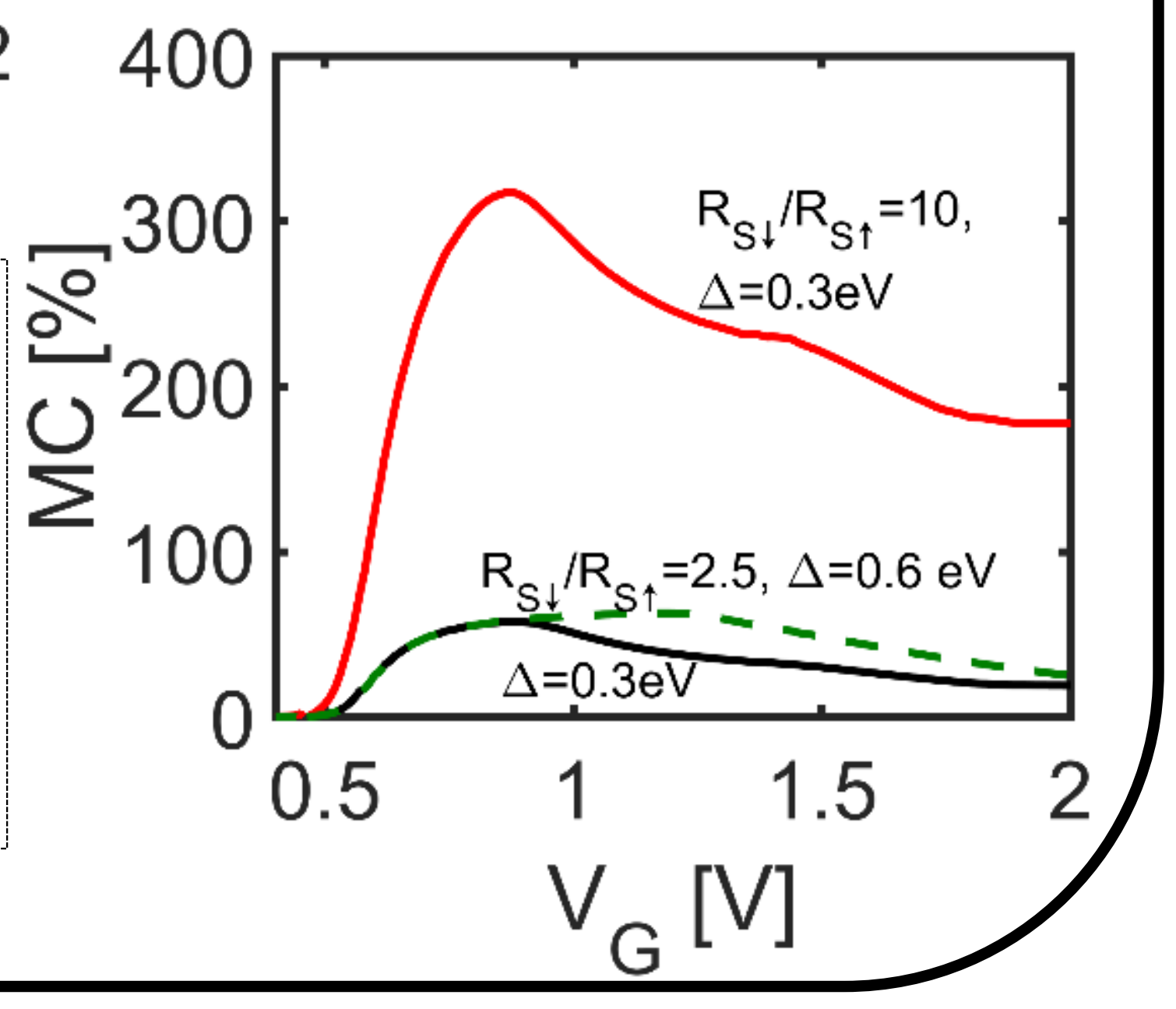
SP = (I↑-I↓)/(I↑+I↓) , Q = V^{SPmax}xV^{on/off_max}

