Spin flip lasers

Tim Verhagen, Stefano Voltan & Hiske Overweg

Groupmeeting, May 4th 2011

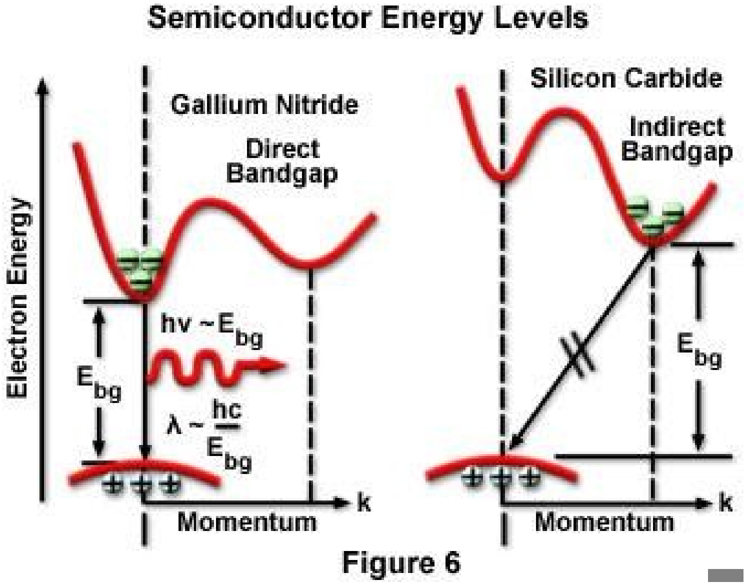
Background

Point contact spectroscopy

Hard magnets

Spin flip laser

Semiconductor (laser diode)



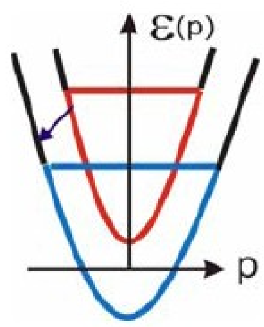
$\Delta k = 0$

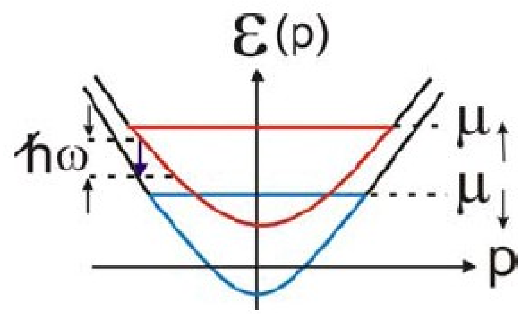
photon

$\Delta k \neq 0$

phonon

Magnetic (spin flip laser)





$\Delta k \neq 0$

magnon

↓

High frequency oscillators

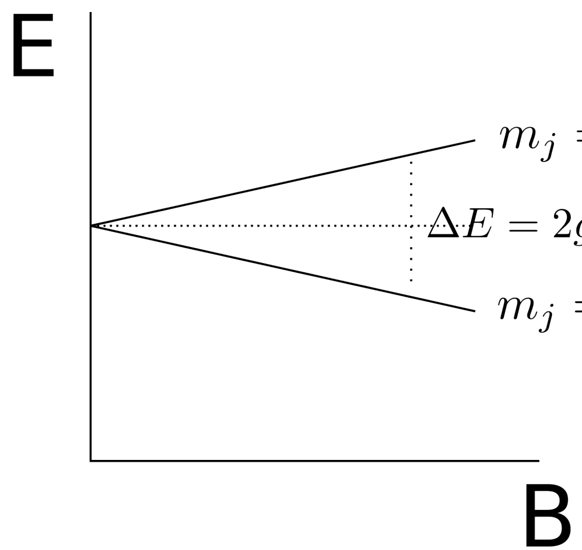
$\Delta k = 0$

photon

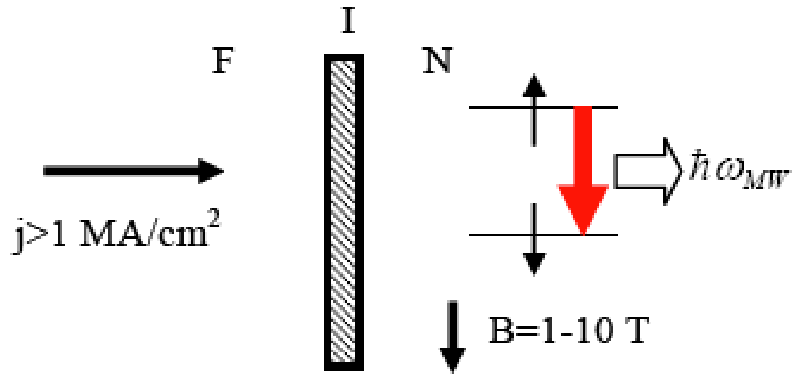
↓

High frequency lasers

Zeeman split transition



Zeeman effect



$$
\begin{aligned}
h\nu &= 2g\mu_B m_s B \\
\nu &= 0.014 g B \left[\frac{THz}{T}\right]
\end{aligned}
$$

Devices, Majority F

If coercive field of F is (much) bigger than applied field

$SmCo_5, AlNiCo, Nd_2Fe_{14}B$

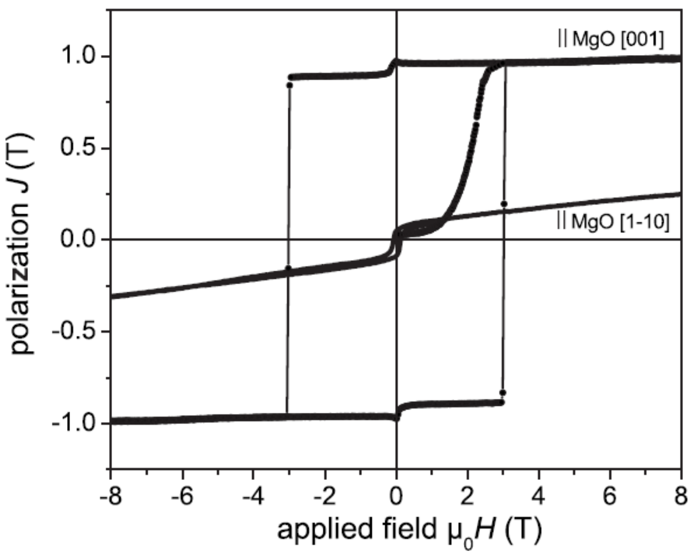


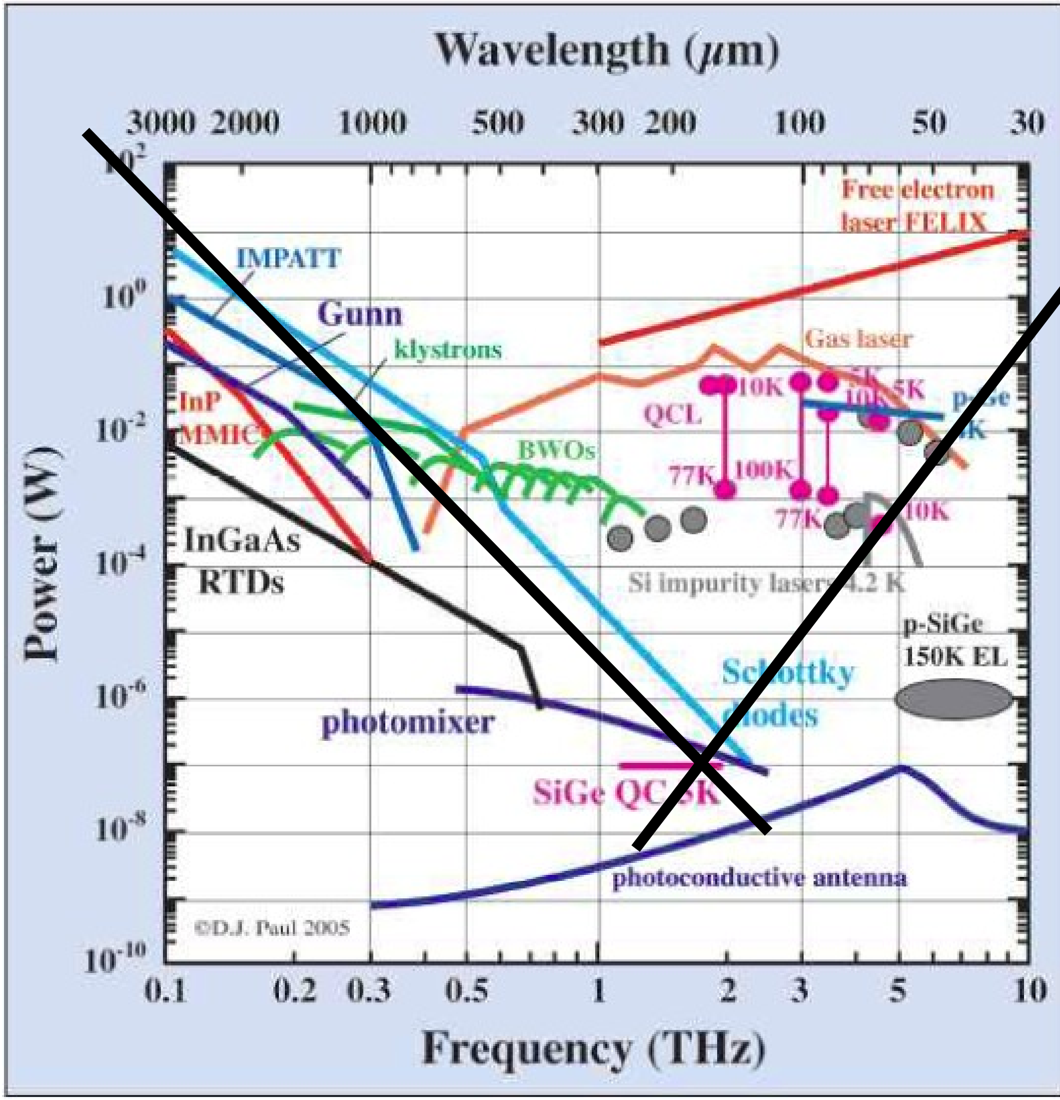
FIG. 2. Magnetic hysteresis of a $SmCo_5$ film measured along the easy magnetization axis (||MgO[001]) and along the in-plane hard axis (||MgO[1−10]).

PRB 77 104443

Why magnetic lasers?

