J. M. Teixeira

IFIMUP and IN- Institute of Nanoscience and Nanotechnology

Temperature dependent transport properties of MgO-based ultra-thin magnetic tunnel junctions: experiment and modeling

TNT2008 Trends in NanoTechnology

Oviedo (Spain)

September 01-05, 2008

Transport mechanisms in magnetic tunel junctions

Acknowledgments

J. Ventura, J. P. Araújo and J. B. Sousa

IFIMUP and IN- Porto

P. Wisniowski and P. P. Freitas

INESC-MN and IN - Lisbon

FCT Fundação para a Ciência e a Tecnologia MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E ENSINO SUPERIOR

2007 CIENCIA

Ciência.Inovação 2010

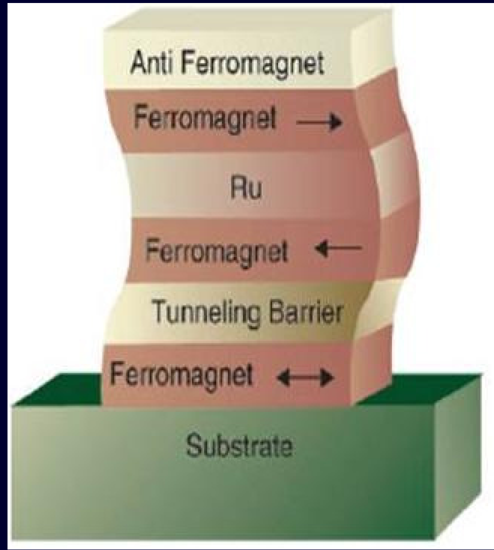
Outline

- Introduction
  - Magnetic tunnel junctions
    - Fundamental concepts and Applications
- MgO-based magnetic tunnel junctions (MTJ´s)
  - Transport characterization
  - Pinholes and the temperature dependence of the electrical resistance
  - Model of two conductance channels in parallel (metallic + tunnel)
- Conclusions

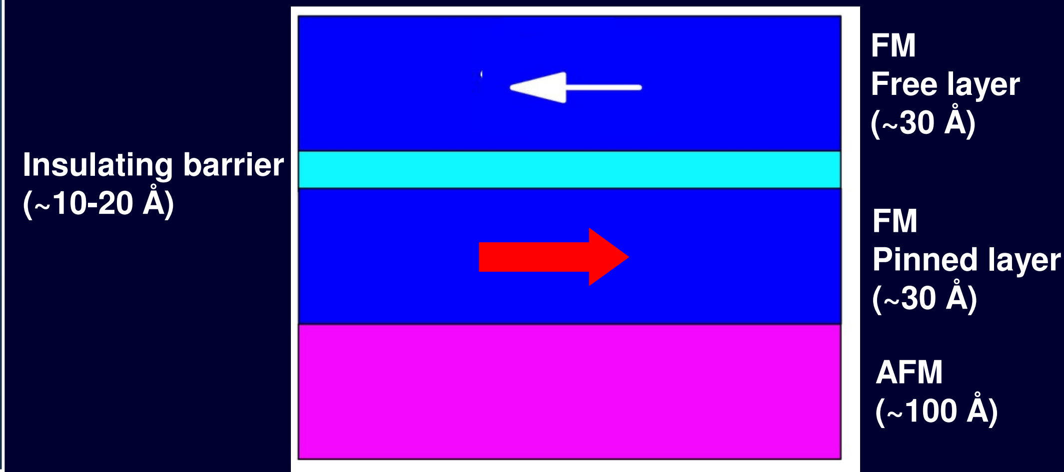
Transport mechanisms in magnetic tunel junctions

