Spin transfer torque in CPP nano-pillars fabricated using 3D-gallium focused ion beam milling

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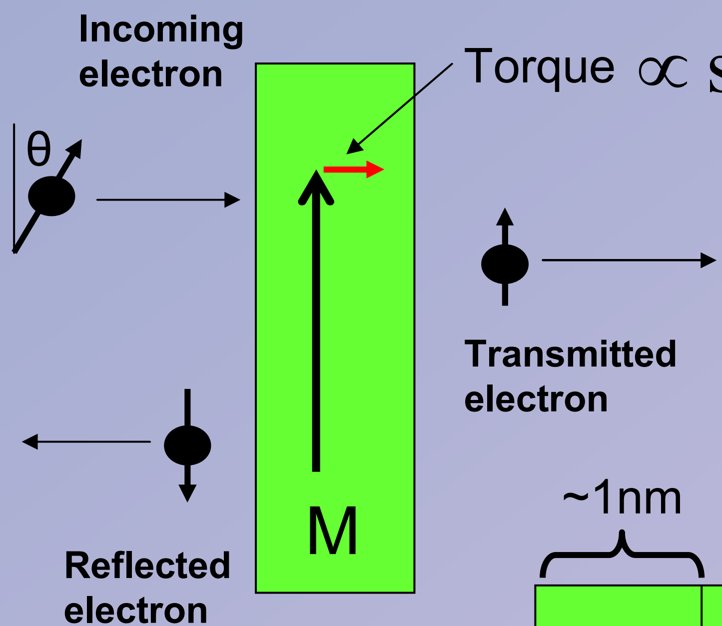
Outline

- Spin transfer torque phenomenon
- STT device fabrication techniques
- STT switching in FIB fabricated CPP devices
- Non-local devices
- Conclusion

Spin torque transfer to the single layer

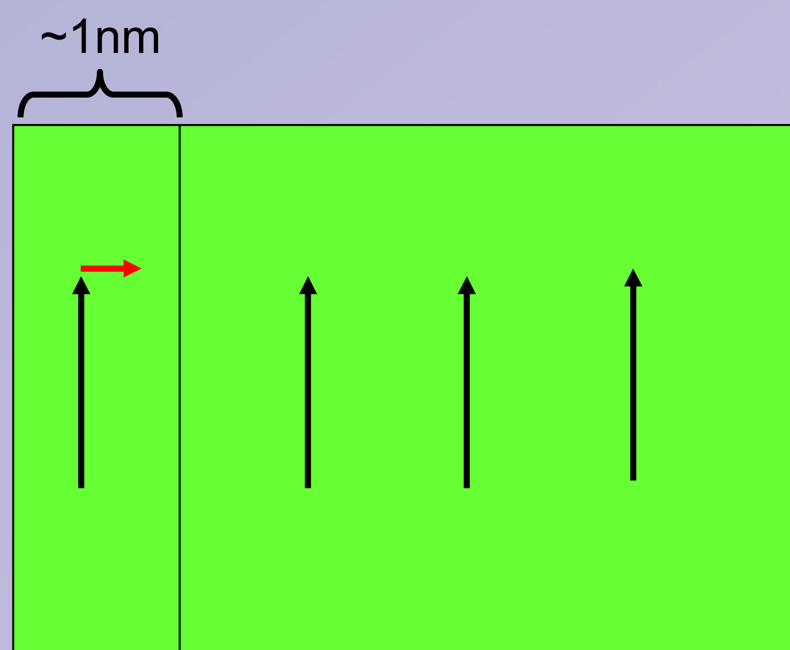
$$\psi_{ins} \sim \begin{pmatrix} \cos\theta/2 \\ \sin\theta/2 \end{pmatrix}$$

$$\psi_{ref} \sim \begin{pmatrix} 0 \\ \sin\theta/2 \end{pmatrix}$$



Torque $\propto \sin(\theta)$

$$\psi_{tra} \sim \begin{pmatrix} \cos\theta/2 \\ 0 \end{pmatrix}$$

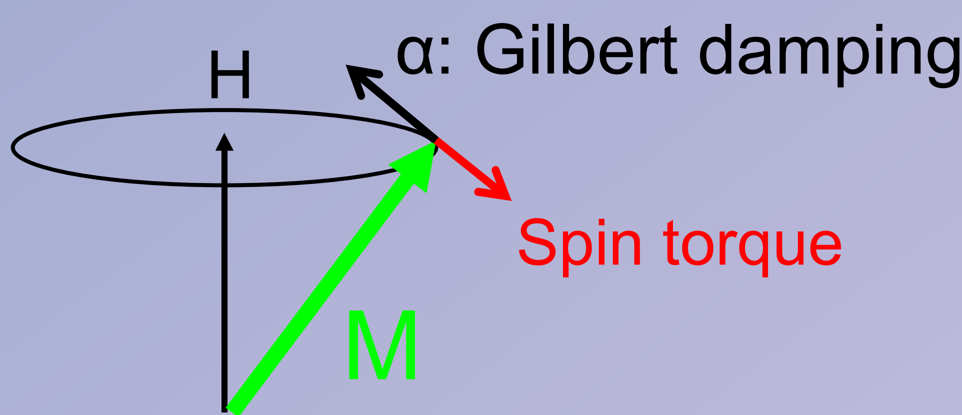


Spin torque is mainly transferred near the interface
Therefore, thin layers switch easier than thick layers.

Slonczewski J, JMMM 159, L1-L7 (1996)

Modified LLG equation

$$\frac{1}{\gamma}\frac{d\vec{M}}{dt} = -\vec{M}\times\vec{H} - \frac{\alpha}{Ms}\vec{M}\times(\vec{M}\times\vec{H}) + \frac{g}{\gamma\mu_o e}\frac{I}{A}\vec{M}\times(\vec{M}\times\vec{M}_{fixed})$$



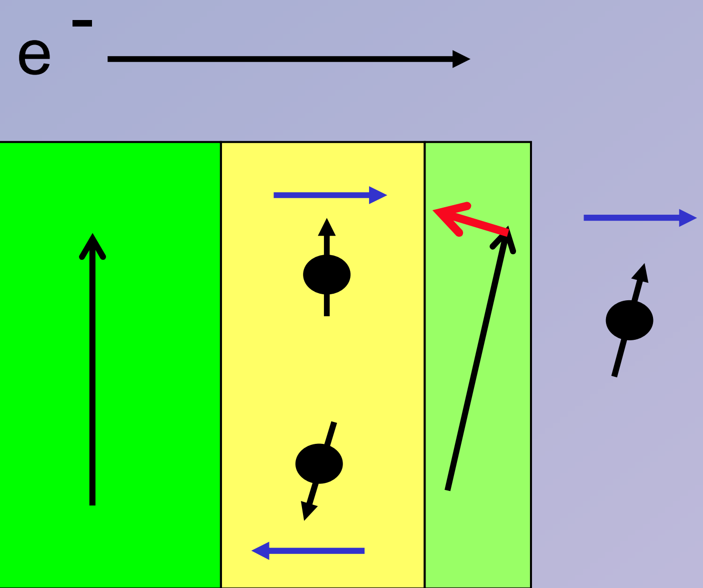
γ: gyromagnetic ratio
α: Gilbert damping coefficient
g: efficiency of spin transfer effect
A: area
I: current
μ_o: permeability of free space