Electronics

$$P \propto \frac{1}{\nu^4}$$



Optics

$$k_b T < h\nu$$

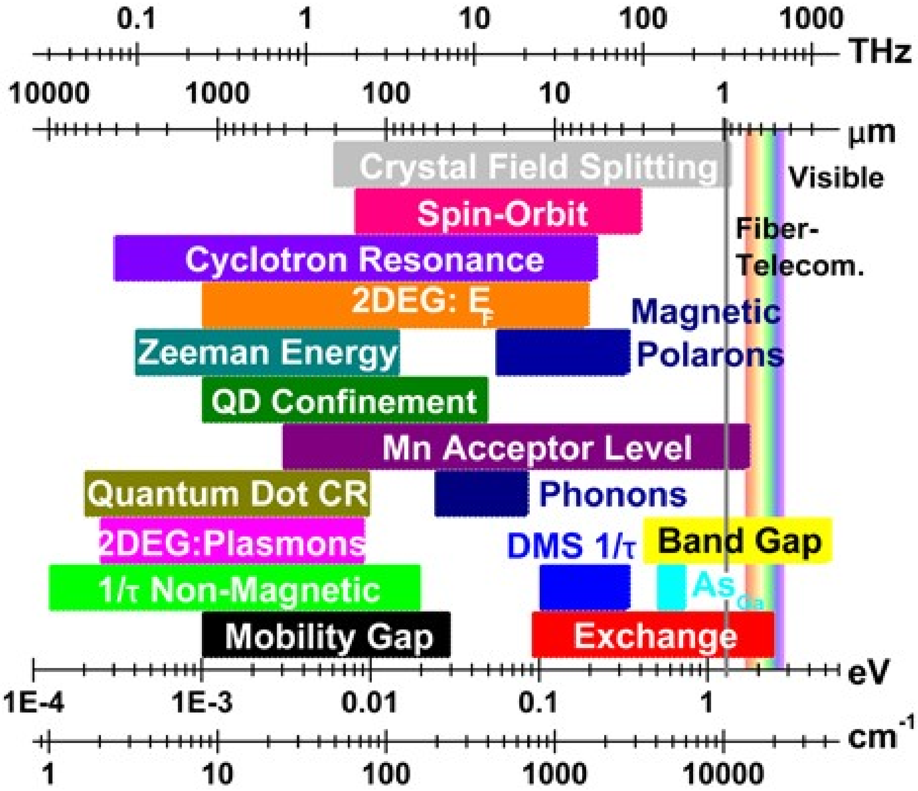
1 THz = 4meV

1 THz = 48K

1 THz = 33cm-1

1 THz = 0.3mm

What physics at THz frequencies?