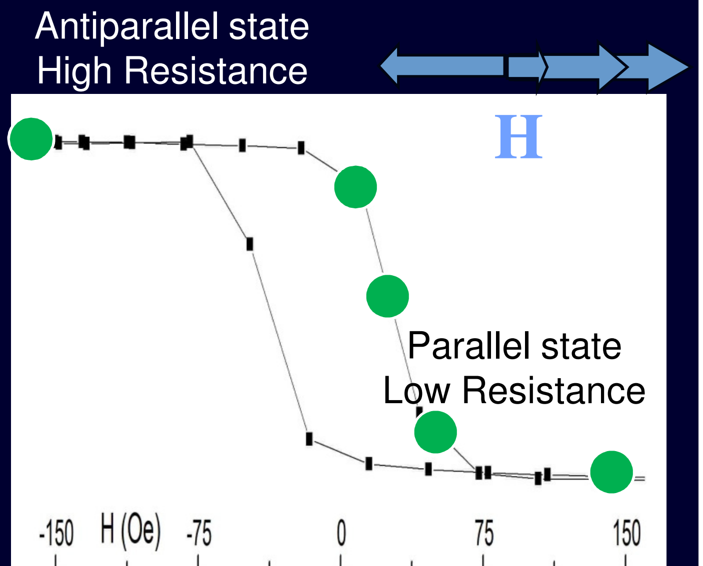
MTJ - Spintronic device

- Magnetoresistive devices
- R depends on the relative orientation of the FM layer magnetizations
- AF layer pins the magnetization of one FM layer
- The magnetization of the other FM layer rotates freely (sensing layer)

