

Physics and applications of spintronics

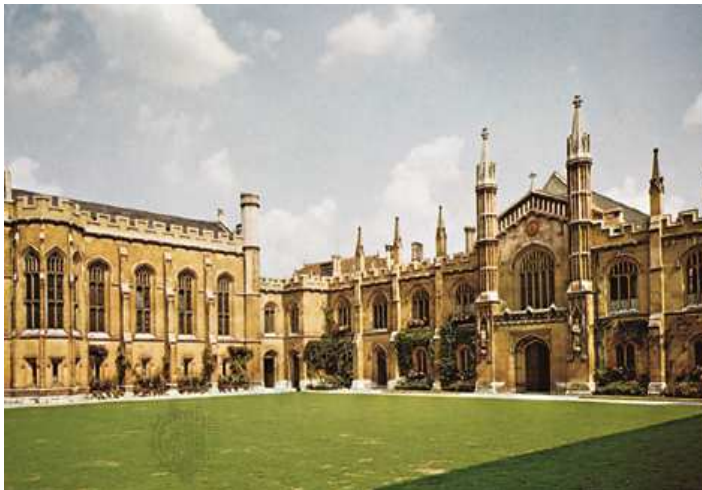
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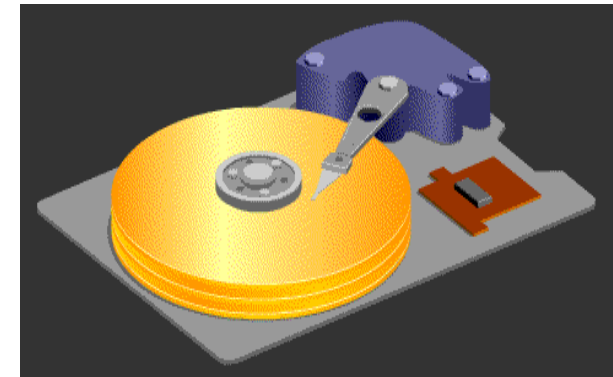
University of Cambridge & Hitachi Cambridge Lab



Spintronics explores new avenues for

- **Information reading**

GMR, TMR sensors



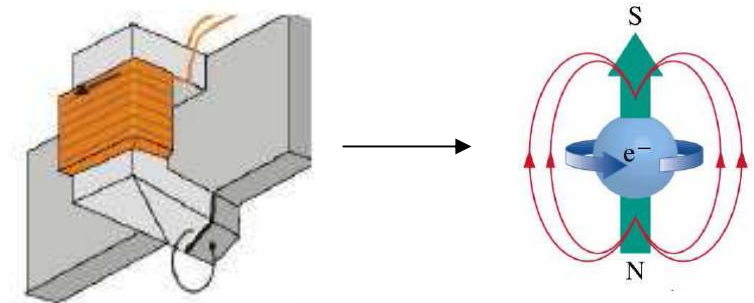
- **Information reading & storage**

MRAM chips



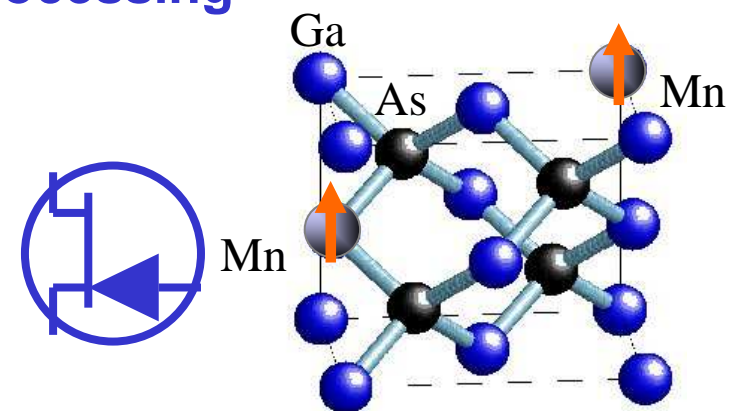
- **Information reading & storage & writing**