Device operation



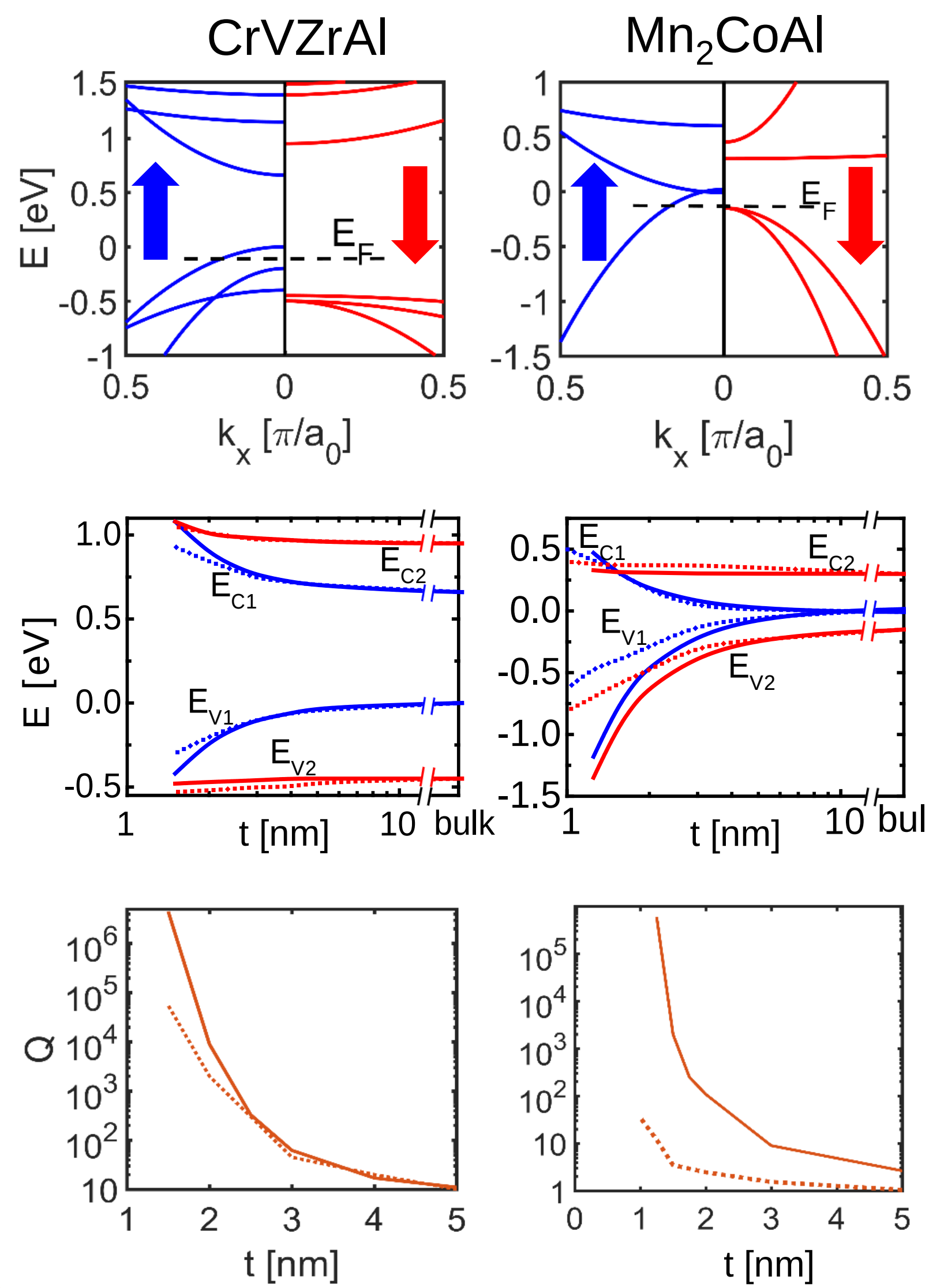
I_D-V_G at V_D = 0.75 V (ITRS target) for Δ = 0.3 eV, m_h=m_0 and m_e=0.1m_0. The vertical solid blue lines show V_G^{off} and V_G^{on} for which high I_{ON}/I_{OFF} ratio is achived for a bias window $V_G = V_D$ = 0.75 V for both orientations (I_{ON}/I_{OFF} is ~10^4 in all the cases.