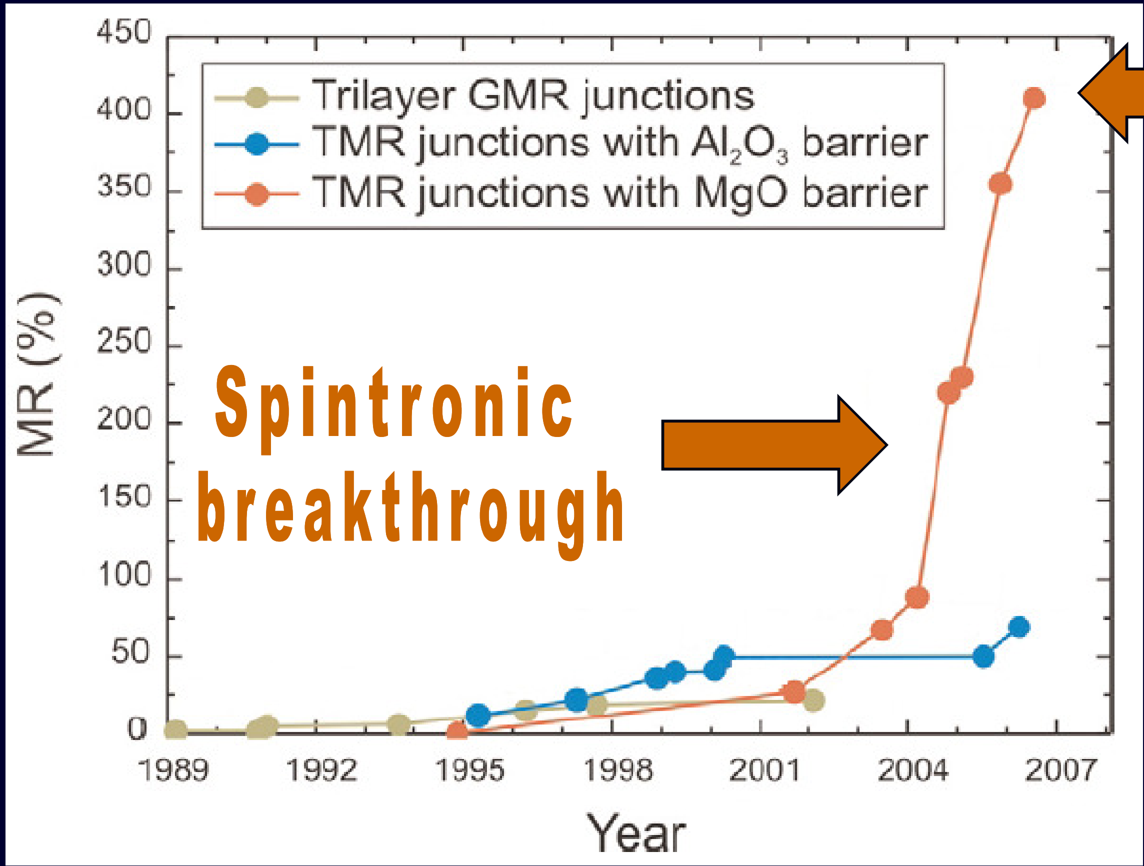


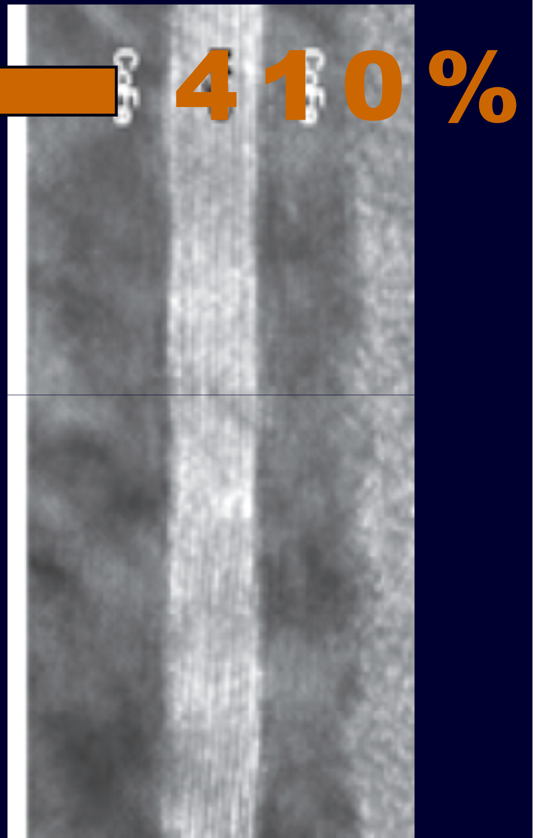
Magnetic tunnel junction (MTJ):





MR ratio evolution at 300 K



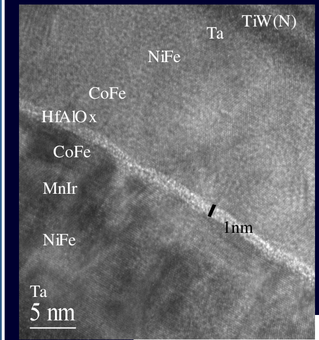


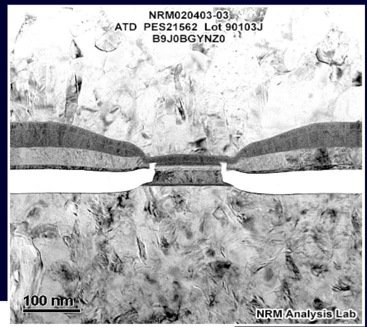
Christian Heiliger, Peter Zahn, and Ingrid Mertig, Materials today **9**, 46 (2006)

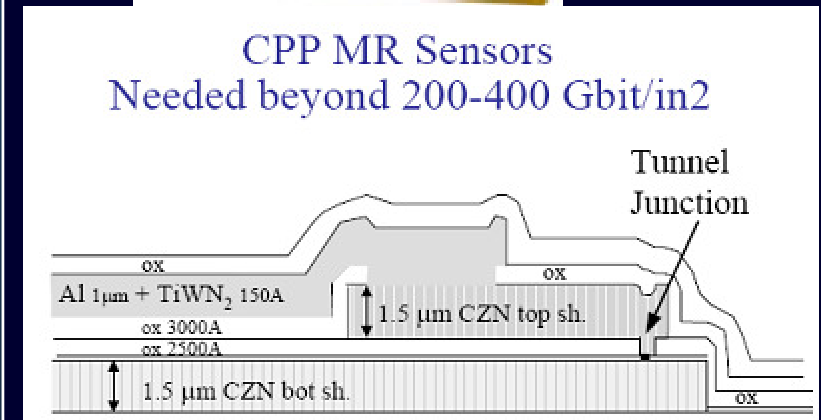
Coherent tunneling

Transport mechanisms in magnetic tunel junctions

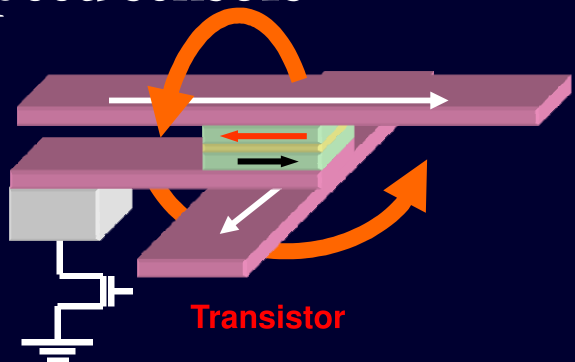
Nano-Electronics and Information Technologies