magnetization switching by spin-currents

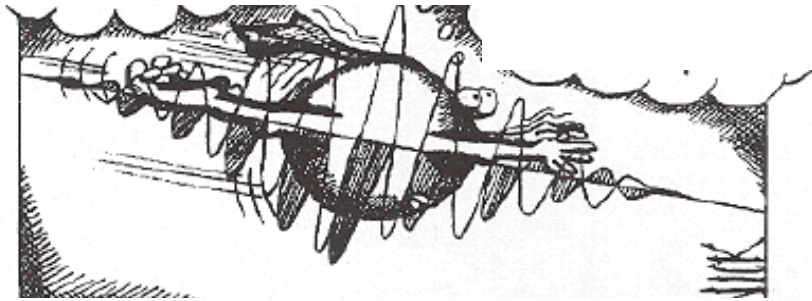


- **Information reading & storage & writing & processing**

spins & transistors & semiconductors



Spin from relativistic quantum mechanics



quantum mechanics

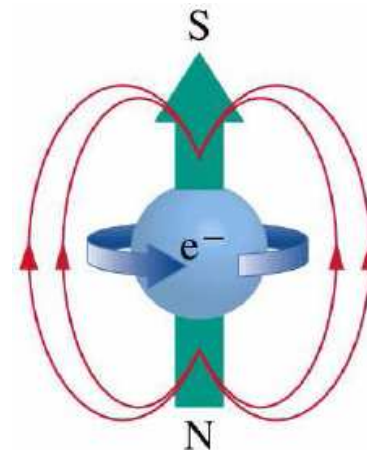
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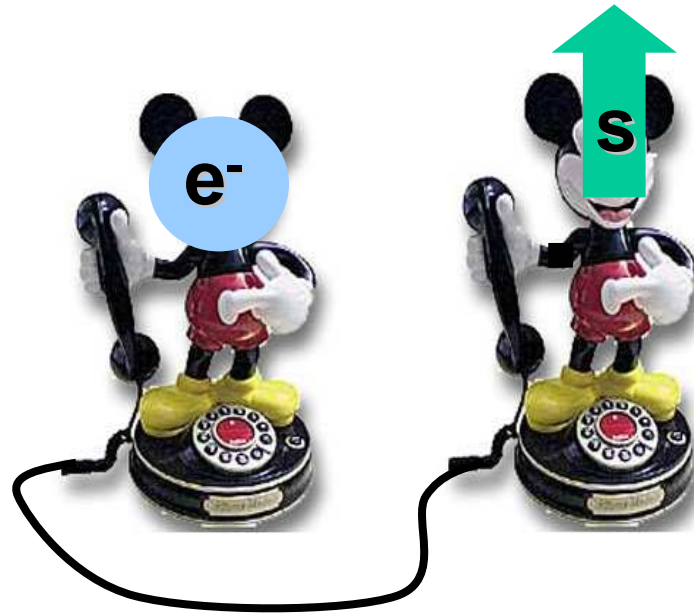
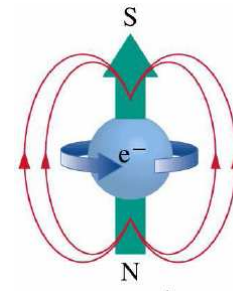
special relativity

Dirac equation → electron has charge and internal angular momentum

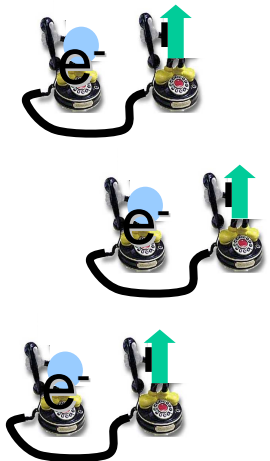
→ internal magnetic moment = spin



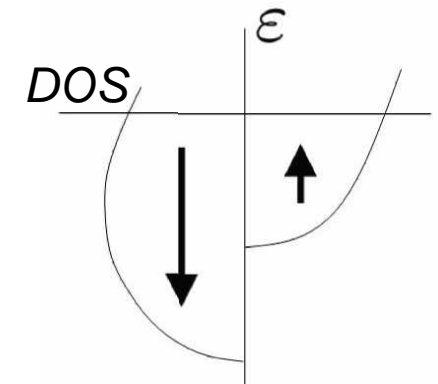
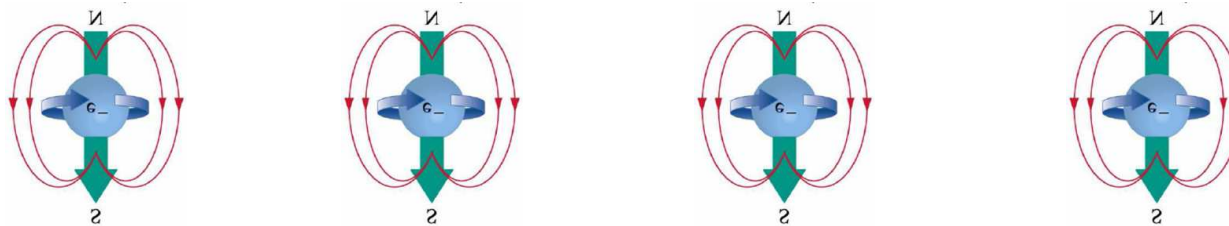
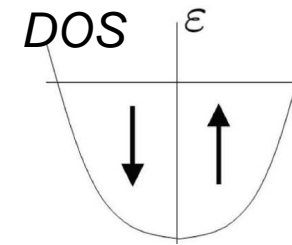
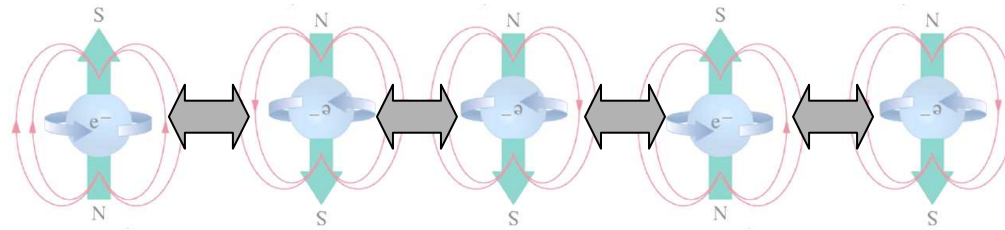
Spintronics



... it's all about spin and charge of electron communicating with each other...



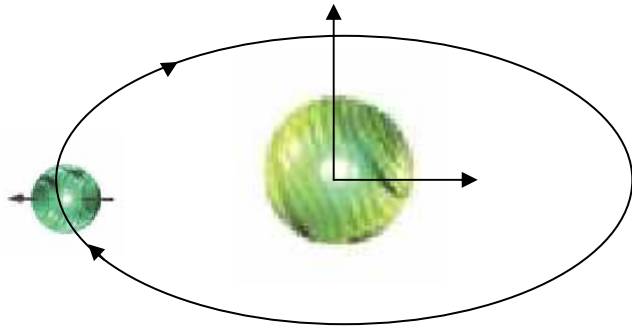
Ferromagnetism = Pauli exclusion principle & Coulomb repulsion



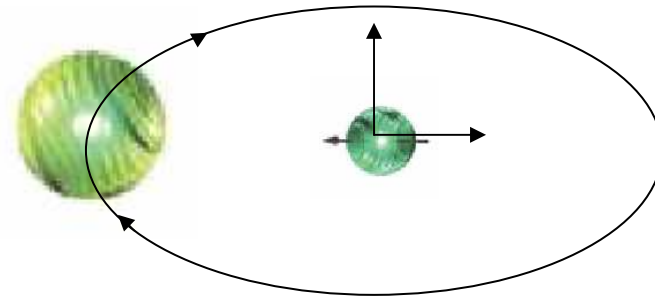
Collective spin behavior → easy to manipulate spins
 → large sensitivity (magnetic fields)