Switching: when spin torque >> damping torque
Study precession: when spin torque ~ damping torque

Slonczewski J, JMMM 159, L1-L7 (1996)

Spin transfer torque I

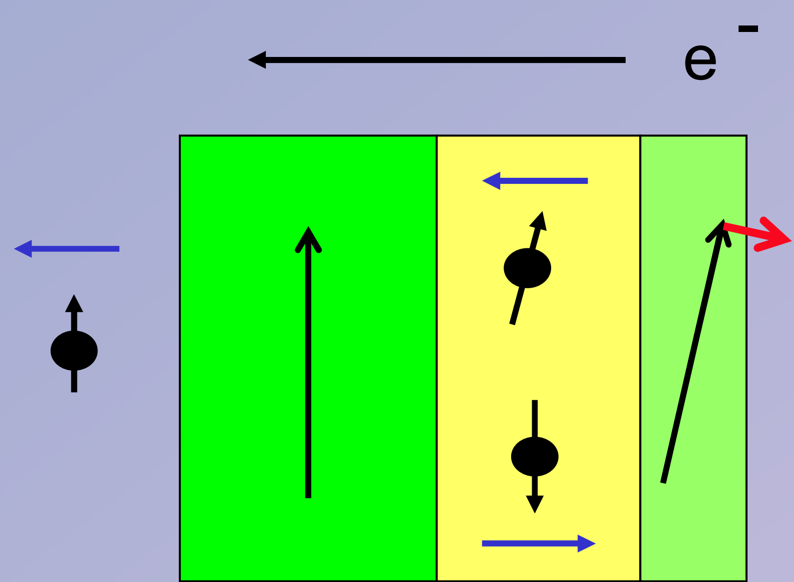
Fixed to free layer



Favours parallel
Magnetisation

Spin transfer torque II

Free to fixed layer

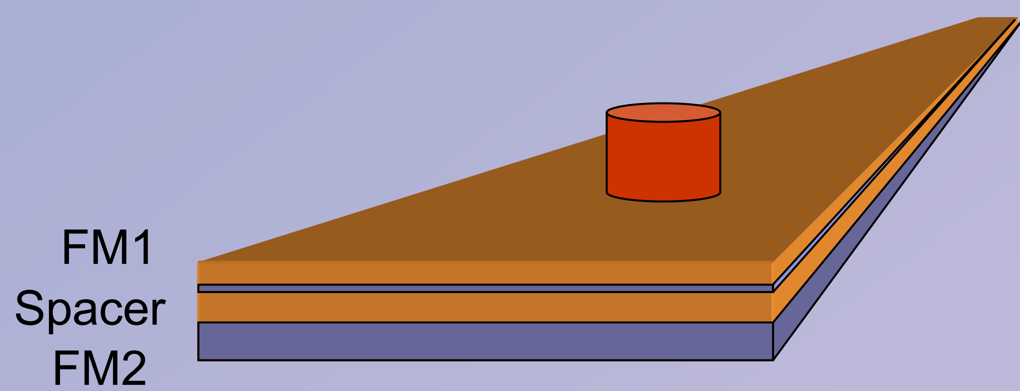


Favours anti-parallel Magnetisation

Current density required for switching or for achieving steady precession is very high (~ $10^7 A/cm^2$)

CPP device fabrication techniques

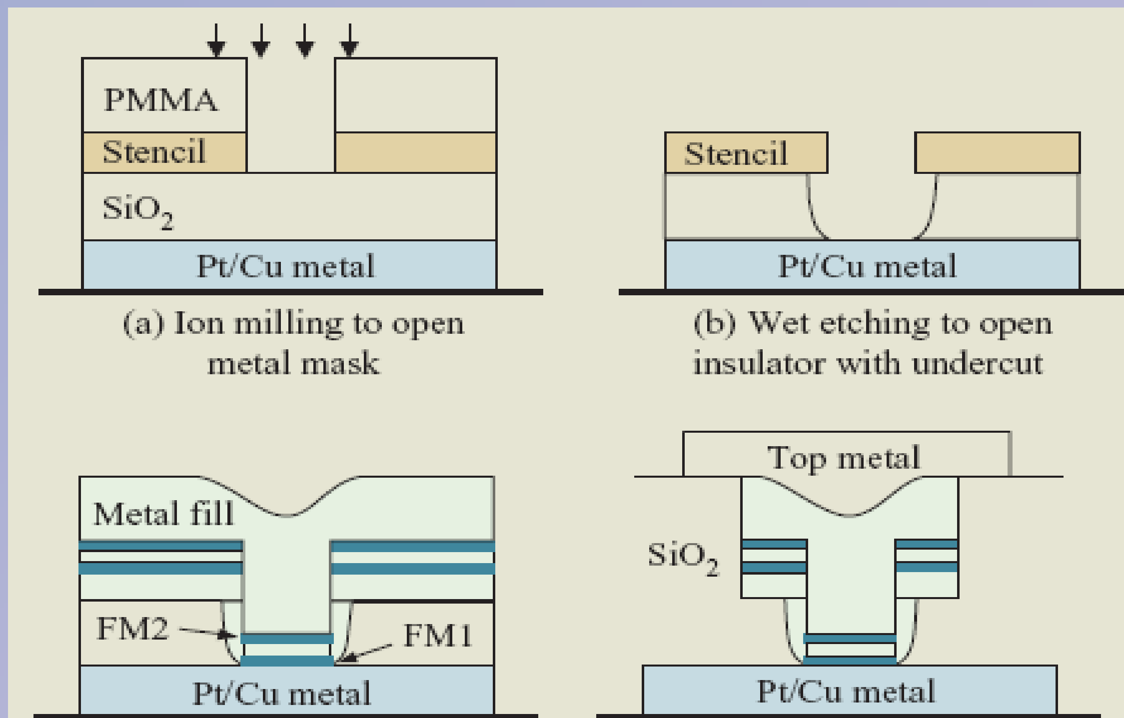
(a) Point contact



- Relatively easy to fabricate point contact devices
- Microwave generation
- Not very useful for spin switching