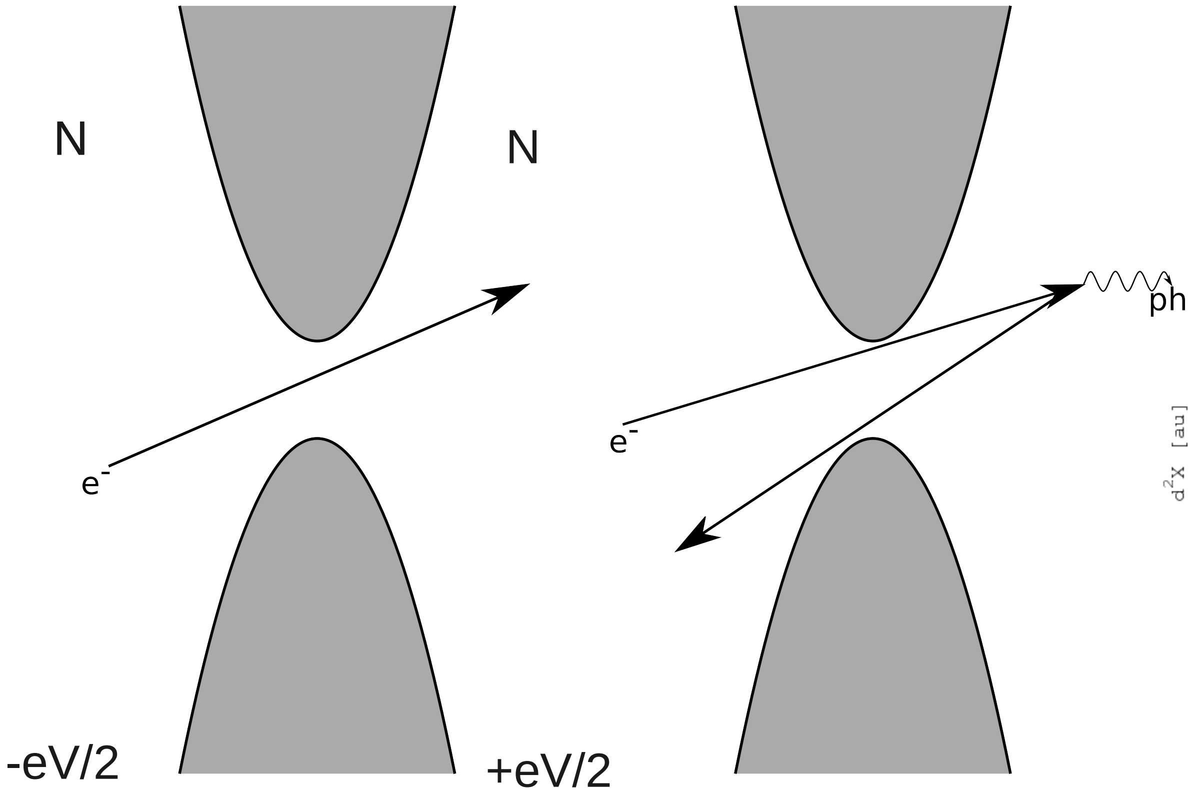


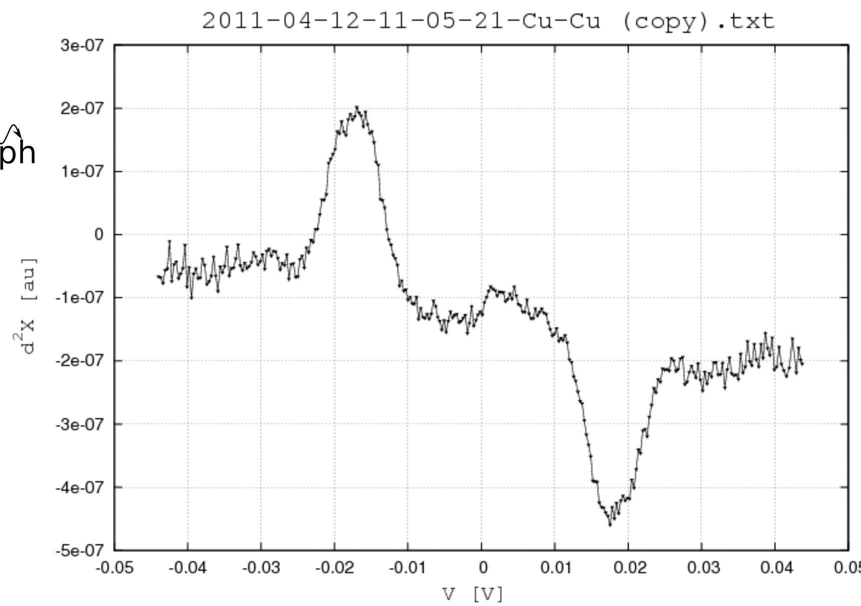
Background

Point contact spectroscopy

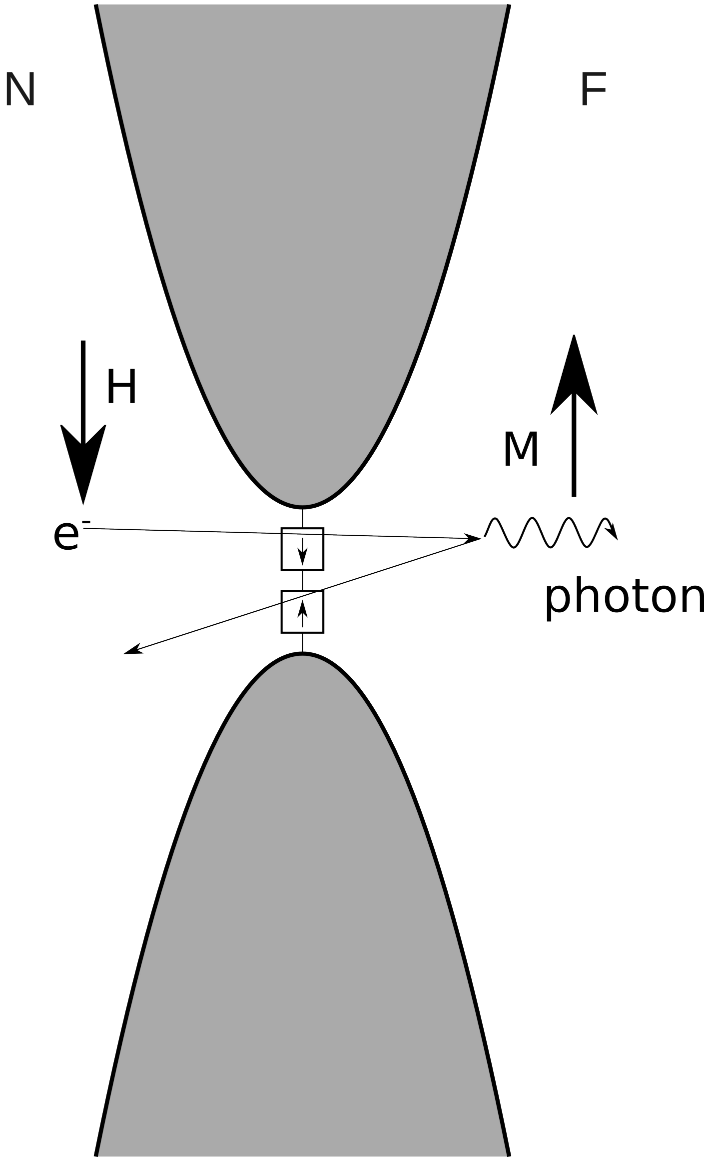
Hard magnets

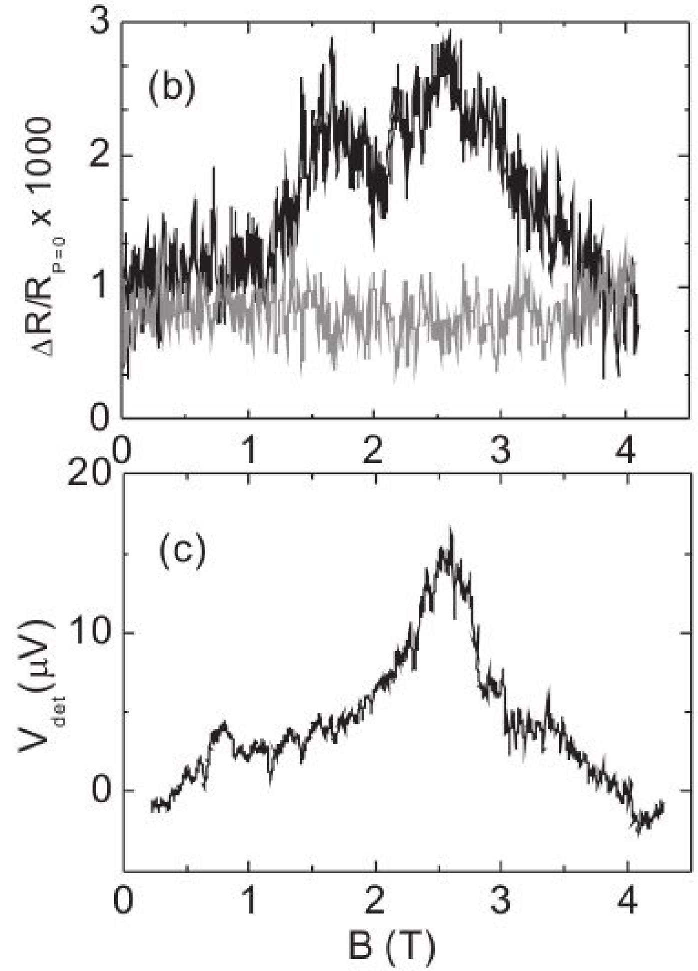
Point contact spectroscopy





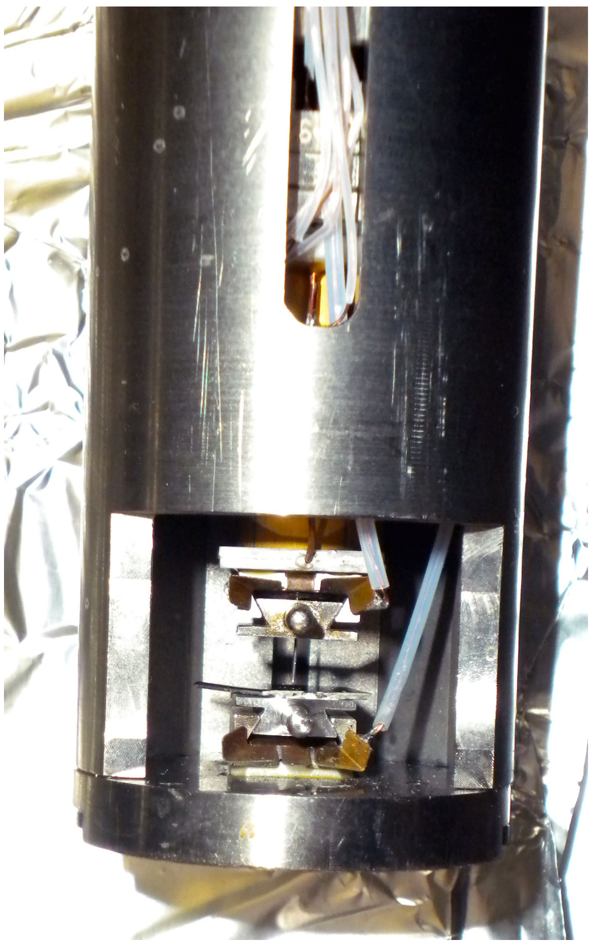
FN point contact spectropy

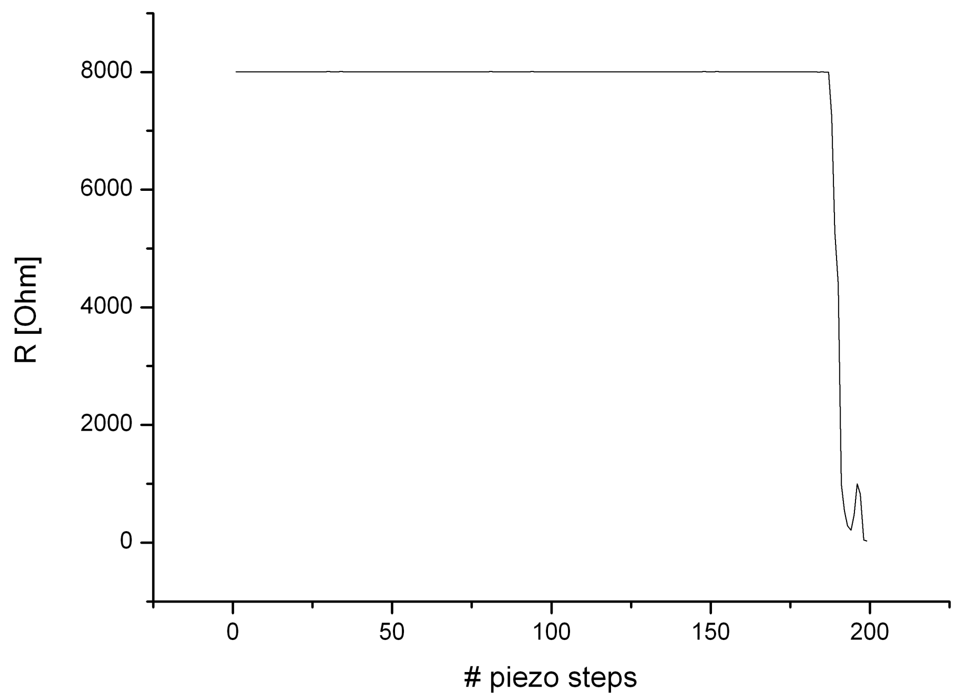




A M Kadigrobov et al 2011 New J. Phys. 13 023007

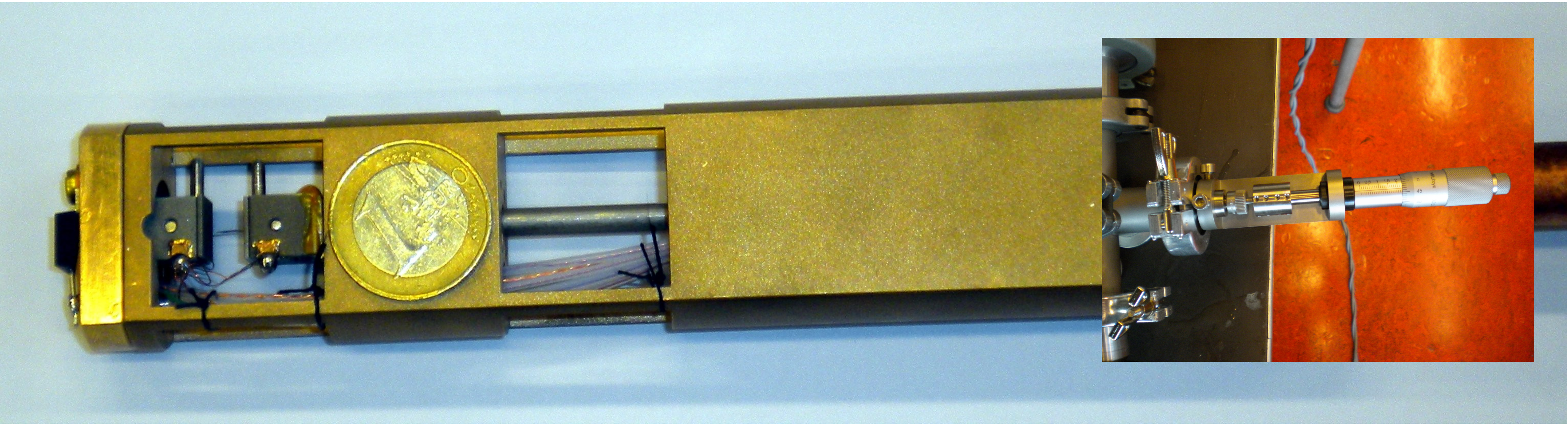
Making a point contact with attocube



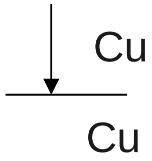


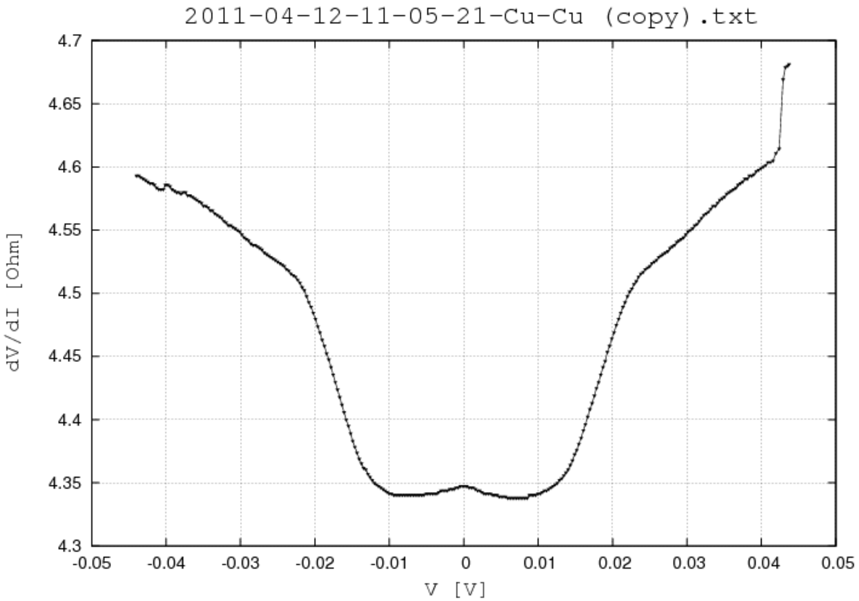
Together with A.Naylor, Leeds

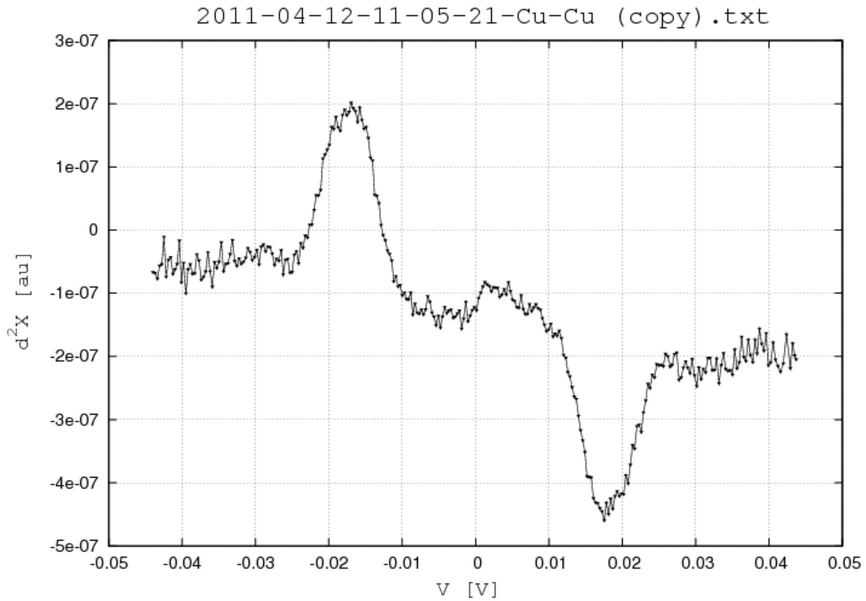
Making a point contact with a micrometer screw