Spin-orbit coupling

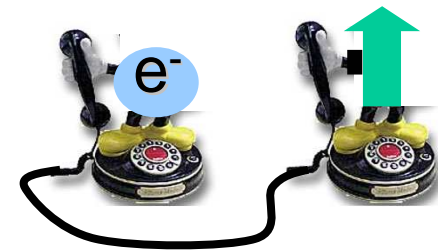
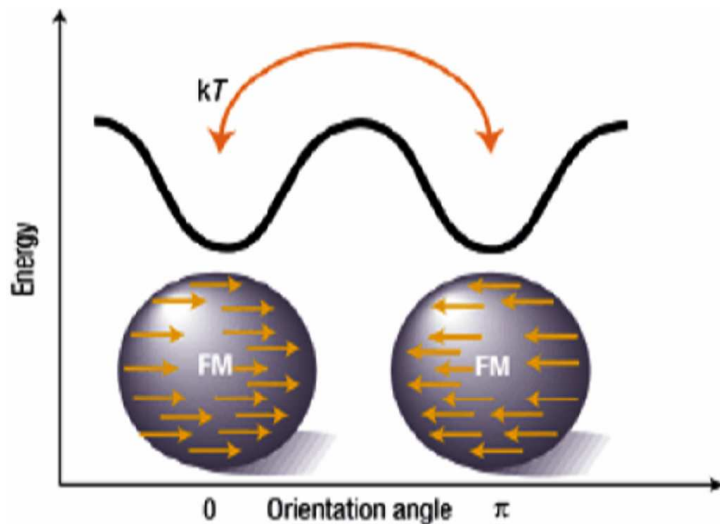
nucleus rest frame



electron rest frame



$$H_{SO} = \frac{g\mu_B}{2\hbar} \mathbf{S} \cdot \mathbf{B} = \frac{e}{2mc^2} \mathbf{S} \cdot \mathbf{v} \times \mathbf{E}$$

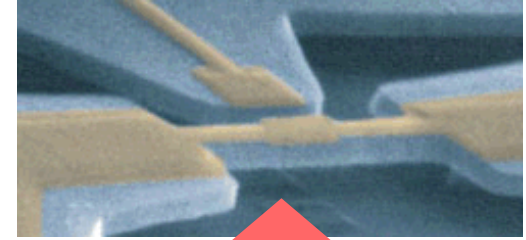


Magnetic anisotropy → bistability & hysteresis
→ magnetic memory

Efficiency of spintronic devices

Simplicity of translation from physics to electronics

Complexity of design

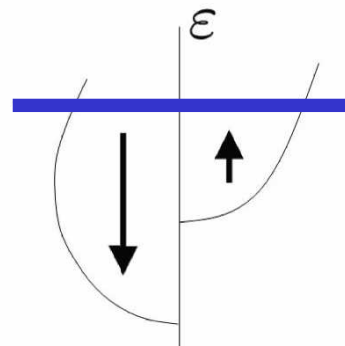


Single Electron Transistor

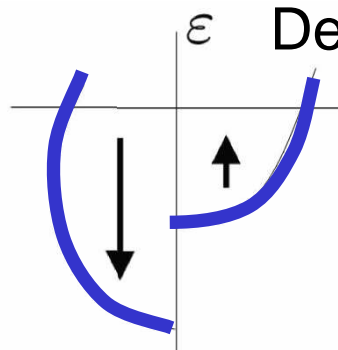


Resistor

Electro-chemical potential

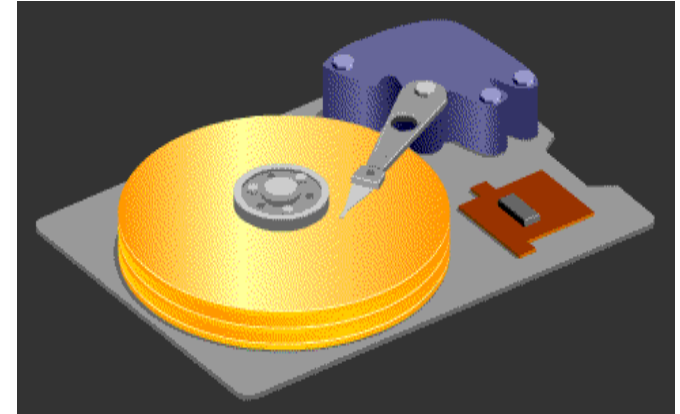
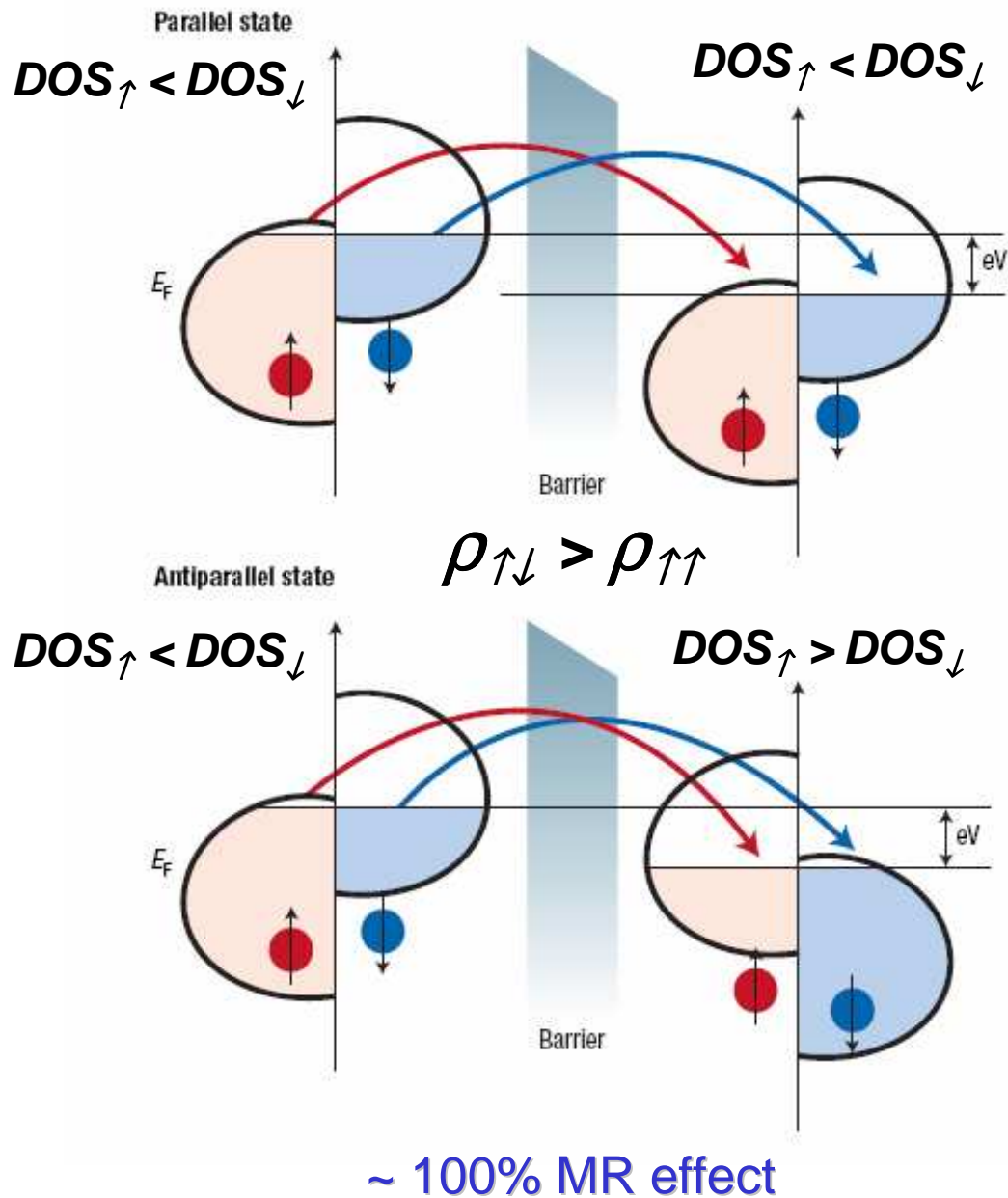