CPP device fabrication techniques

(b) E-beam stencil process



(a) Ion milling to open metal mask

(b) Wet etching to open insulator with undercut

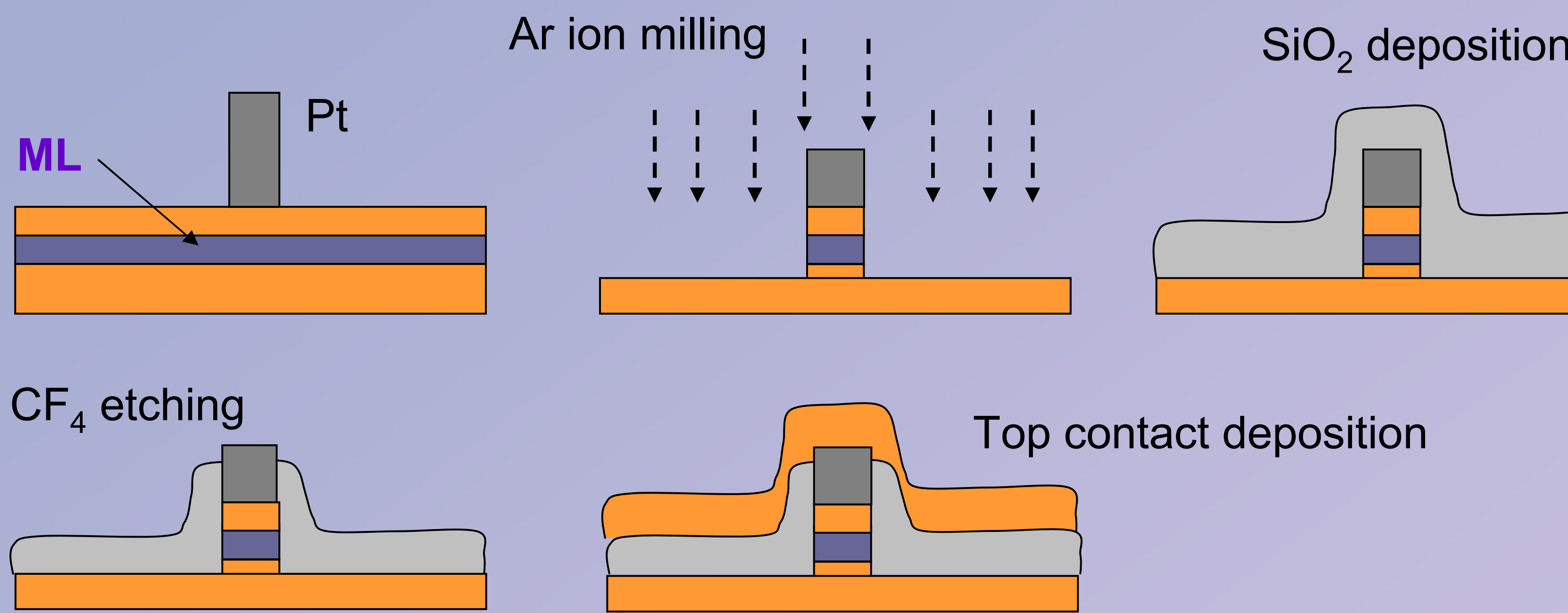
(c) Deposition of multilayer films

(d) Formation of top-level contact

J. Z. Sun. et.al. J. Appl. Phys. 93, 6859 (2003)

CPP device fabrication techniques

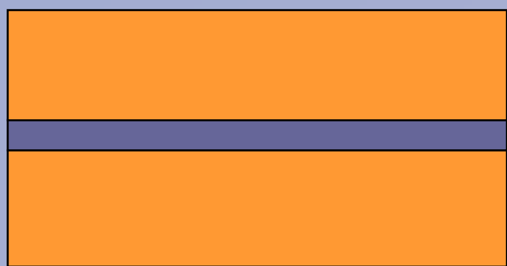
(c) E-beam lithography



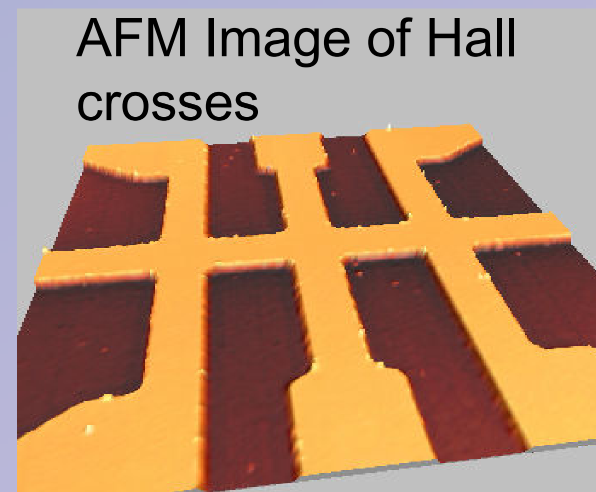
- Use for both switching and MW excitations
- Reproducible devices
- Difficult fabrication process

3D FIB fabrication of STT devices

(1)

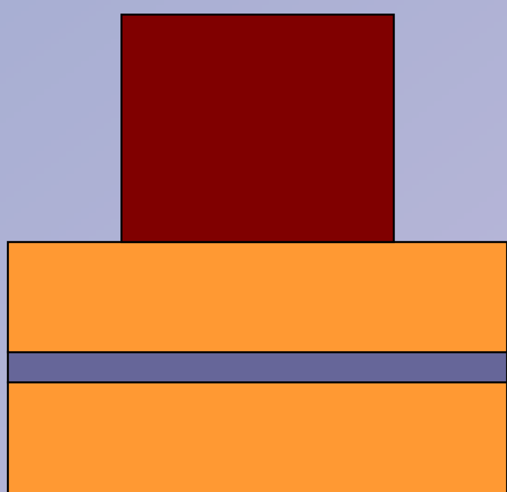


Cu(200nm)
Spin valve
Cu(200nm)



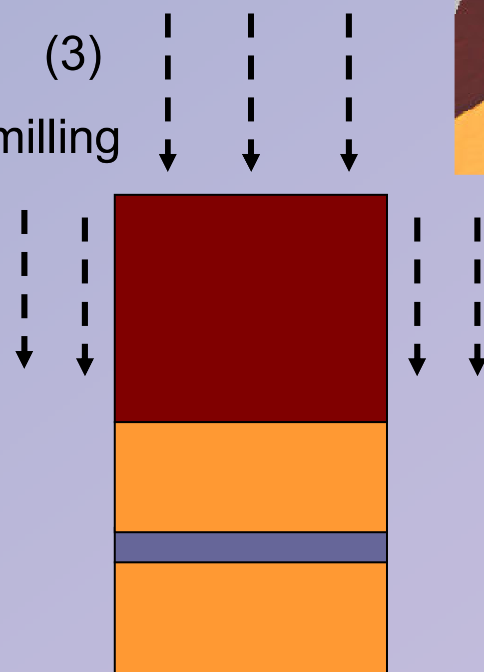
(2)