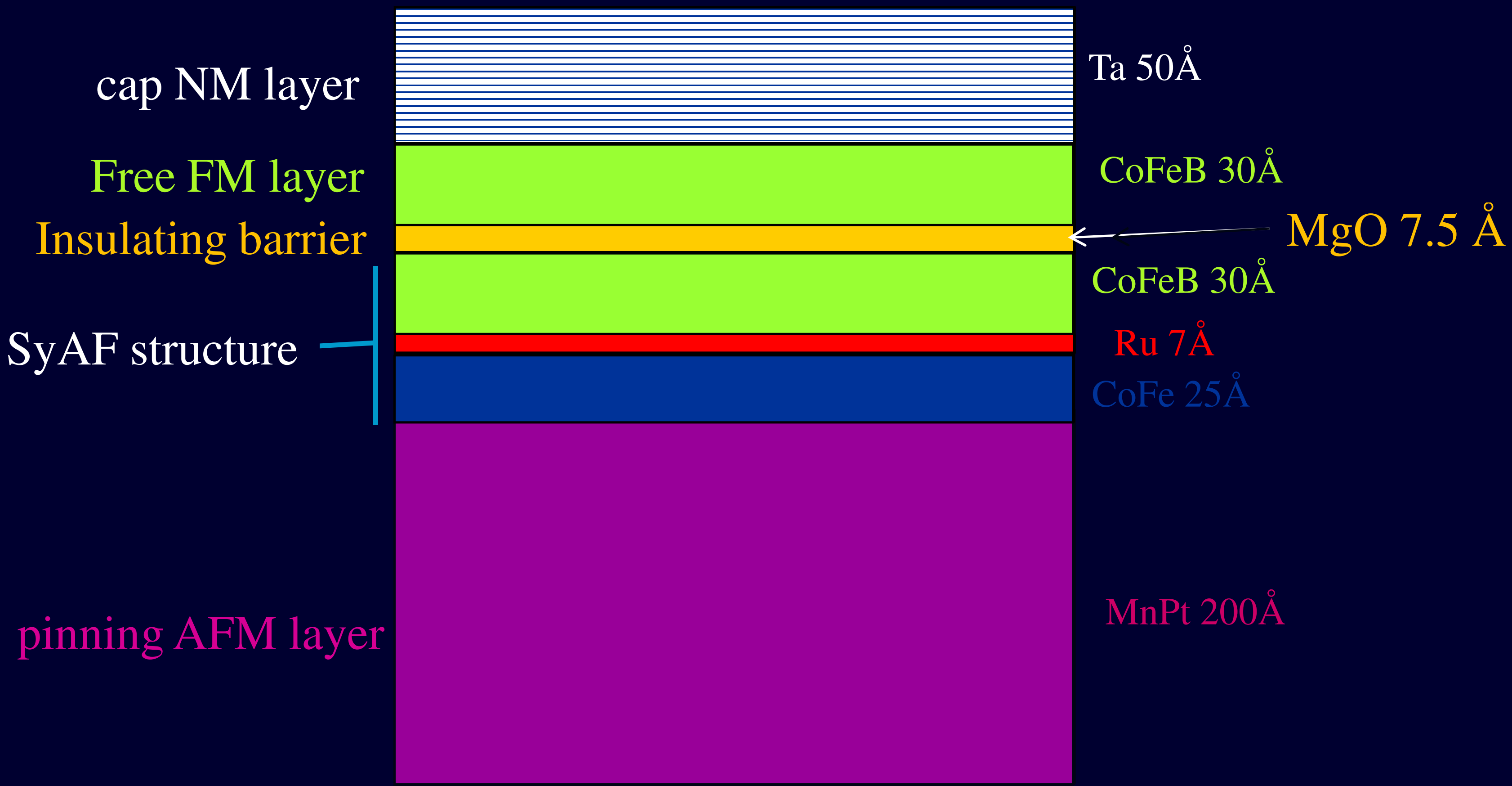


- **High density magnetic data storage systems**
  - MTJ read heads for 1 Tbit/in^2
    - Reasonable TMR (~20%)
    - Low RxA (~ 1 Ωμm^2)
    - Ultra-thin MTJs (5-8 Å)
- **Magnetic memories**
  - Spin transfer MRAMs
- **Sensor applications**
  - Strain, Current, Position and Speed sensors