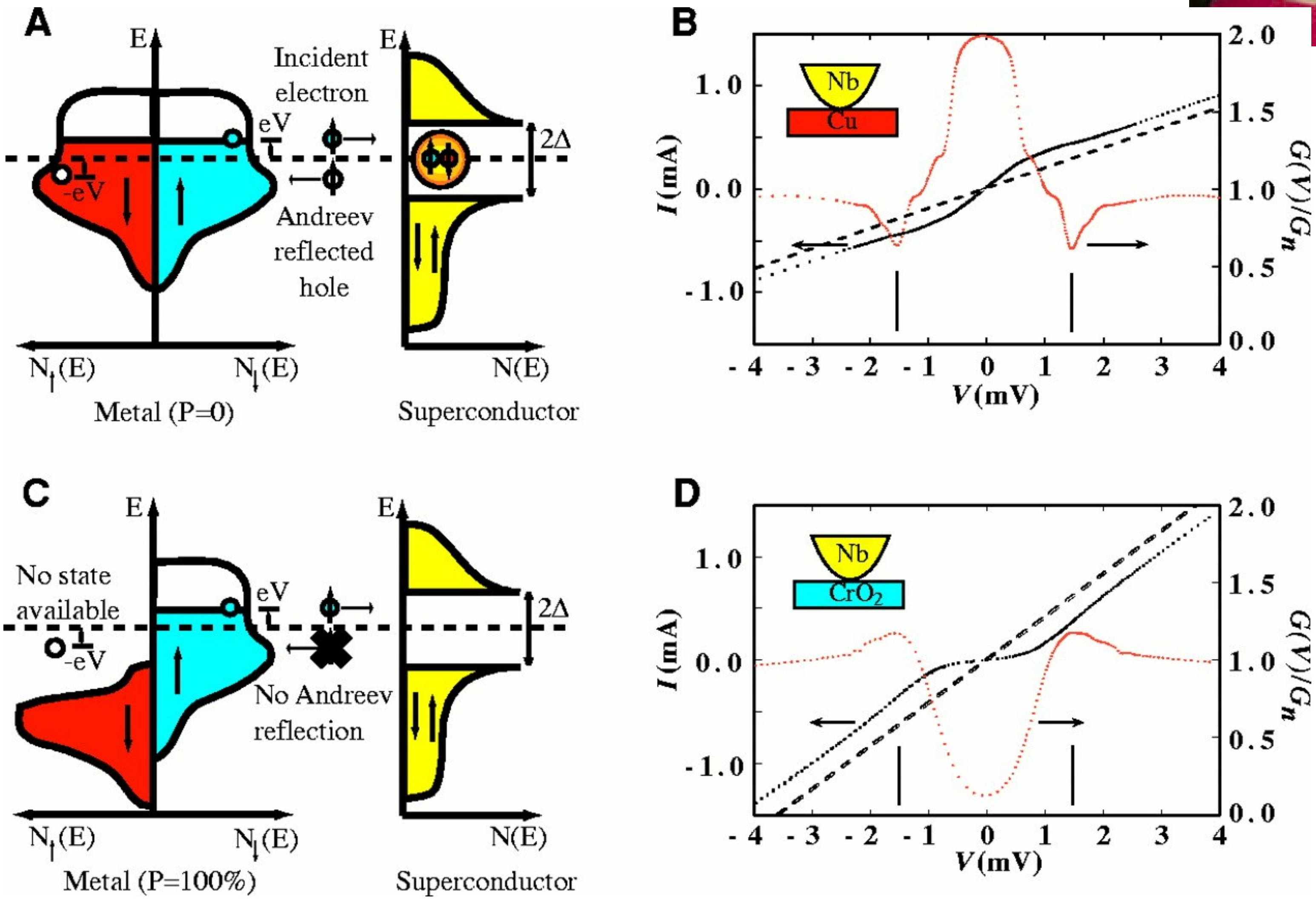
Cu/Cu point contact



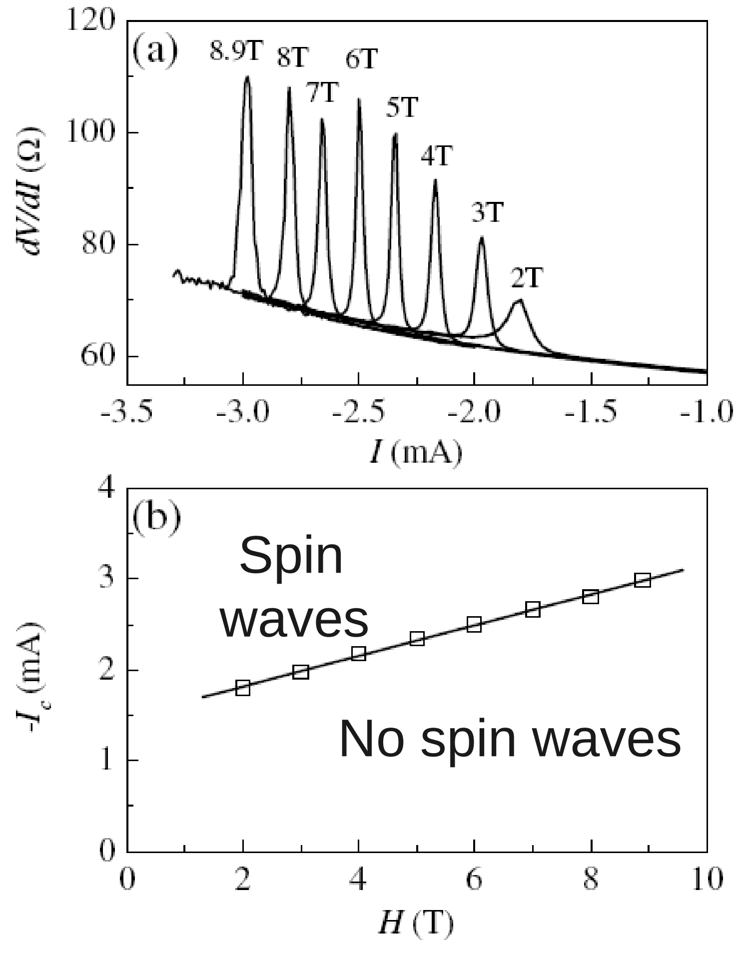




Measure polarization



Excitations magnetic layer



H > Hsaturation

↓

Excite spin waves

↓

Magnetisation changes

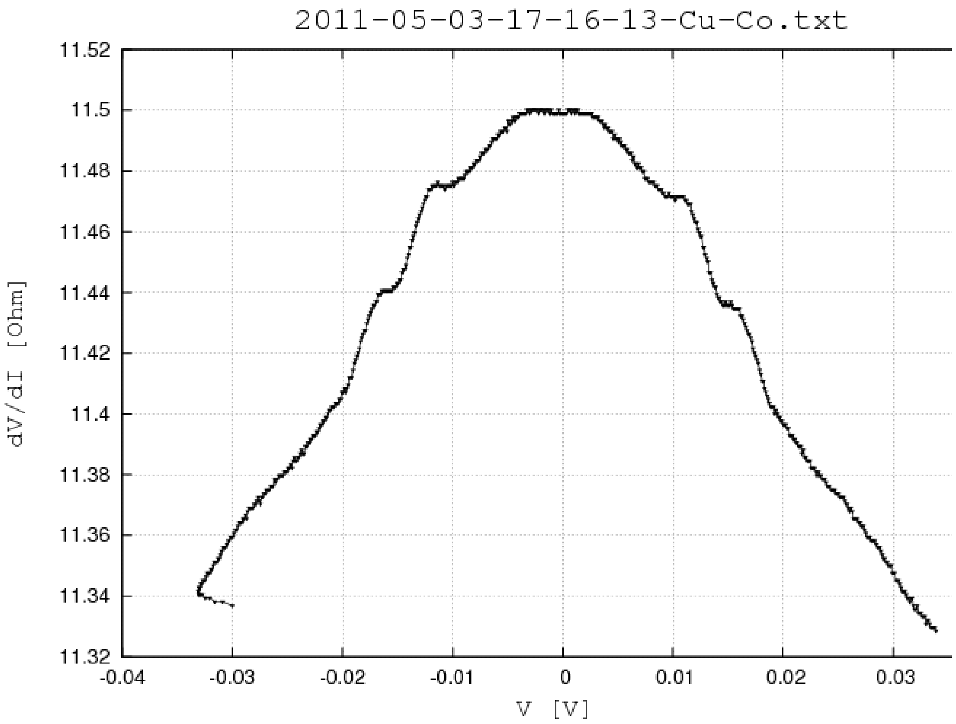
↓

Increase R

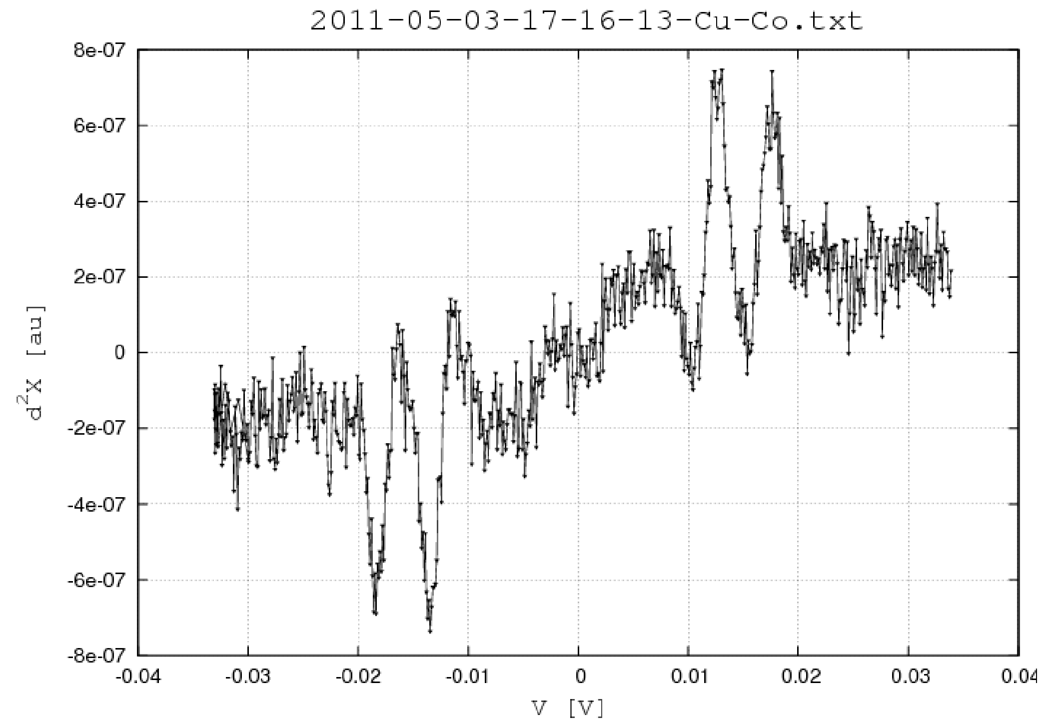
Co|Ag

Ji, Chien and Stiles, prl 90, 106601 (2003)