Density of states



Scattering lifetimes

Spin-dependent DOS \rightarrow tunneling magnetoresistance

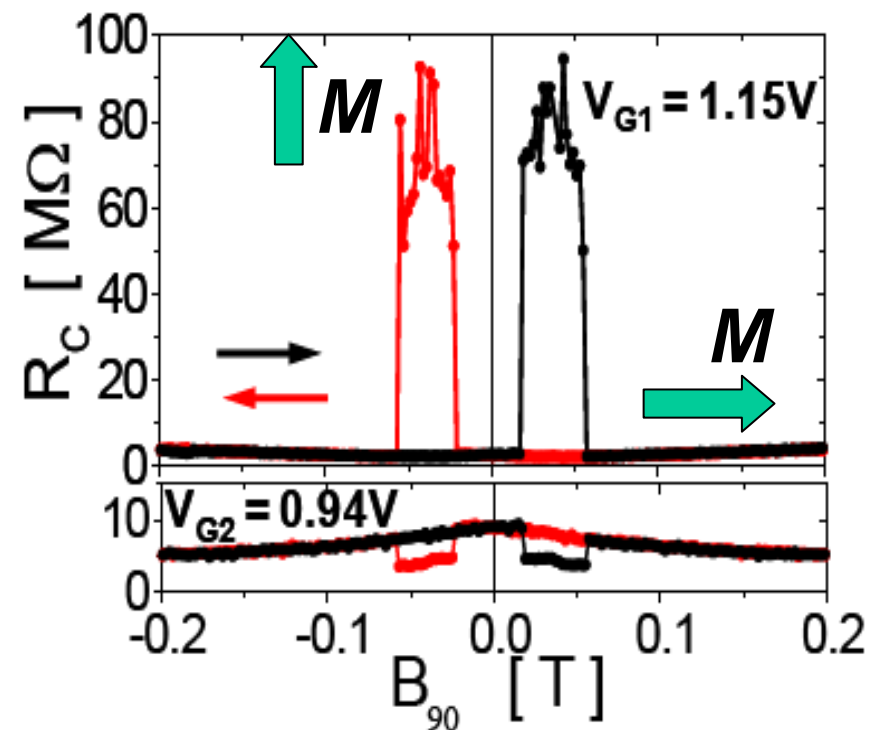
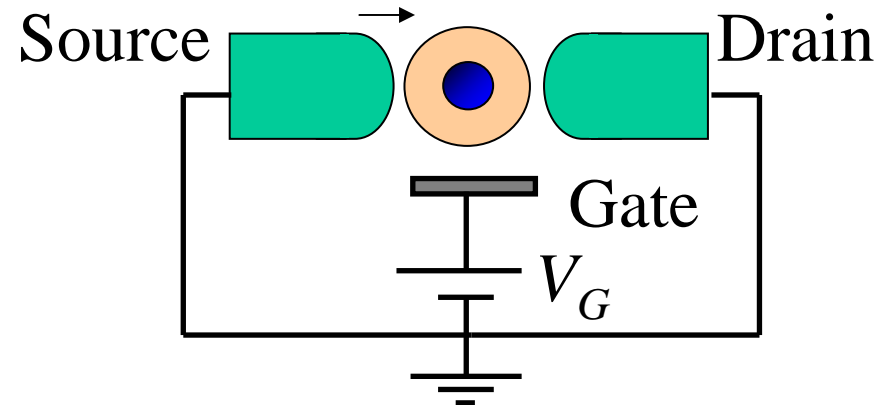
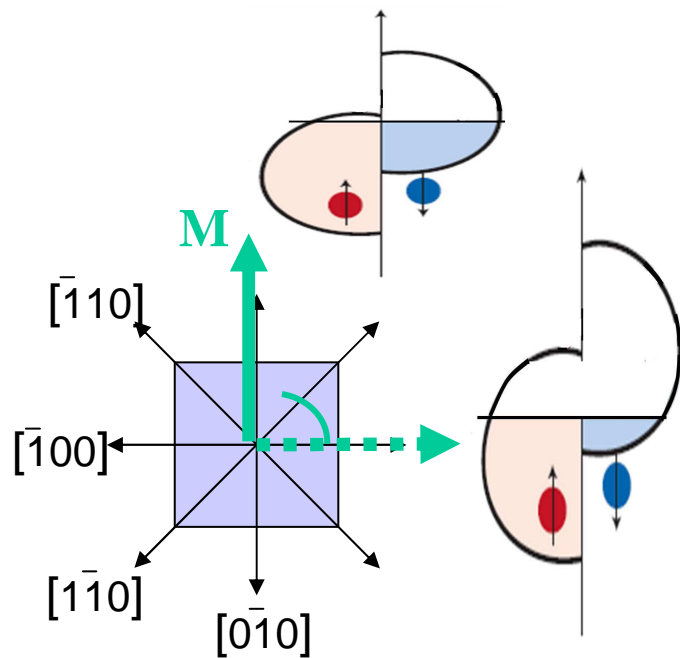