MgO-tunnel junctions

Deposited by magnetron sputtering



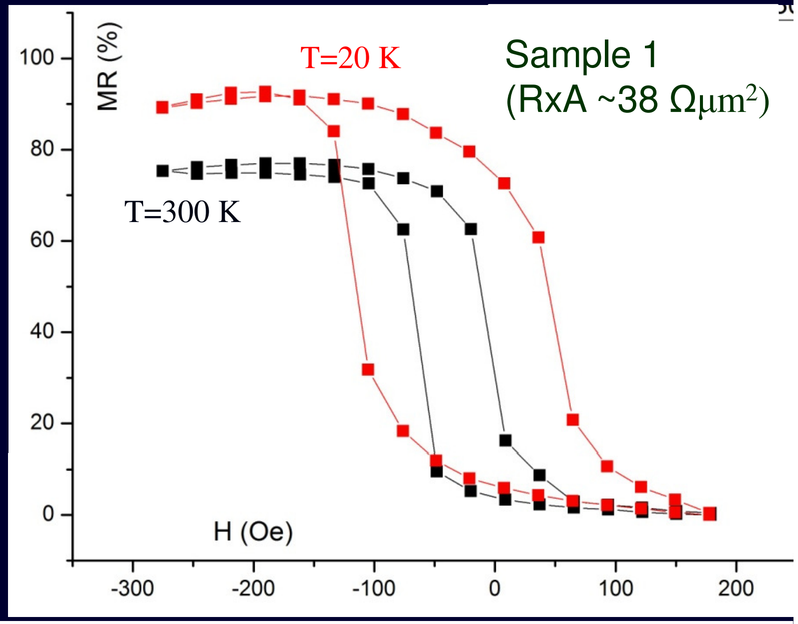
Transport properties (t_{MgO}= 7.5 Å)

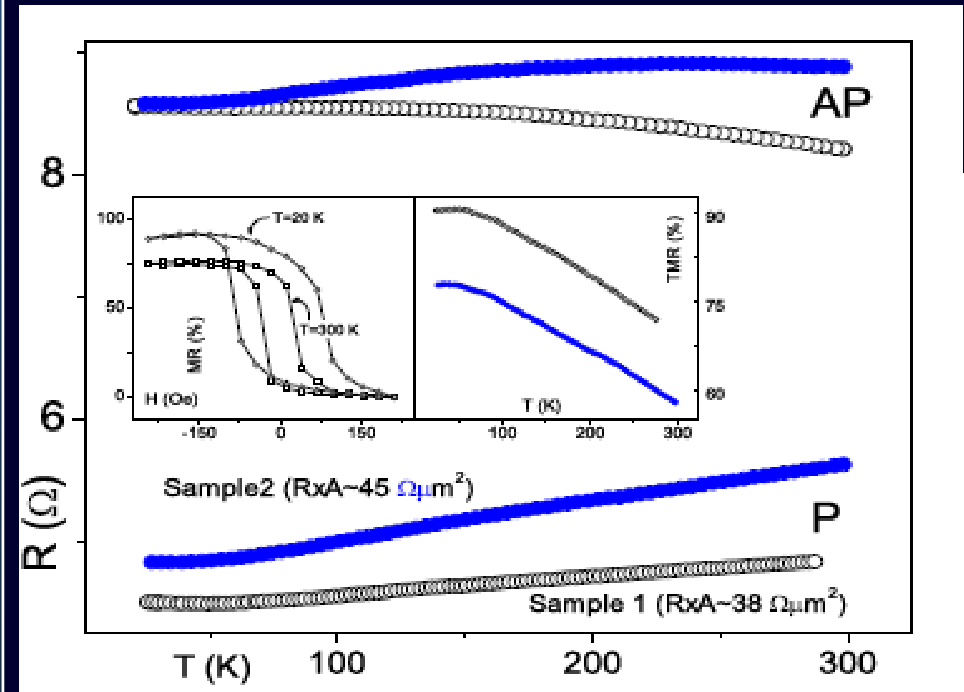
- For the P state, R(T) clearly exhibits the standard metallic behavior.
- For the AP state, we observe a mixed character, with a crossover from negative to positive dR/dT with increasing temperature.
- This indicates a competition between conductance channels (metallic and tunnel).