AZ Photo resist



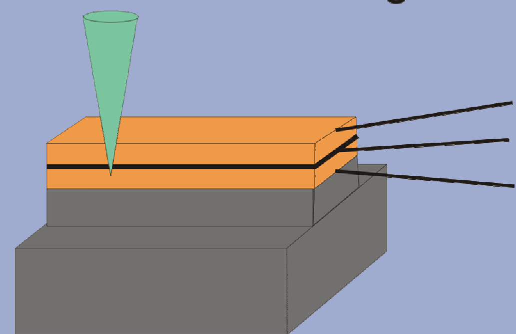
(3)

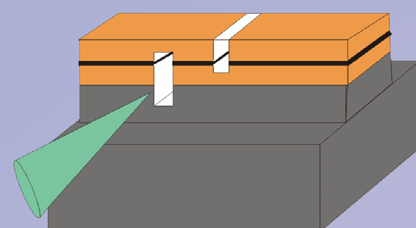
Ar ion milling



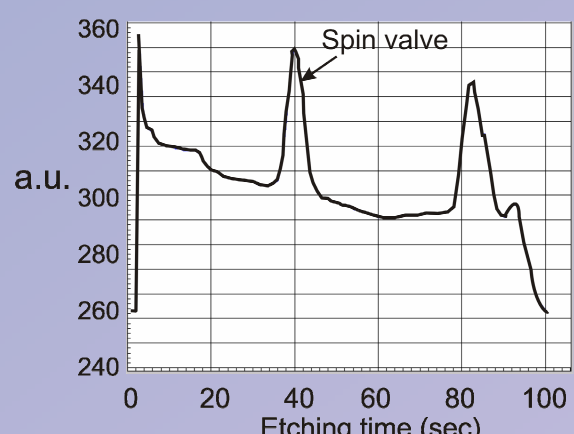
 M. C. Wu et. al. Appl. Phys. Lett. 92, 142501 (2008)