HDD read-head sensors



Non-volatile magnetic RAM

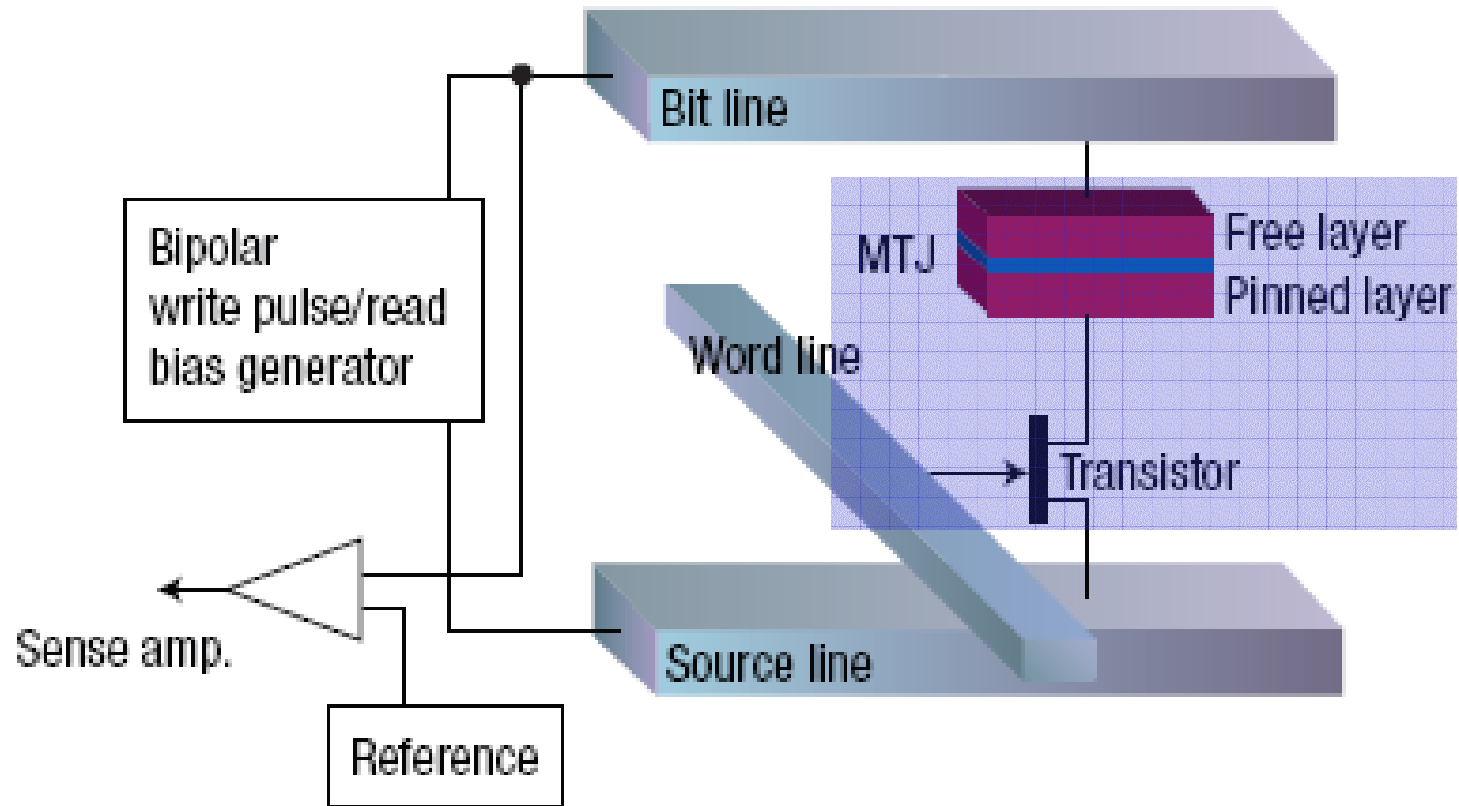
Spin-dependent electro-chemical potential