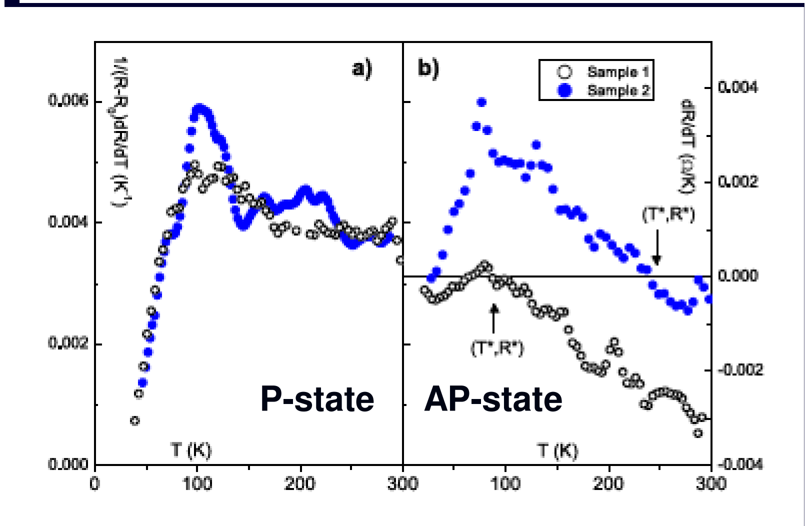
TMR (300 K) ~70-100%

RxA~40 Ωμm²

J. Ventura, J. M. Teixeira, J. P. Araújo, J. B. Sousa, P. Wisniowski and P. P. Freitas, *J. Appl. Phys.* **103**, 07A909 (2008)







R(T) Modeling

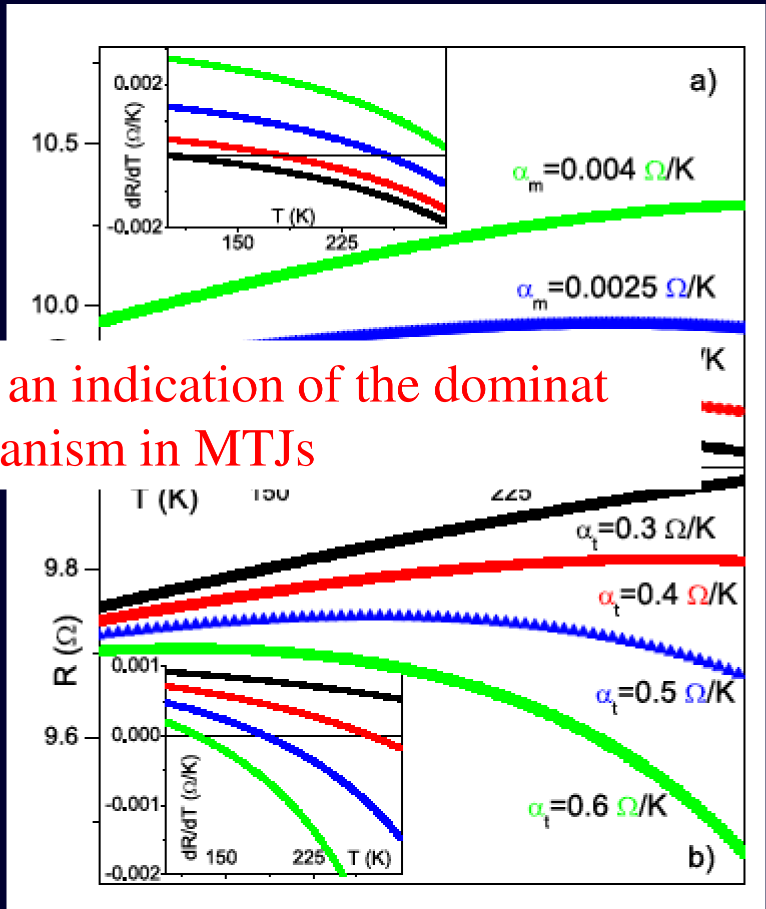
- Two conductance channels in parallel (metallic and tunnel)
- Assumed a linear temperature variation of R with coefficients α_m and α_t