PCS Cu/Co

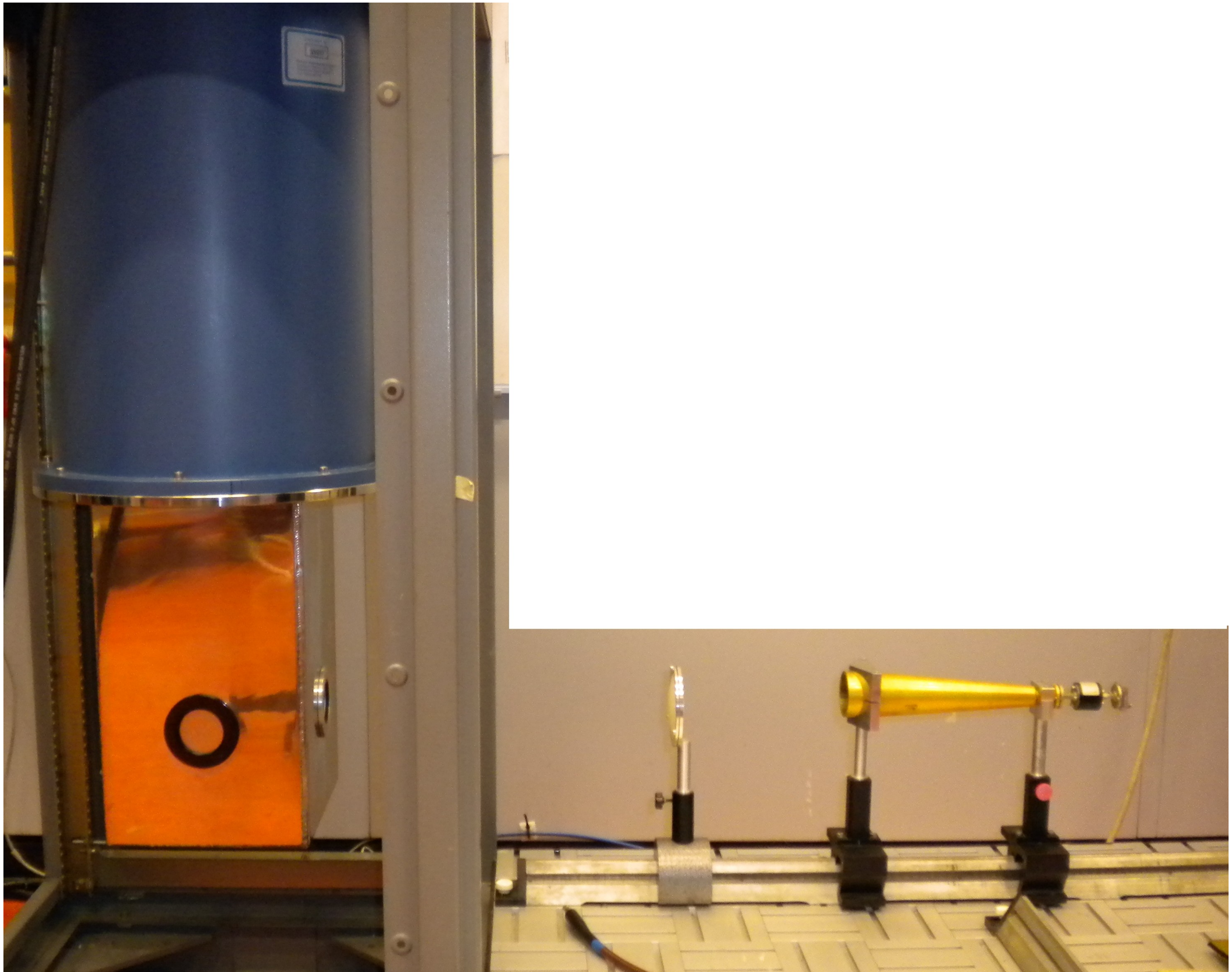


2011-05-03-17-16-13-Cu-Co.txt
dV/dI [Ohm]
11.52
11.5
11.48
11.46
11.44
11.42
11.4
11.38
11.36
11.34
11.32
-0.04
-0.03
-0.02
-0.01
0
0.01
0.02
0.03
V [V]



2011-05-03-17-16-13-Cu-Co.txt
d2X [au]
8e-07
6e-07
4e-07
2e-07
0
-2e-07
-4e-07
-6e-07
-8e-07
-0.04
-0.03
-0.02
-0.01
0
0.01
0.02
0.03
0.04
V [V]

Add radiation



Background

Point contact spectroscopy

Hard magnets

Devices, Majority F recap

If coercive field of F is (much) bigger than applied field

$SmCo_5, AlNiCo, Nd_2Fe_{14}B$

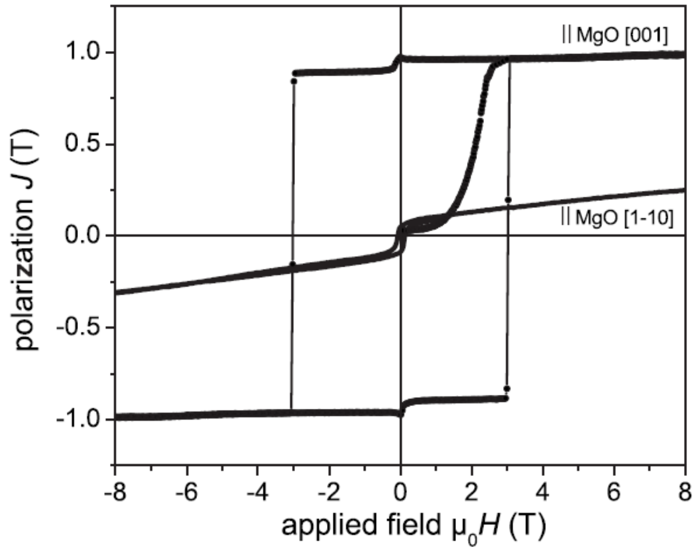
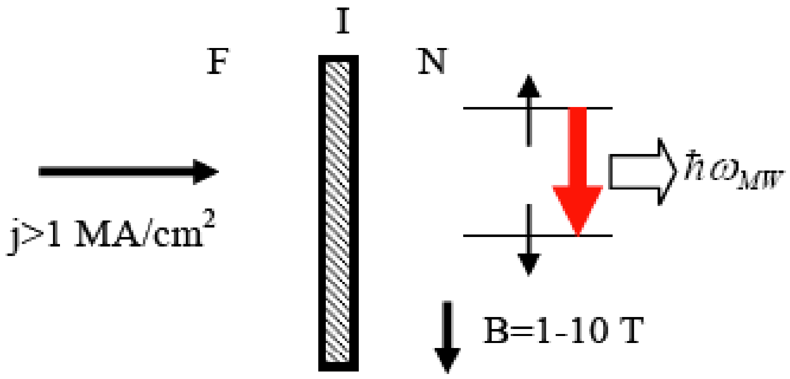


FIG. 2. Magnetic hysteresis of a $SmCo_5$ film measured along the easy magnetization axis (||MgO[001]) and along the in-plane hard axis (||MgO[1−10]).

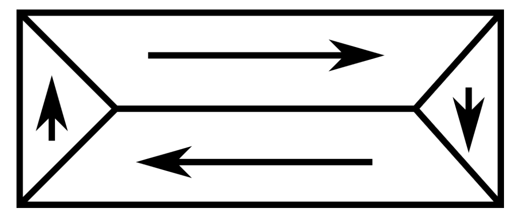


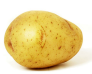
PRB 77 104443

Recipe to make a hard magnet

- Stoner-Wohlfarth criterium:

$$E = K \sin^2(\theta - \phi) - \mu_0 H M_s \cos\phi$$



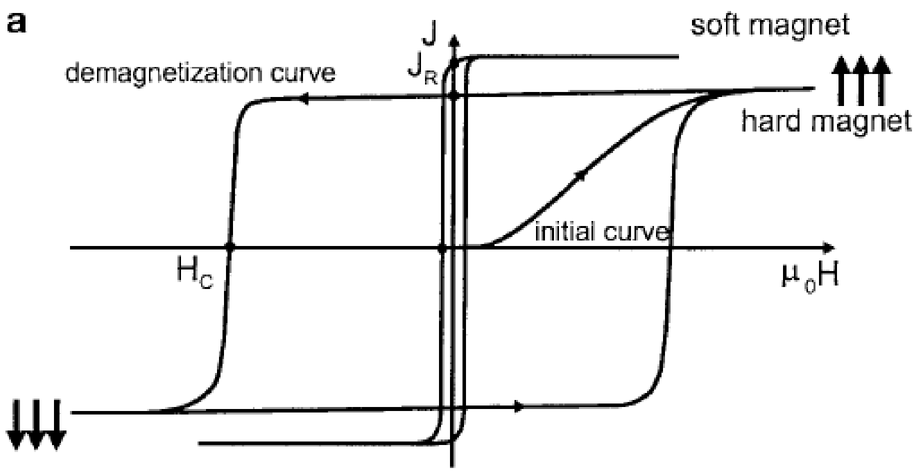

strong uniaxial magnetic anisotropy K
-> crystallography, shape, ...

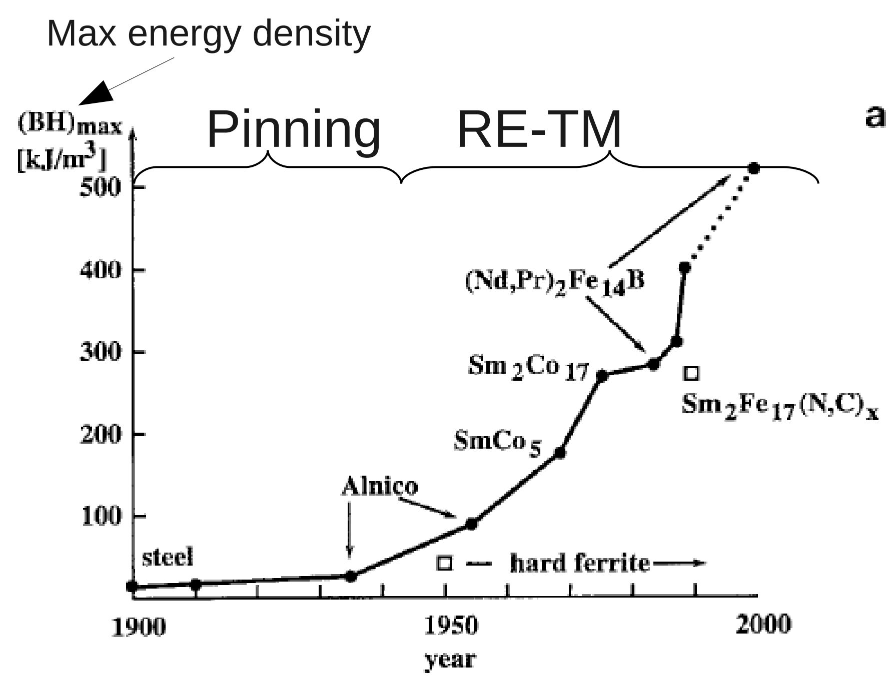

maximize $B_{remnance}$
-> crystal, epitaxial, ...


eliminate domain walls
-> single domain, pin domains, ...


minimize exchange coupling between domains
-> nonmagnetic defects, ...