~1000% MR controlled by low-gate-voltage

↓
spintronic transistor for amplification and logic

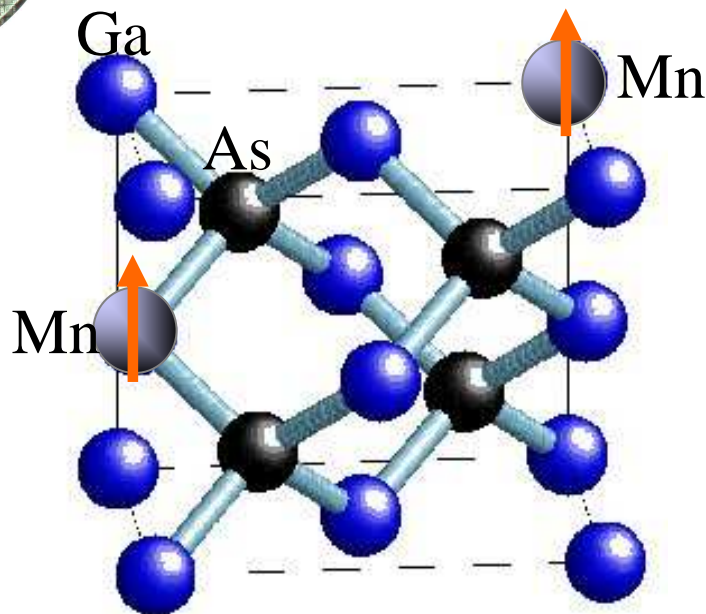
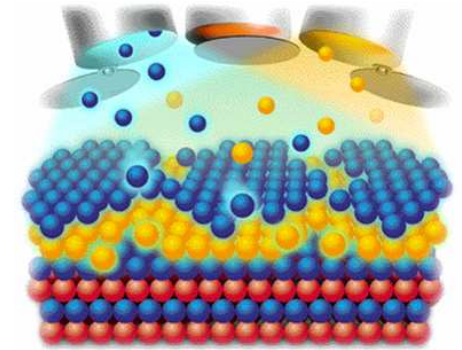
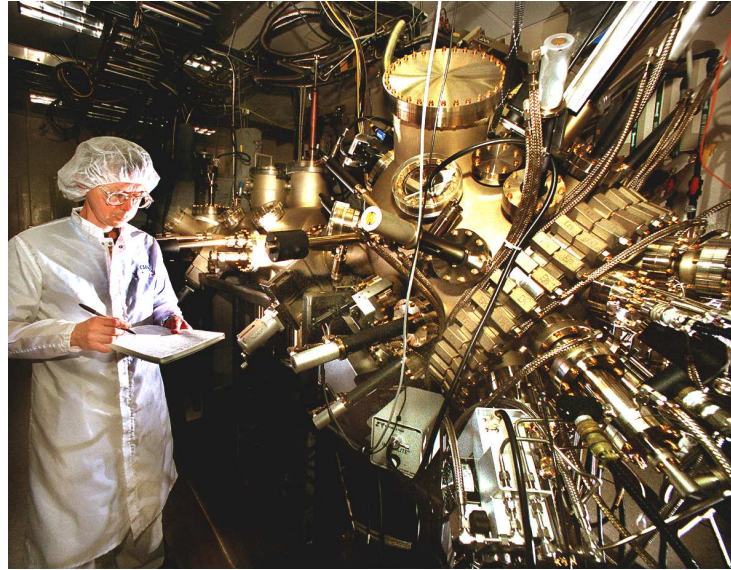
Why spintronic transistors?



- **Intergrating conventional spintronic and electronic devices in one physical element**
e.g. TMR magnetic tunnel junctions with transistors
- **Pure electrical control (no external magnetic fields) of spintronics**
e.g. magnetization switching induced by gate voltage on a spintronic transistor

Other approach: make conventional SC magnetic

More tricky than just hammering an iron nail in a silicon wafer

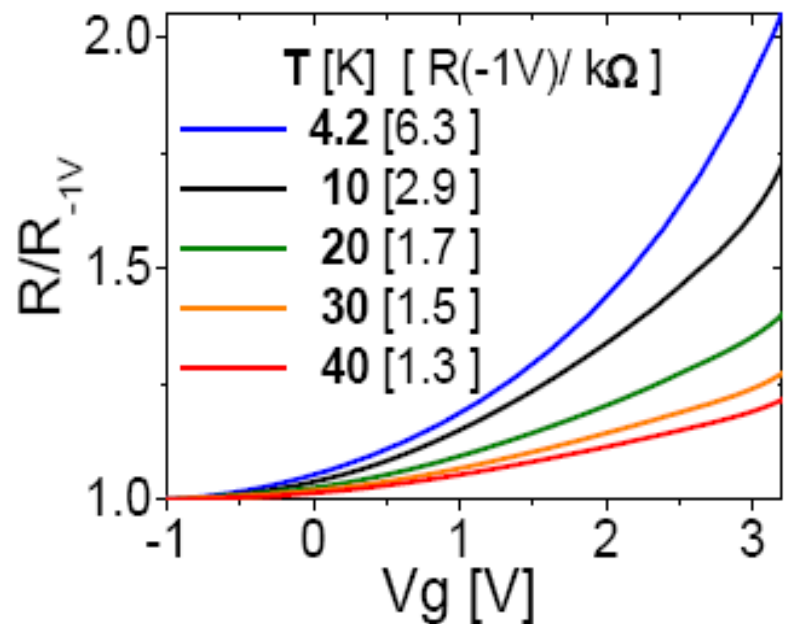


GaAs - standard III-V semiconductor

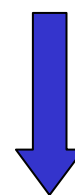
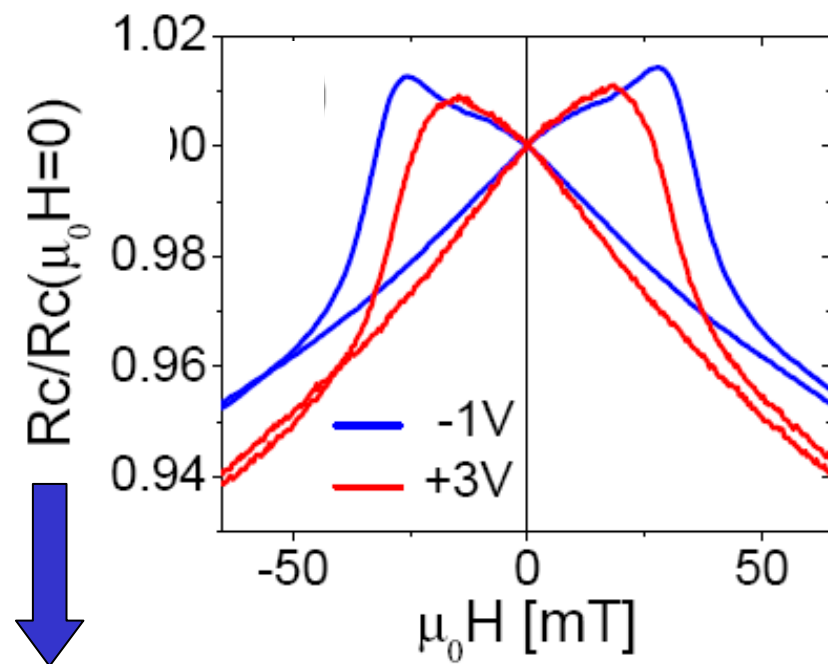
Group-II Mn - dilute magnetic moments & holes