The sign of dR/dT does not give an indication of the dominat transport mechanism in MTJs

$$R_m(T) = R_{m_0} + \alpha_m T$$

$$R_t(T) = R_{t_0} - \alpha_t T$$

- A crossover from positive to negative dR/dT can be modeled
- Changing the model parameters leads to changes in the crossover temperature
- Tunnel-like behavior can be observed even for $R_t > R_m$
- Increasing α_m (α_t) increases (decreases) the crossover temperature



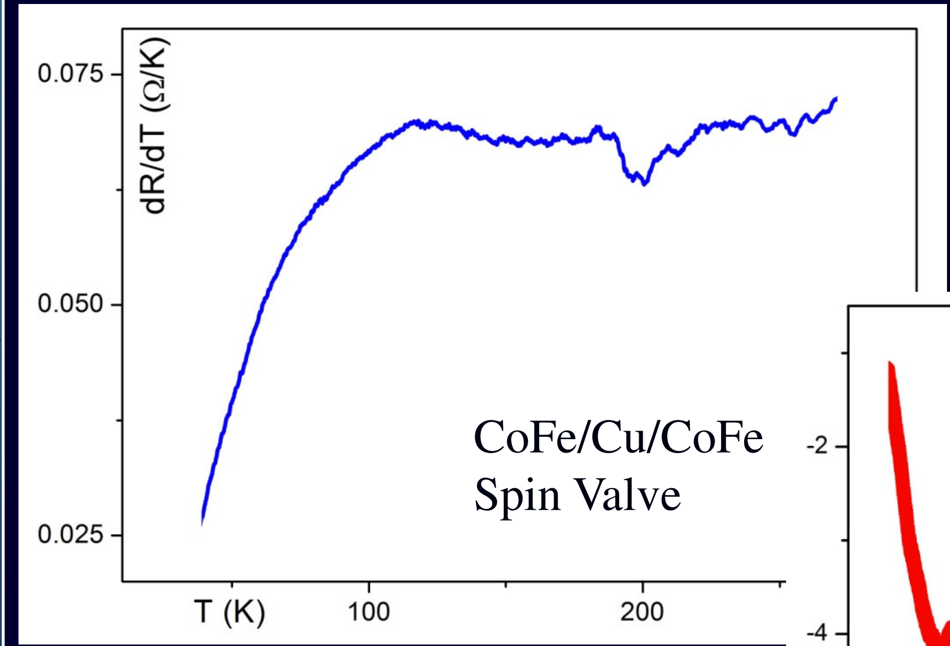
J. Ventura, J. M. Teixeira, J. P. Araújo, J. B. Sousa, P. Wisniowski and P. P. Freitas, *Phys. Rev. B* **78**, 024403 (2008)

Transport mechanisms in magnetic tunel junctions

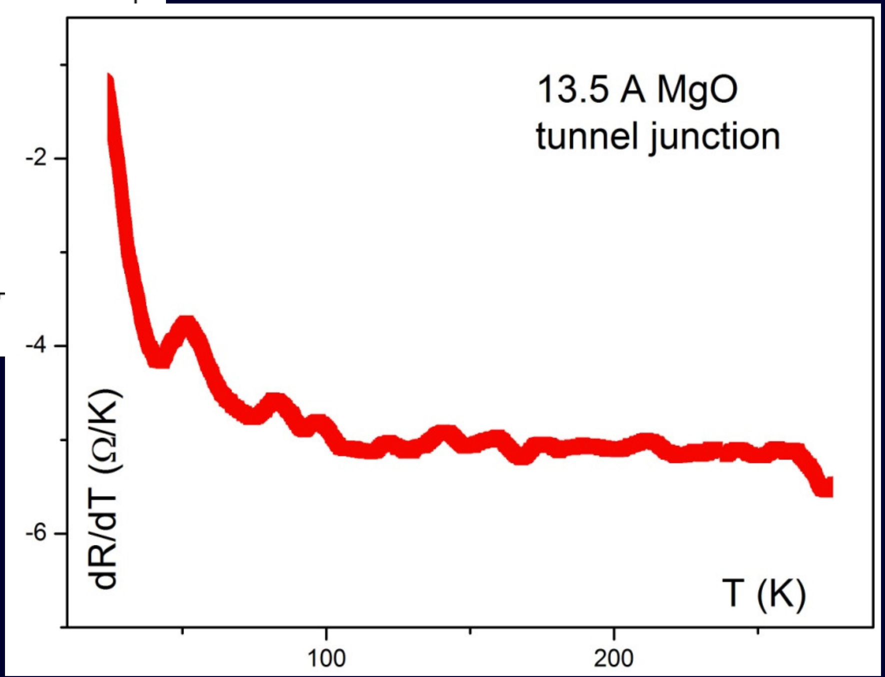
Transport mechanisms in magnetic tunel junctions