3D FIB fabrication of STT devices

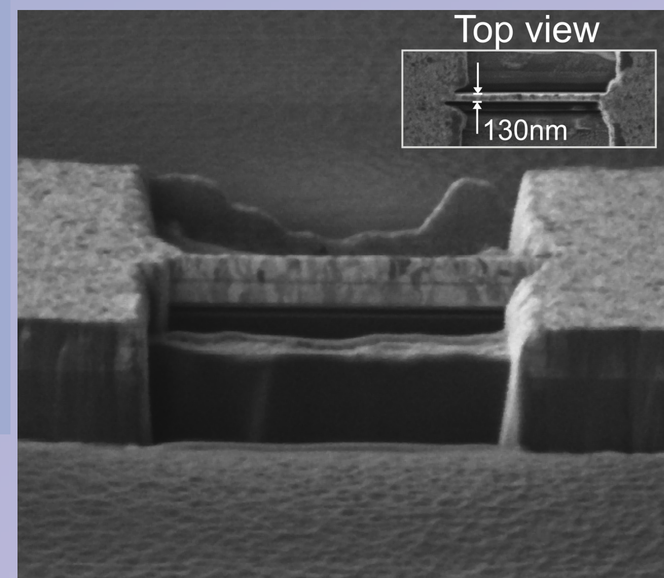


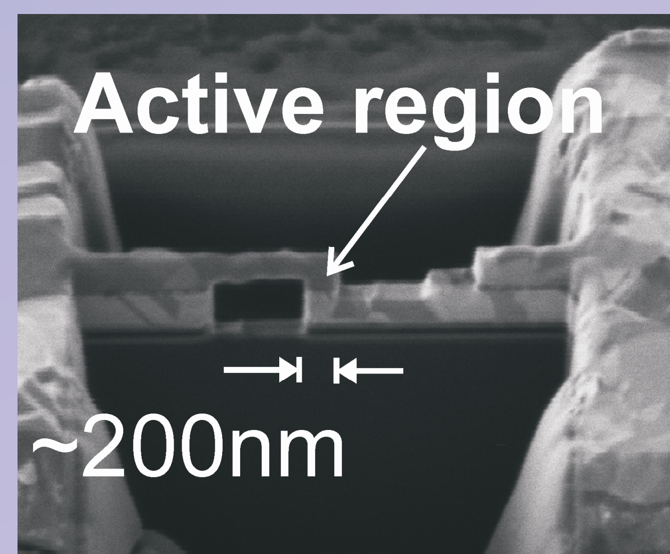


2nd Ga FIB milling after rotating the sample to 90°

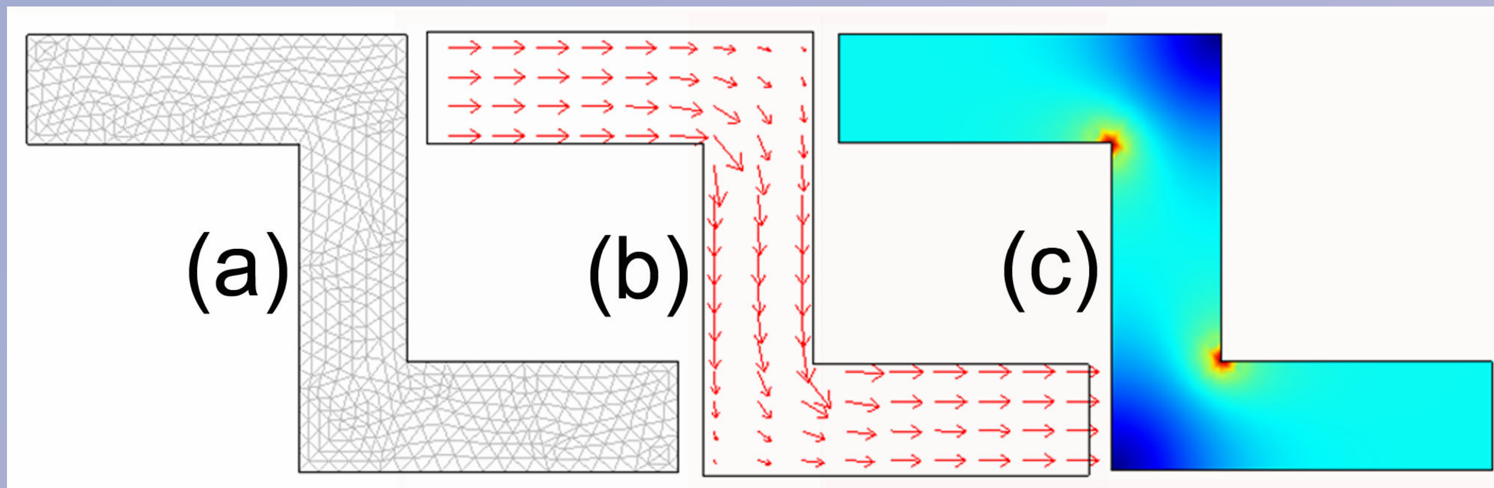


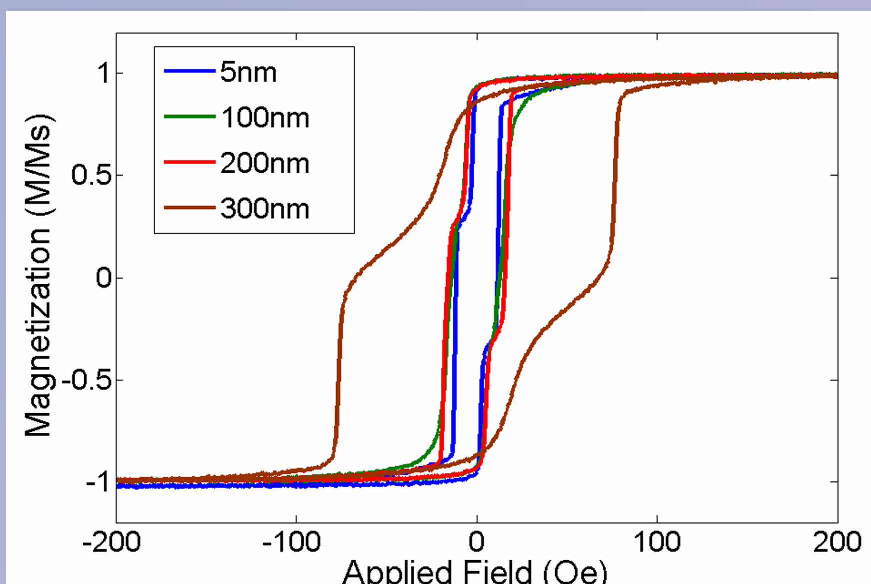
Elements	30keV Ga-ion range
Cu	9.8 nm
Au	7.7 nm
Co	9.5 nm
Fe	10.4 nm
Ir	6.6 nm
Mn	11.1 nm





Finite element simulation of current through a nano-pillar:





Current flows perpendicular to the plane

Cu(x)/Py(12nm)/Cu(15nm)/Co(12nm)/Cu(x)

X=5nm, 100nm,200nm and 300nm
rms surface roughness: 0.5nm (200nm)
rms surface roughness: 1.2nm (300nm)

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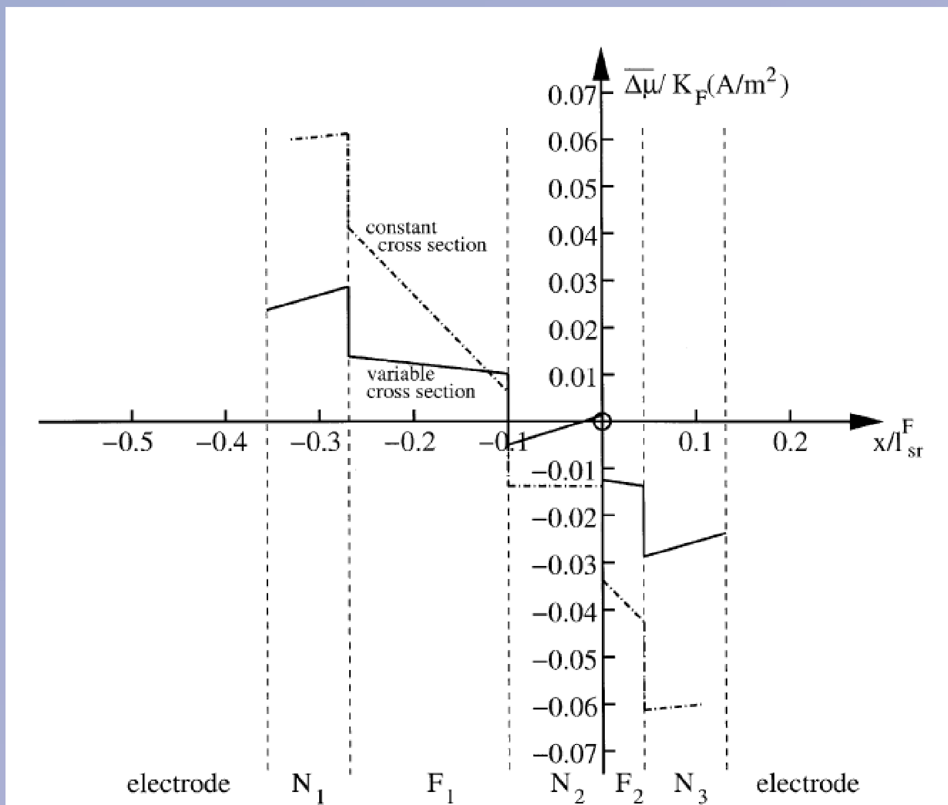
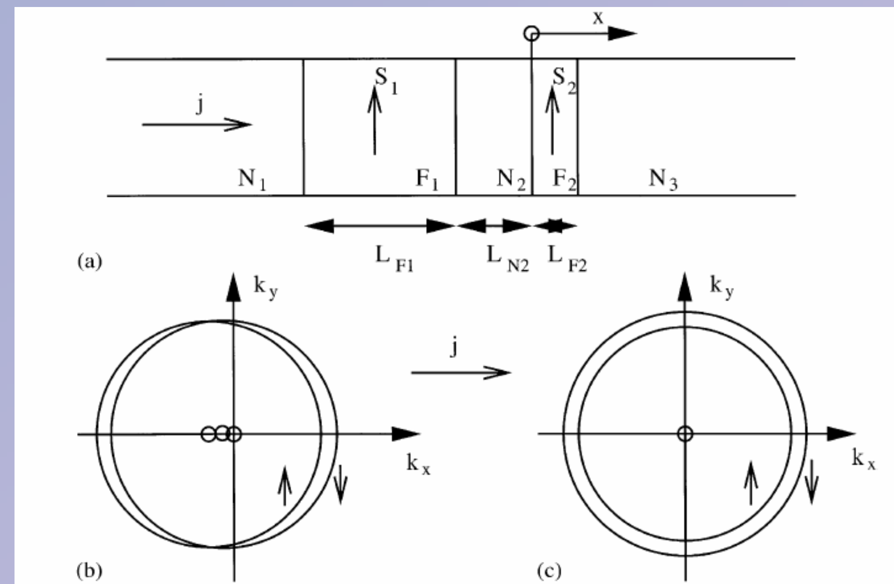
Influence of leads on nano-pillar devices