GaAs:Mn - ferromagnetic & electrically doped semiconductor

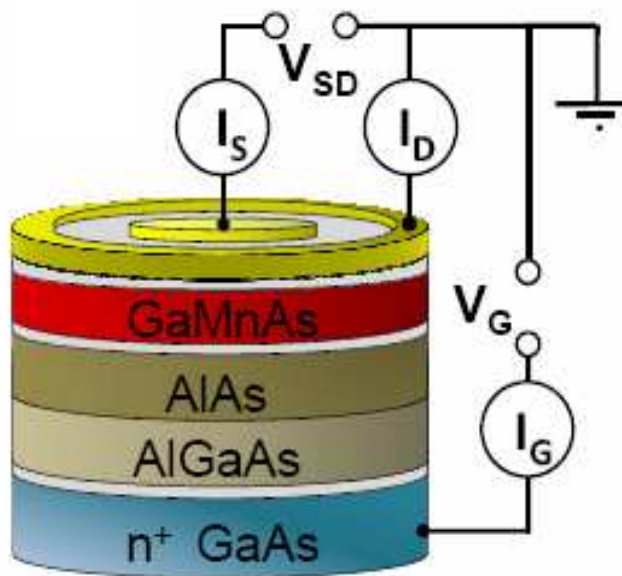
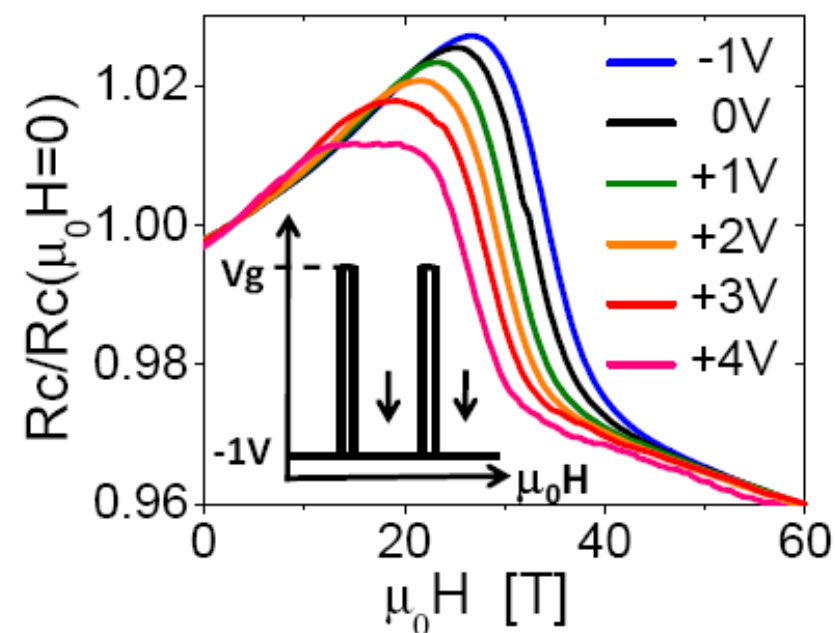
Gate controlled accumulation/depletion