Hard magnets





Thermally activated switching:

$$\tau \propto \exp^{\frac{K_u V_{grain}}{k_b T}}$$

10 years stable

$$\frac{K_u V_{grain}}{k_b T} > 60$$

Naturwissenschaften **87** 423

JOURNAL OF APPLIED PHYSICS VOLUME 38, NUMBER 3 1 MARCH 1967

A Family of New Cobalt-Base Permanent Magnet Materials

K. STRNAT, G. HOFFER, J. OLSON, AND W. OSTERTAG
Air Force Materials Laboratory, Dayton, Ohio
AND
J. J. BECKER
General Electric Research and Development Center, Schenectady, New York

The magnetocrystalline anisotropy of several intermetallic phases of the type RCo_5 (R = Y, Ce, Pr, Sm, Y-rich and Ce-rich mischmetals) has been investigated, and it is concluded that these alloys are promising candidates for fine-particle permanent magnets. They have extremely high uniaxial anisotropy ($K = 5.4$ to 7.7×10^7 erg/cm^3), single easy axis, high saturation ($B_s = 8500$ to 11 200 G) and Curie point ($t_c = 464°$ to 747°C). Approximate upper limits for the possible energy product lie between 18 and 31.3 MGOe. Experimentally, coercive forces of over 8000 Oe and $(BH)_{max} = 5.1$ MGOe have been observed in $SmCo_5$ merely ground at room temperature. Grinding of YCo_5 and (Ce–MM)Co_5 produces an increase of $_MH_c$ to 2200 and 2700 Oe, respectively, followed by a decrease as particle size continues to decrease.

Rare earth transition metals

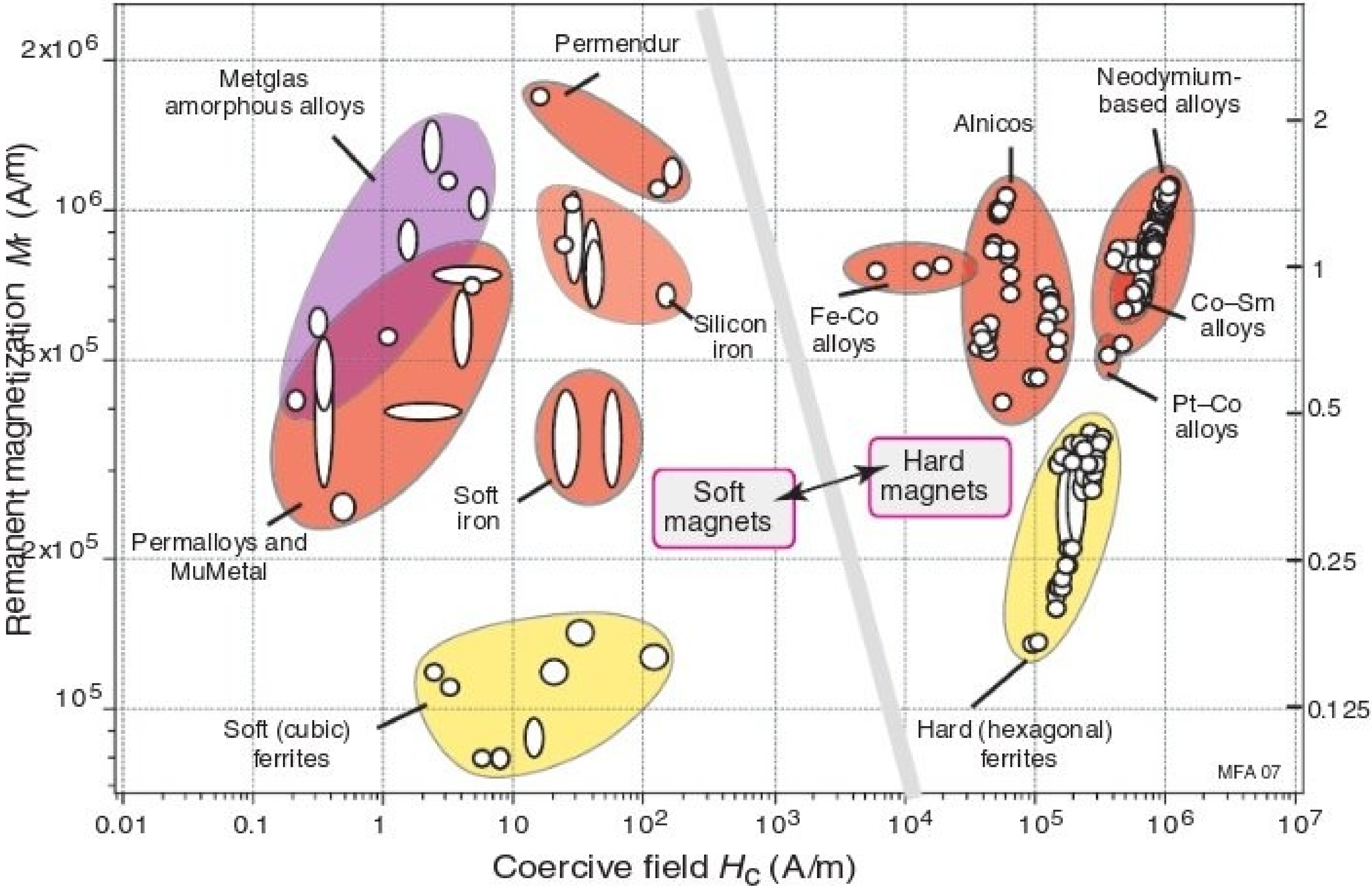
- Nd
- Pr
- Sm

- Fe
- Co

Combine

- High saturation polarization and Tcurie 3d TM
- high crystal anisotropy RE

Hard magnets

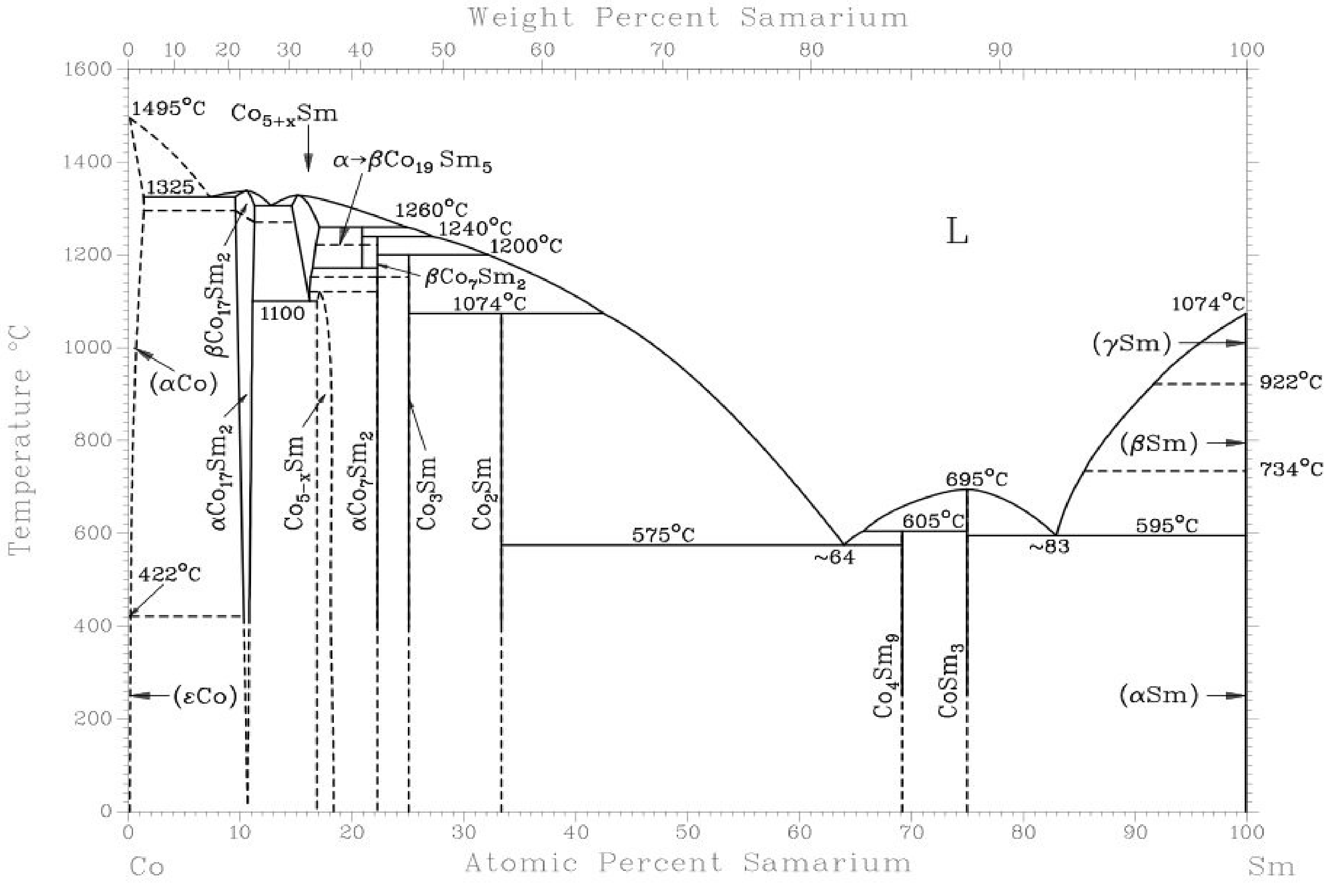


Materials: Engineering, Science, Processing and Design, M.Ashby

1 mT

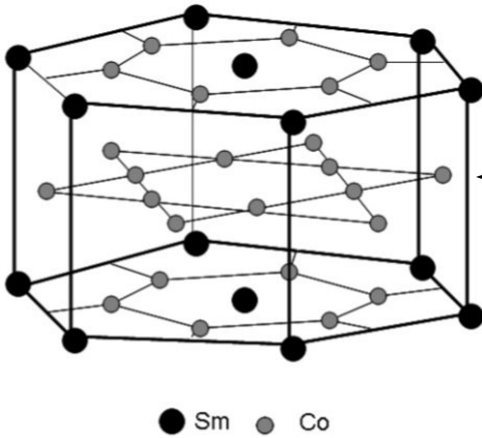
1T

Phase diagram Sm_xCo_y



S. Nagasaki, et al, AGNE Gijutsu Center, Tokyo

$SmCo_5$

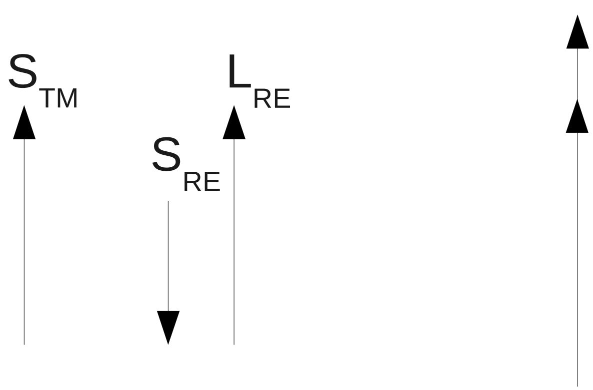


'Sm' sub-lattice

'Co' sub-lattice

Rotated 30°

How to get such a huge magnetization?