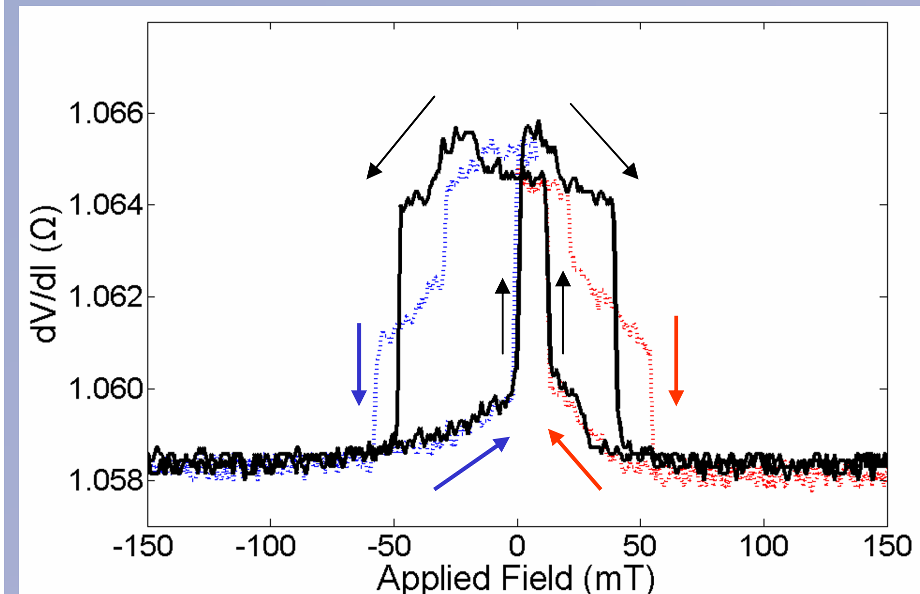


Spin current vs spin accumulation

Cu leads are extended out of the spin valve devices. This geometry is very close to the one dimensional picture and leads to an enhanced spin accumulation in the FIB fabricated dual spin valves than e-beam fabricated and point contact CPP devices.

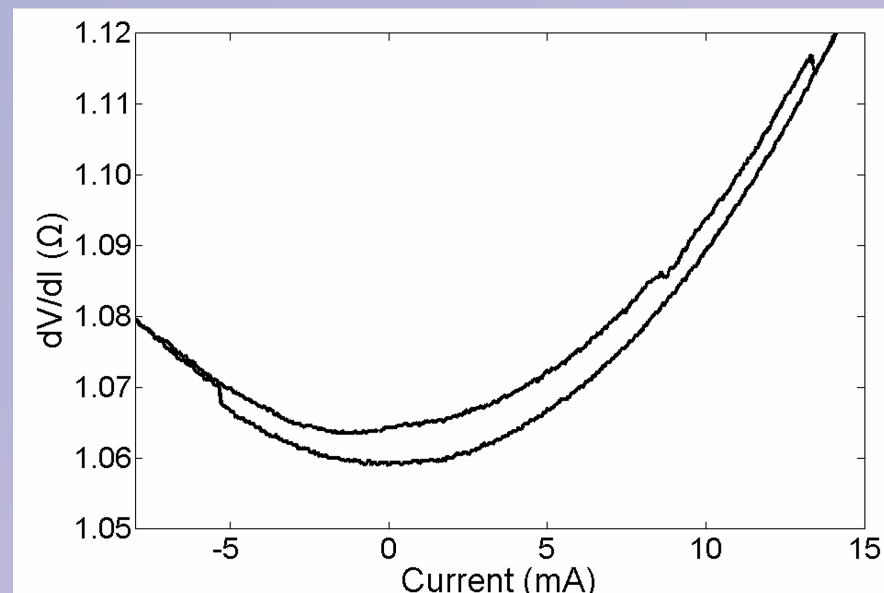
L. Berger JMMM 278, 185 (2004)

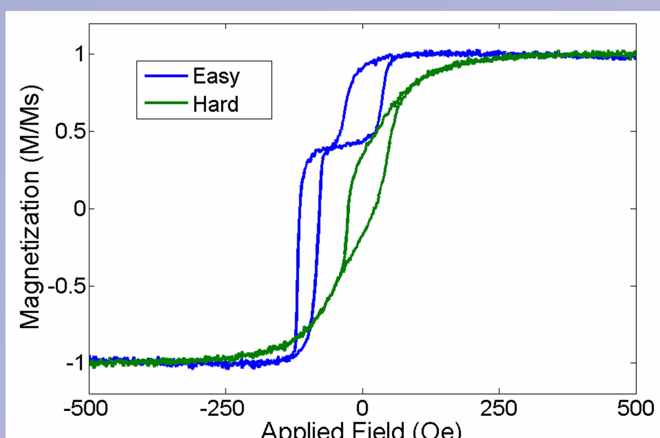
Current dependent switching



CoFe(3nm)/Cu(6nm)/CoFe(8nm)/IrMn(10nm)
Exchange bias~10mT

220nm x 130nm





AP to P switching: Jc~4.65 x 10^7 A/cm^2
P to AP switching: Jc~-1.85 x 10^7 A/cm^2

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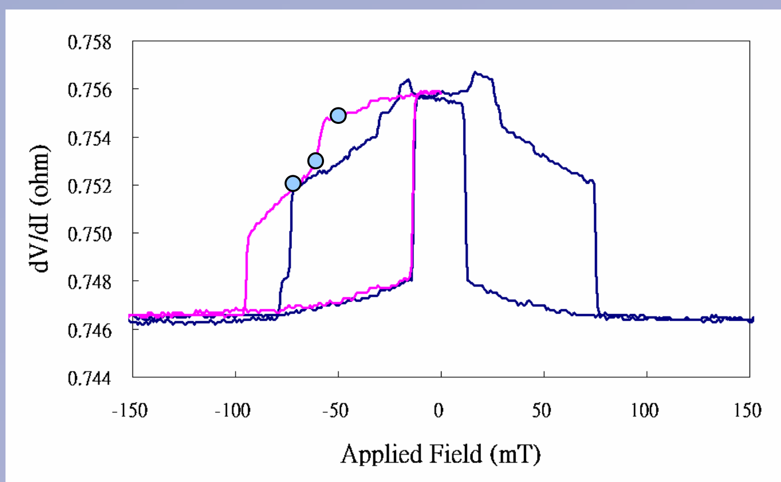
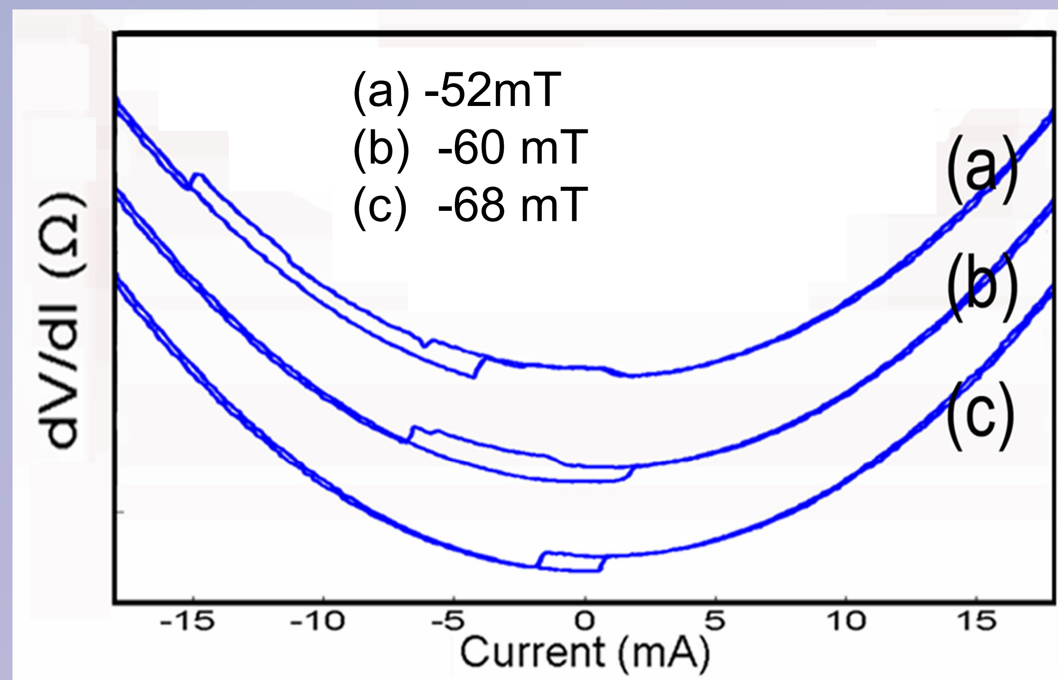
Reduced critical current density of STT devices