R(T) Modeling

Justification for the linear R(T) dependencies



A linear R(T) relation is usual for common metals (at least near RT) . It is indeed observed in CoFe/Cu/CoFe spin valves for *T > 100 K.*



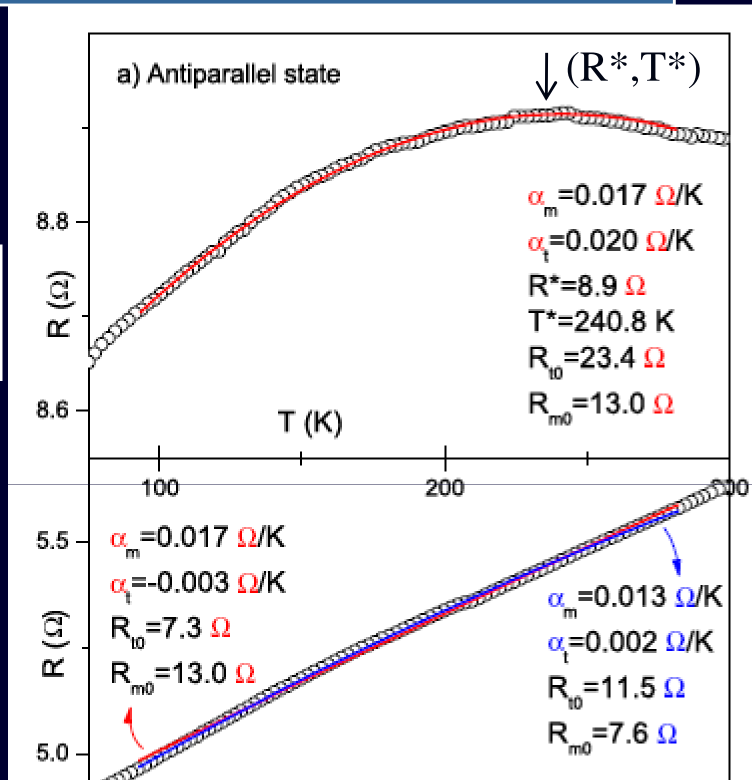
The thermal dependence of the tunnel resistance has several origins. However a fairly linear relation is experimentally observed in thick MgO-MTJs over a broad T-range.

Fitting results

- For the AP state, one can have two fitting procedures:
- For the P state (showing a crossover from negative to positive dR/dT) one has only two independent parameters:
  - Equal metallic parameters for P and AP states
  - Tunneling dR/dT>0 for the P state
  - Very large TMR (~200%)

$$R(T) = R^* - \frac{\sqrt{(\alpha_m \alpha_t)^3}\,(T-T^*)^2}{R^*\left(\sqrt{\alpha_m}+\sqrt{\alpha_t}\right)^2 + (\alpha_m-\alpha_t)\sqrt{\alpha_m \alpha_t}\,(T-T^*)}$$

- Different metallic parameters for P and AP states
  - Four parameter fitting
  - Tunneling dR/dT<0 for the P state
  - Large GMR (~60%)



Sample	State	$T^*(K)$	R^* (Ω)	α_m (Ω/K)	α_t (Ω/K)	MR_{t0} (%)	MR_{m0} (%)
1	AP	89.8	8.56	0.0185	0.0153	-	-
	P	-	-	0.0185	-0.001	195	0
	P	-	-	0.013	0.001	132	61
2	AP	240.8	8.9	0.017	0.020	-	-
	P	-	-	0.017	-0.003	220	0
	P	-	-	0.013	0.002	103	71

Conclusions

- Ultra-thin MTJs show mixed (tunnel and metallic-like) R(T) behaviors.
- The sign of dR/dT does not give an indication of the dominant conductance mechanism.
- The model of parallel resistances explains the observed behaviors.
- Our analysis shows that a metallic spin-dependent transport channel can occur through pinhole nanoconstrictions.