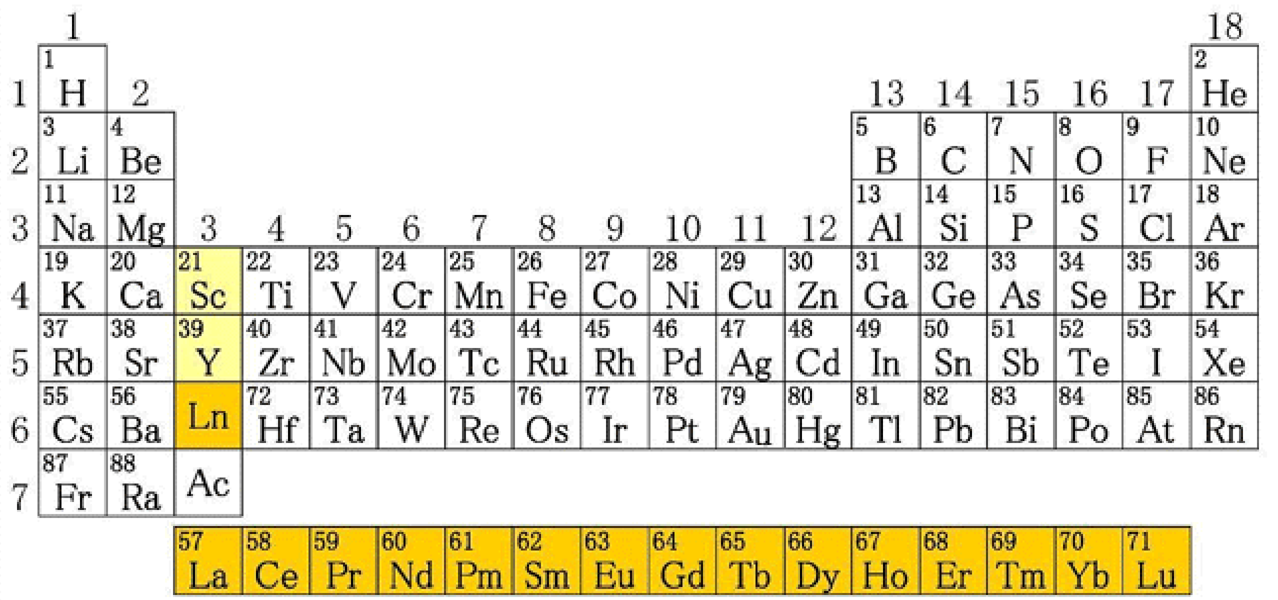
1 Sm, $0.71\mu_B$

5 Co, $8\mu_B$

$M_{exp} = 7.27\ \mu_B$

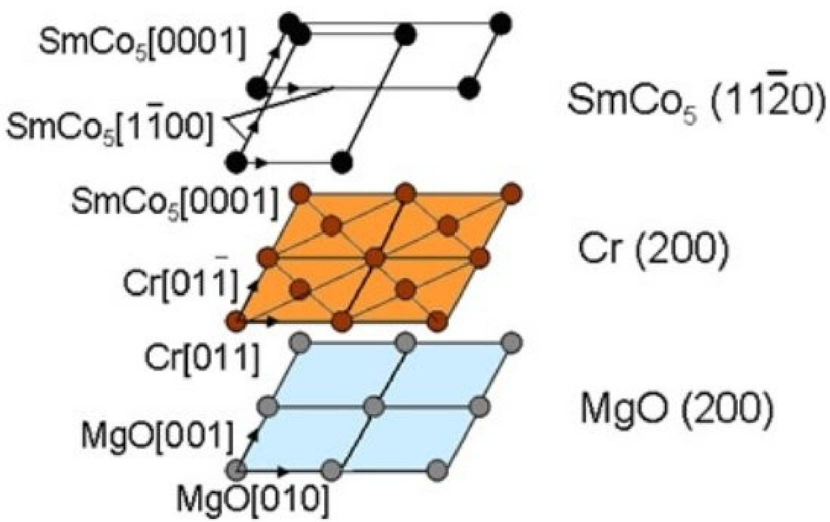
$M_{calc} = 8.71\ \mu_B$

Other systems?



- Anisotropy Co biggest
- Only easy axes of Sm, Er, Tm combines well with Co
- If L & S parallel, total moment antiparallel -> ferrimagnetism (GdNi)

$SmCo_5$ thin film growth



SmCo5

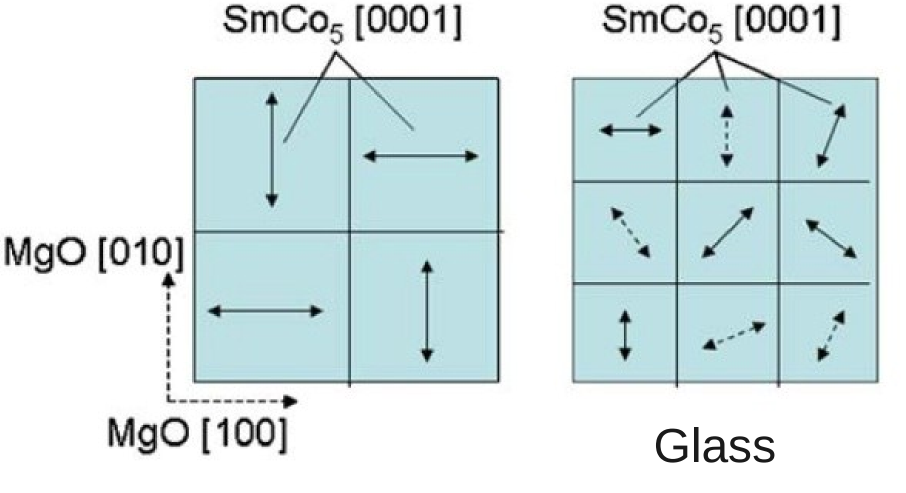
(buffer layer)

Substrate

Substrate

Single crystal to get desired texture
- MgO (100), MgO(110)
- Si (110)

Amorphous glass

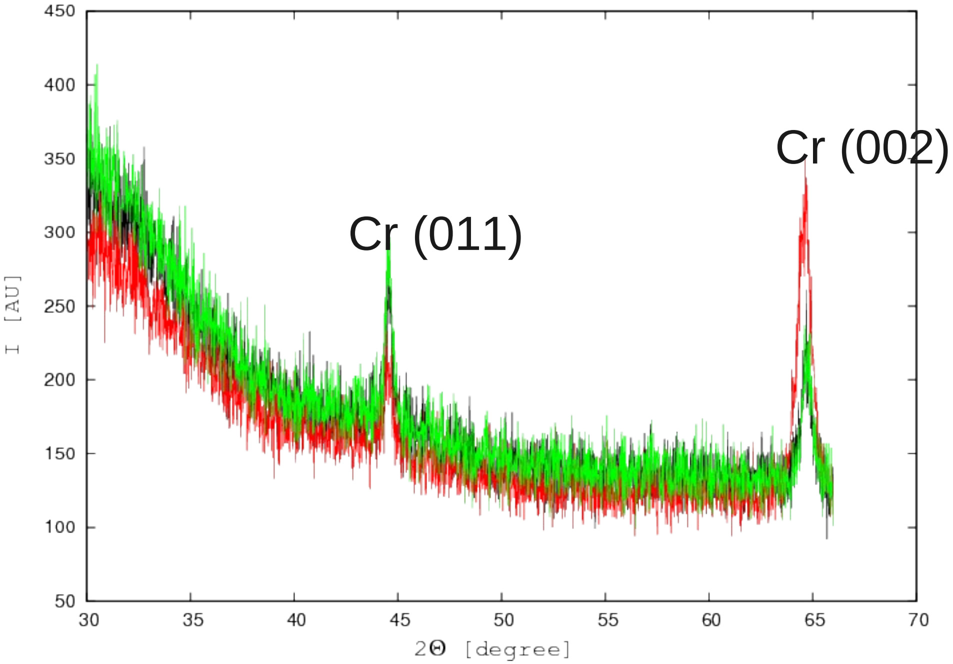


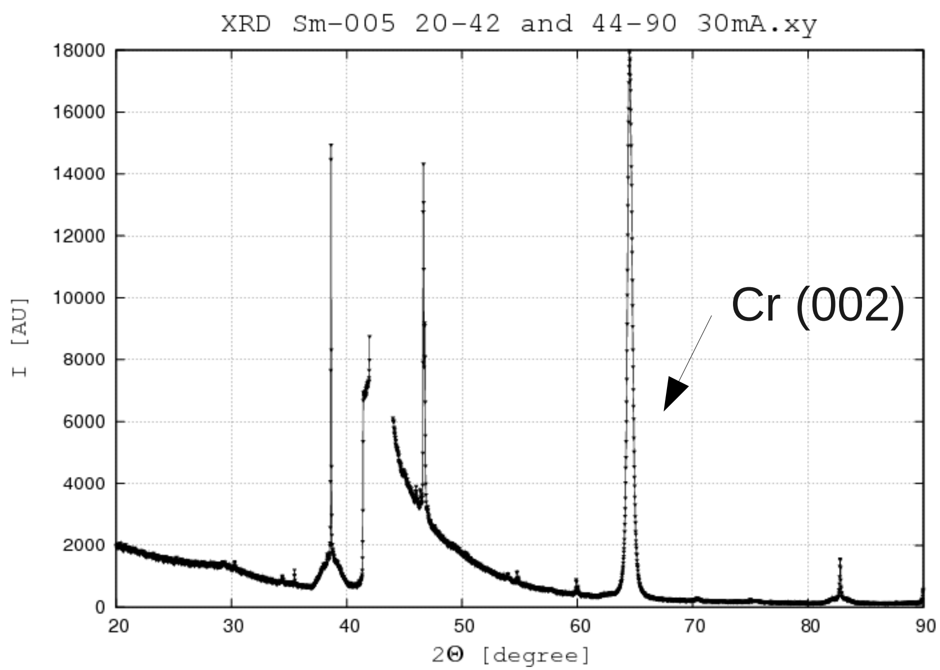
Zhang et al, jmmm 321, 2643 (2009)