Si/SiO2/Ta (5)/Cu (200)/CoFe (3)/Cu (6)/CoFe (12)/Cu (200)/Ta (5)
Thickness in nms



Dim: 200nm x 160nm
Similar results have also been obtained for device of dimensions 190nmx170nm



1mA →3.1 x 10^6 A/cm^2

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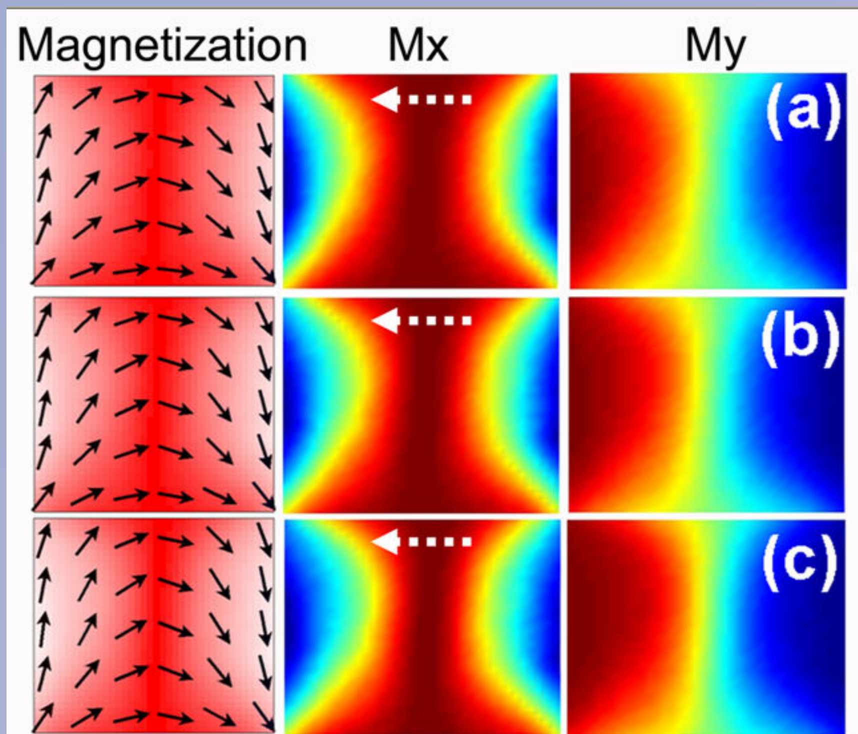
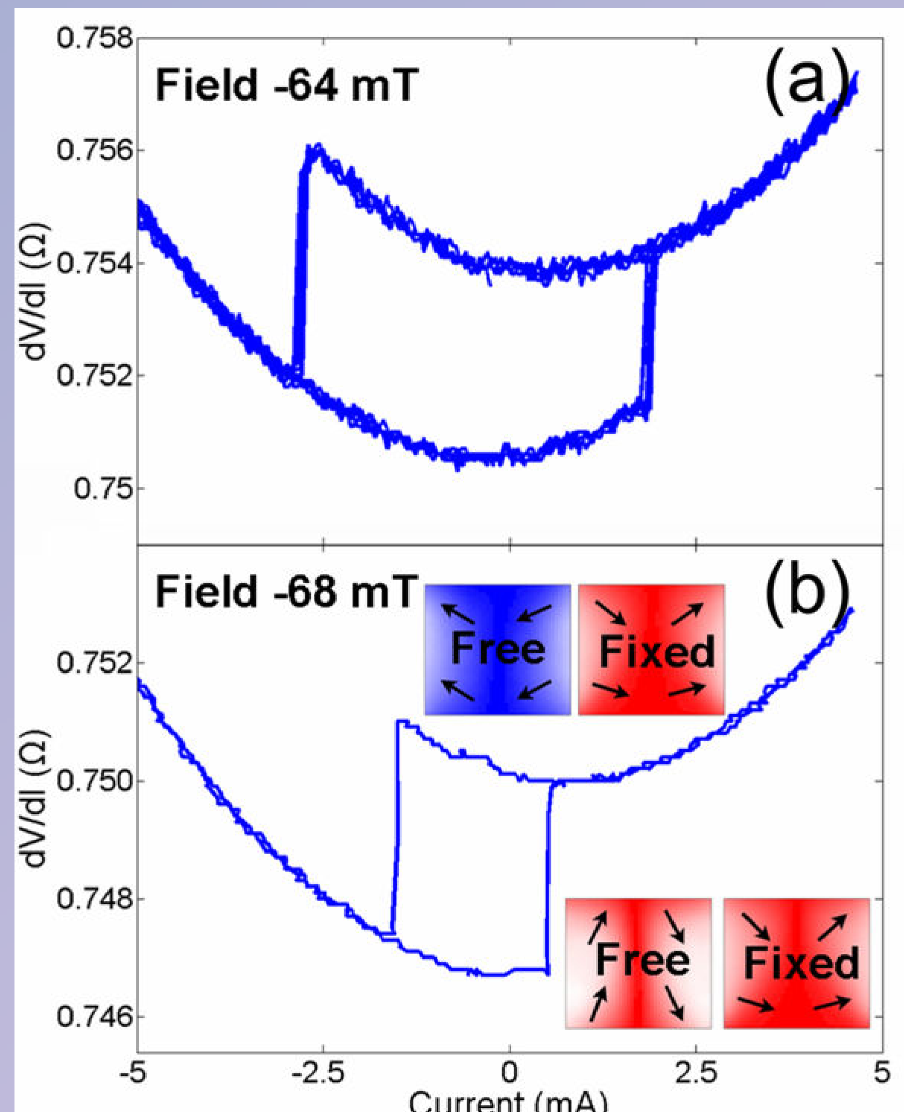
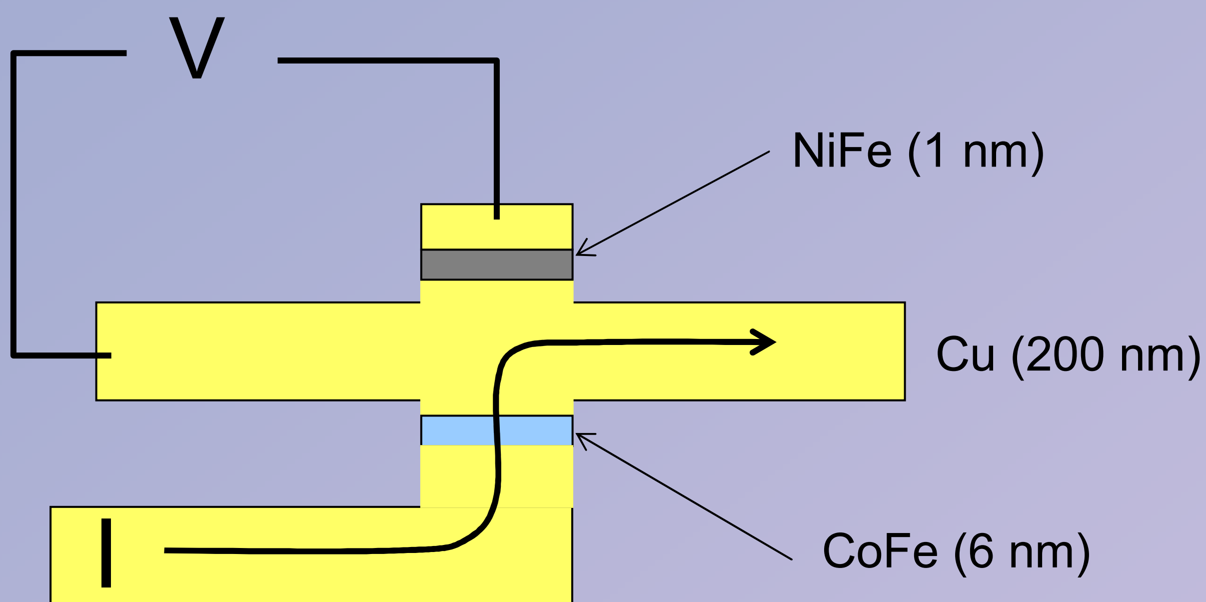
Partial STT switching