The vertical dotted blue line represents the "read" gate bias V_G^{read} for memory operation. The magnetoconductance (MC) for V_D = 0.75 V for three device parameter combinations as indicated, which shows separately the effect of Δ and $R_\uparrow/R_\downarrow$ on the MC.

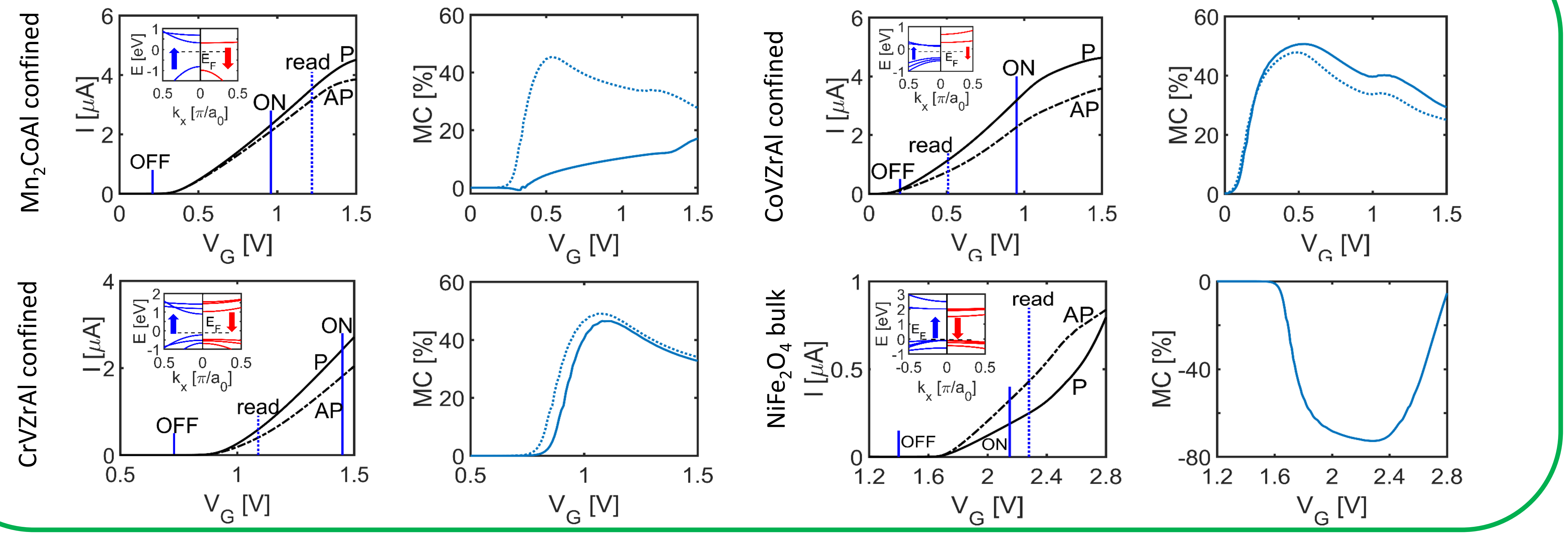


Confinement effect

dotted lines: non parabolicity effects



Real materials – bandstructures in the insets



A new spin MOSFET concept has been explored
Actual ferromagnetic Heuslers require thin layer confinement
Promising candidate for spin-MOFETS with RT operation