Electrically tunable coercivity

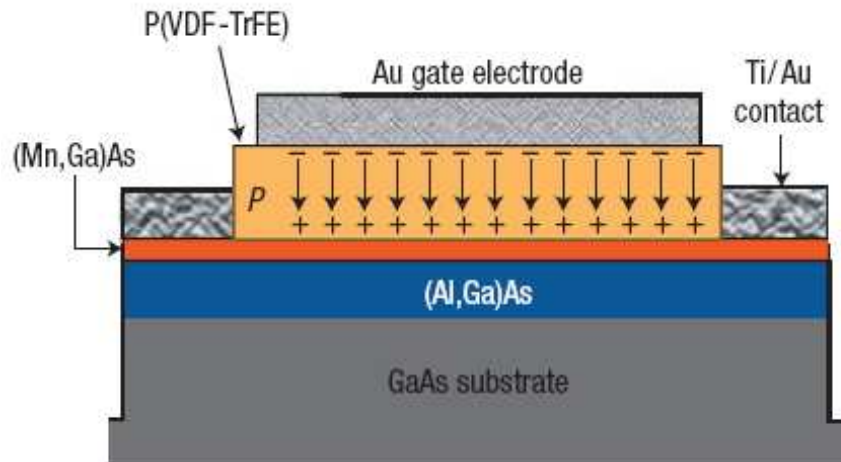


Switching by short low-V pulses

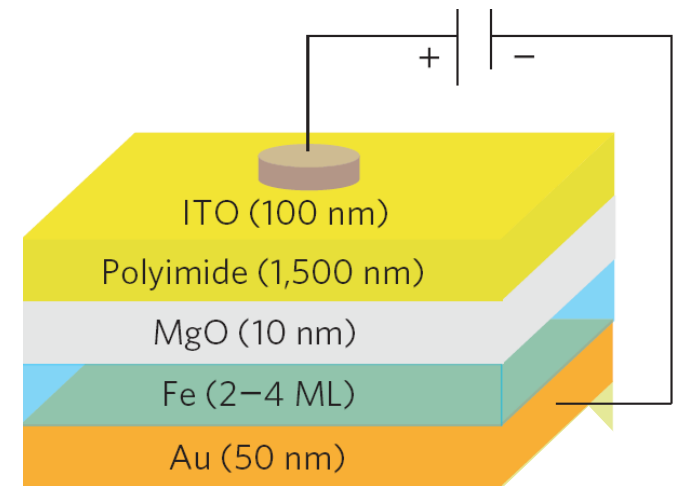


GaAs:Mn p-n junction spintronic transistor

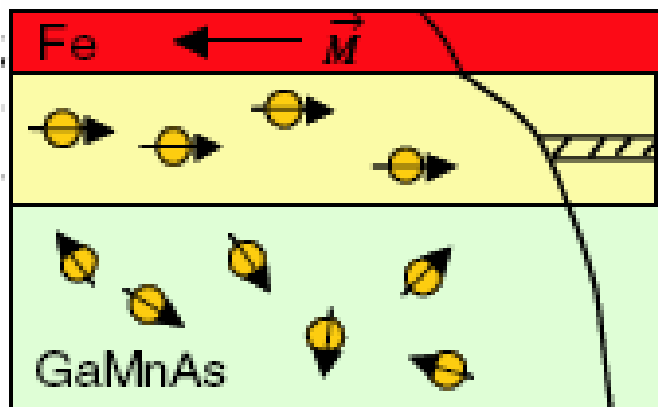
- **Non-volatile gating of GaAs:Mn by ferroelectric gate**
superhybrid ferromagnetic/ferroelectric/semiconducting FET



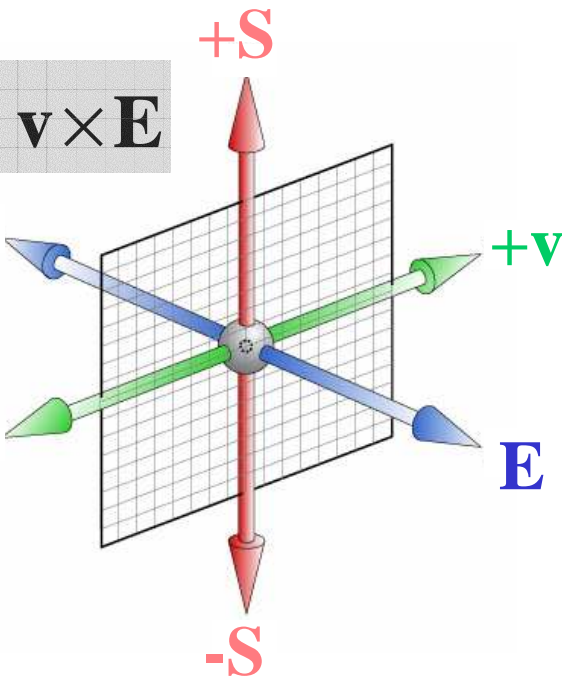
- **Electrical gate control of ultra-thin Fe on Au**
large change of magnetic anisotropy by electric fields in room-temperature FM

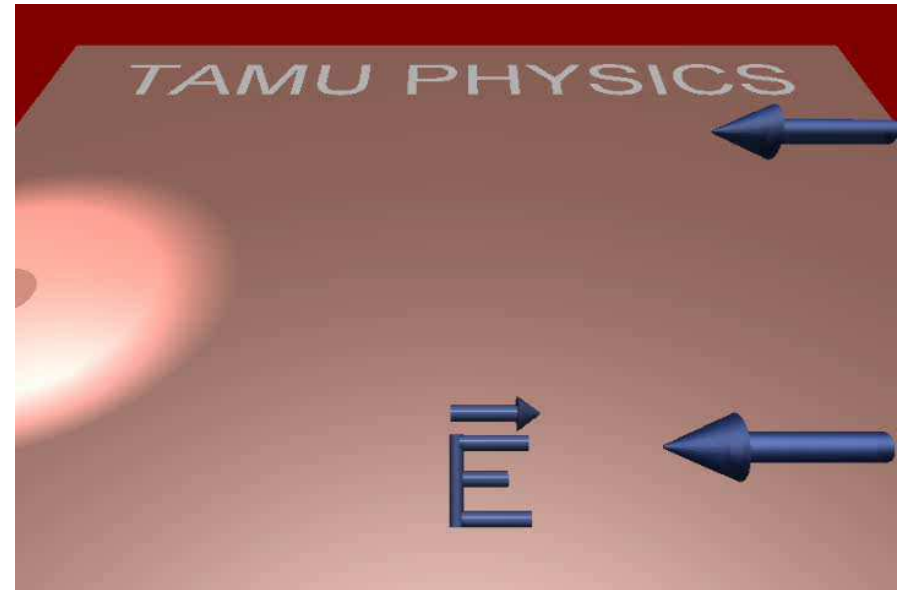


- **Proximity effects in FS/FM hybrids**
magnetic behavior of a GaAs:Mn
interfacial layer at room-temperature



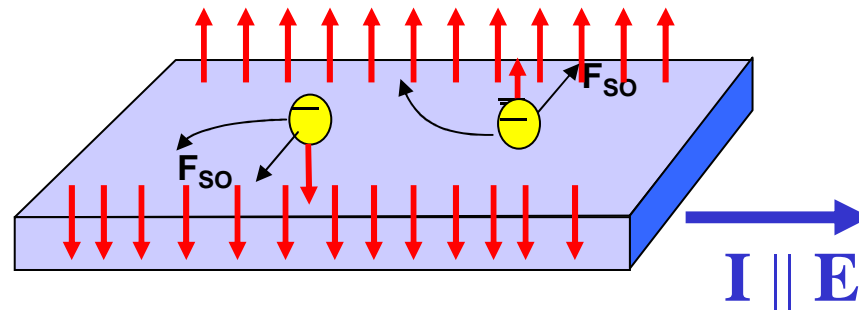
Spintronics in non-magnetic materials

$$H_{SO} = \frac{e}{mc^2} \mathbf{S} \cdot \mathbf{v} \times \mathbf{E}$$




Spin Hall effect

spin-dependent deflection \rightarrow transverse edge spin polarization



The potential of spintronics



spin Hall effect mikro-chip



superconducting magnet

Same magnetization in a normal semiconductor achieved at
 10^6 x smaller dimensions & 10^6 x smaller currents

... need to learn much more to fully exploit spin in microelectronics