(a) -50mT
(b) -60 mT
(c) -70 mT



Non-local devices



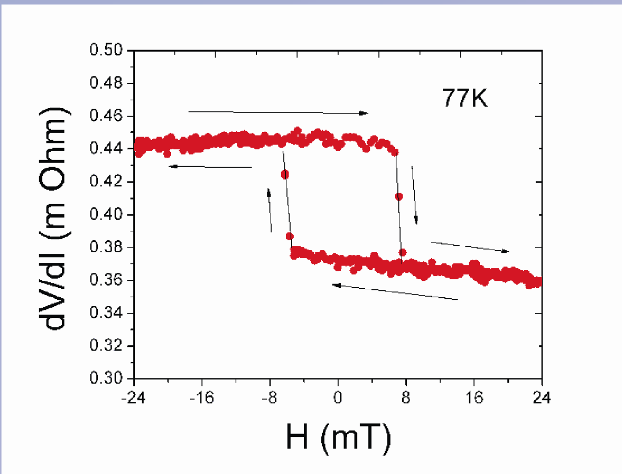
Cu(200nm)/IrMn(10nm)/CoFe(6nm)/Cu(200nm)/NiFe(1nm)/Cu(200nm)/Au(2.5nm)

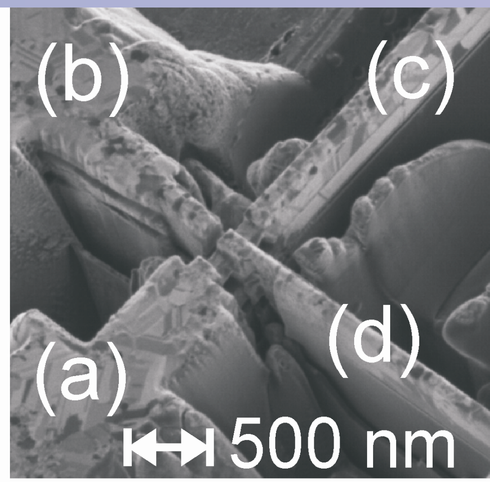
Grown at Leeds

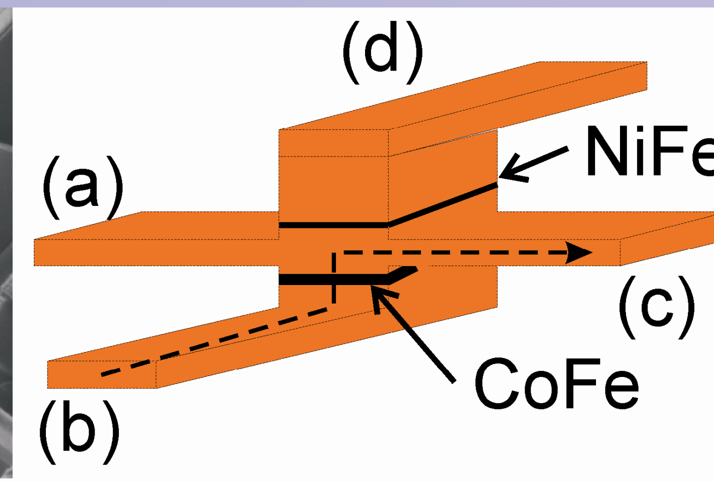
CPP non-local devices

3D-FIB technique can also be used for fabricating complex devices such as CPP non-local devices.
Interfaces are not exposed during fabrication.

T. Kimura et.al. PRL 96, 037201 (2006)
AP to P switching







Pillar area: 200nm x 200nm

These devices will be used for investigating STT switching is non-local devices

Summary

1. Introduced a new way of fabricating CPP devices.
2. STT switching is demonstrated in 3D-FIB fabricated devices.
3. Enhanced spin accumulation in these devices.
4. It is shown that even more complex devices such as CPP non-local devices can also be successfully fabricated using this new process.