Buffer layer

Use Cr buffer layer:

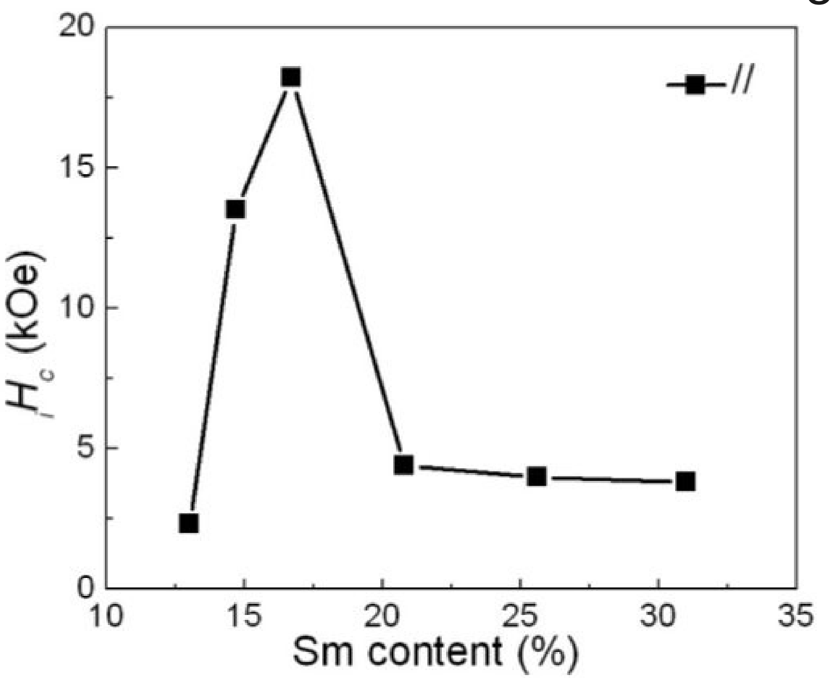
- Lattice mismatch $SmCo_5$| MgO 7 %
  lattice mismatch Cr | MgO ~4 %
- Decrease elastic distortion
- Cr produces:
  - dense film
  - small grains
  - smooth surface

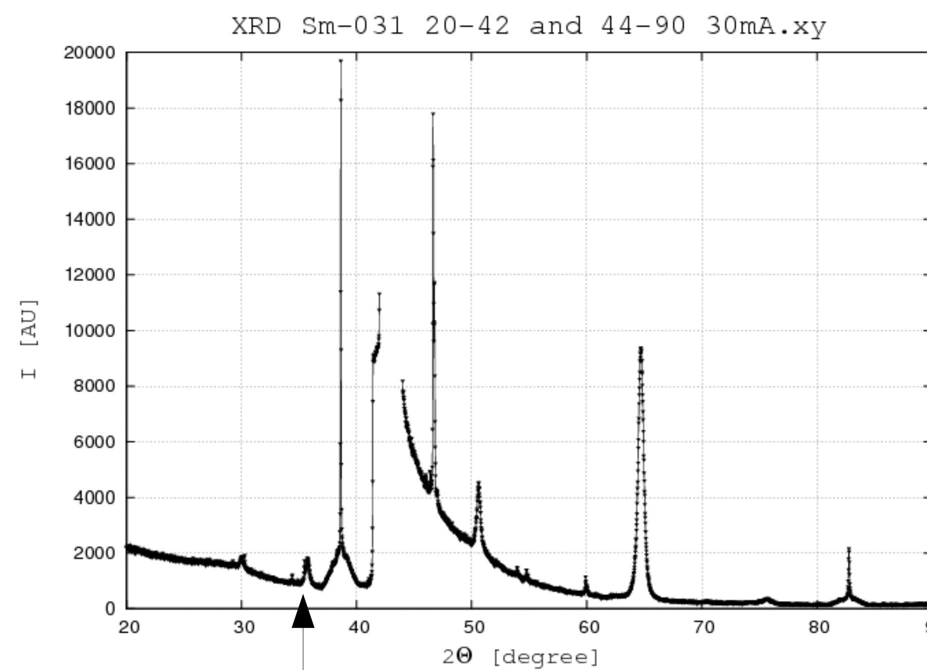




$SmCo_5$ film

- DC sputtering composite target $Sm_{20}Co_{80}$
- [Sputter $Sm(Co,Cu)_5$]*





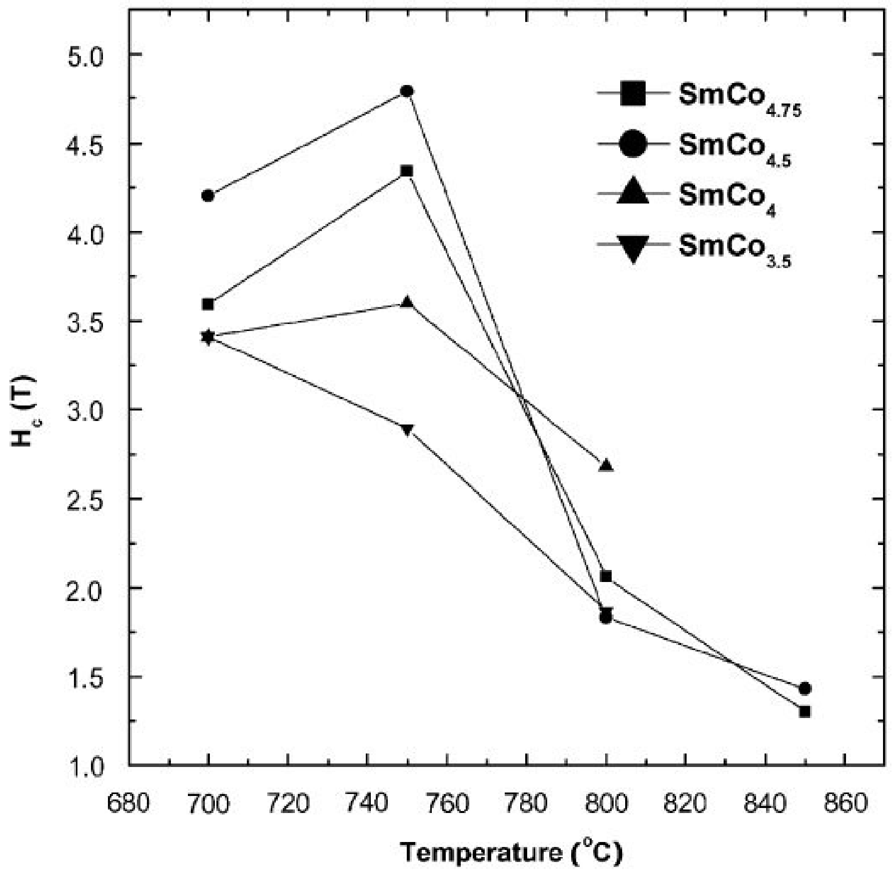
SmCo5 (11-20)

Concentration

Crystal structure

* J.Zhang et al, Jmmm 310, 1

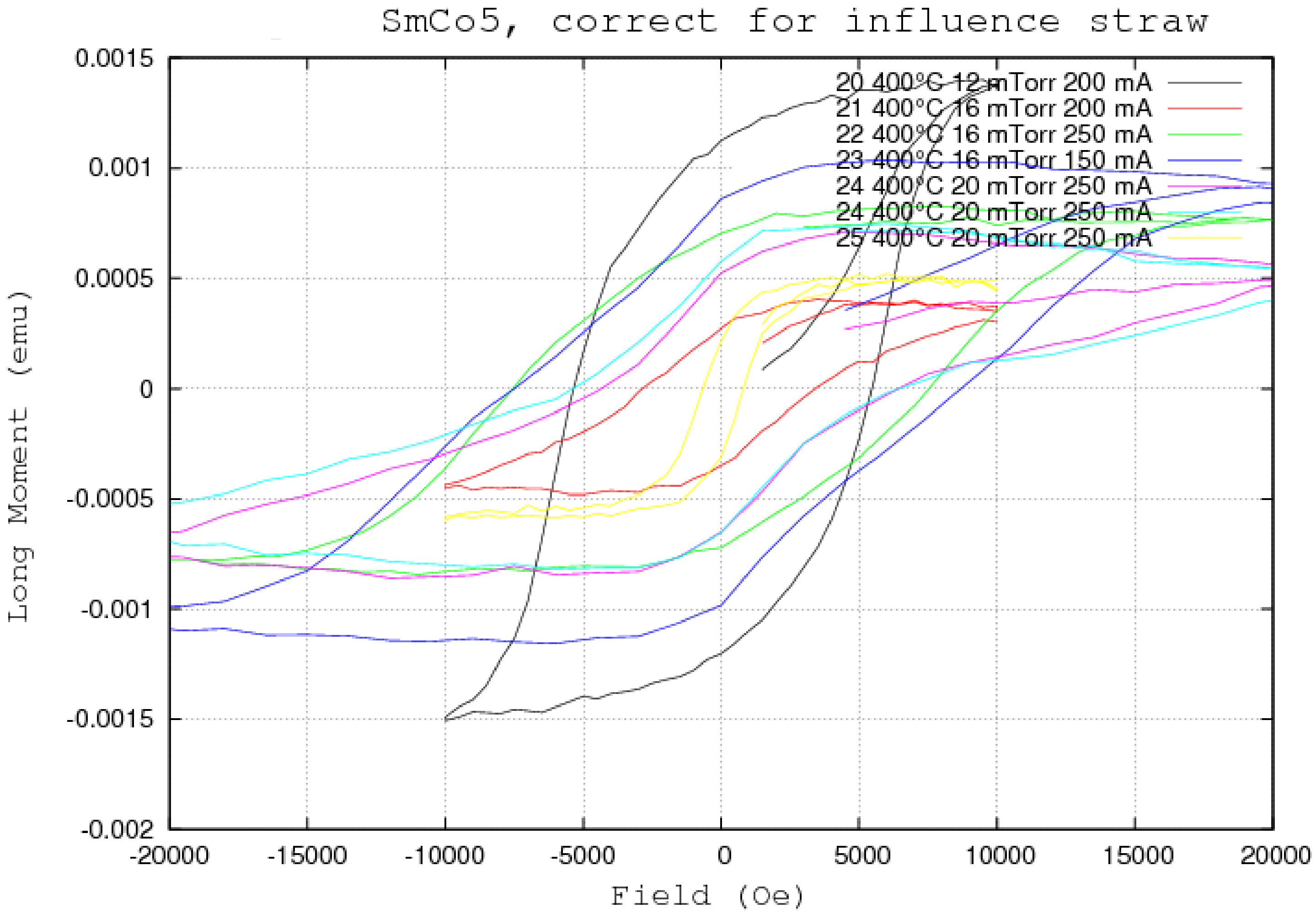
Annealing



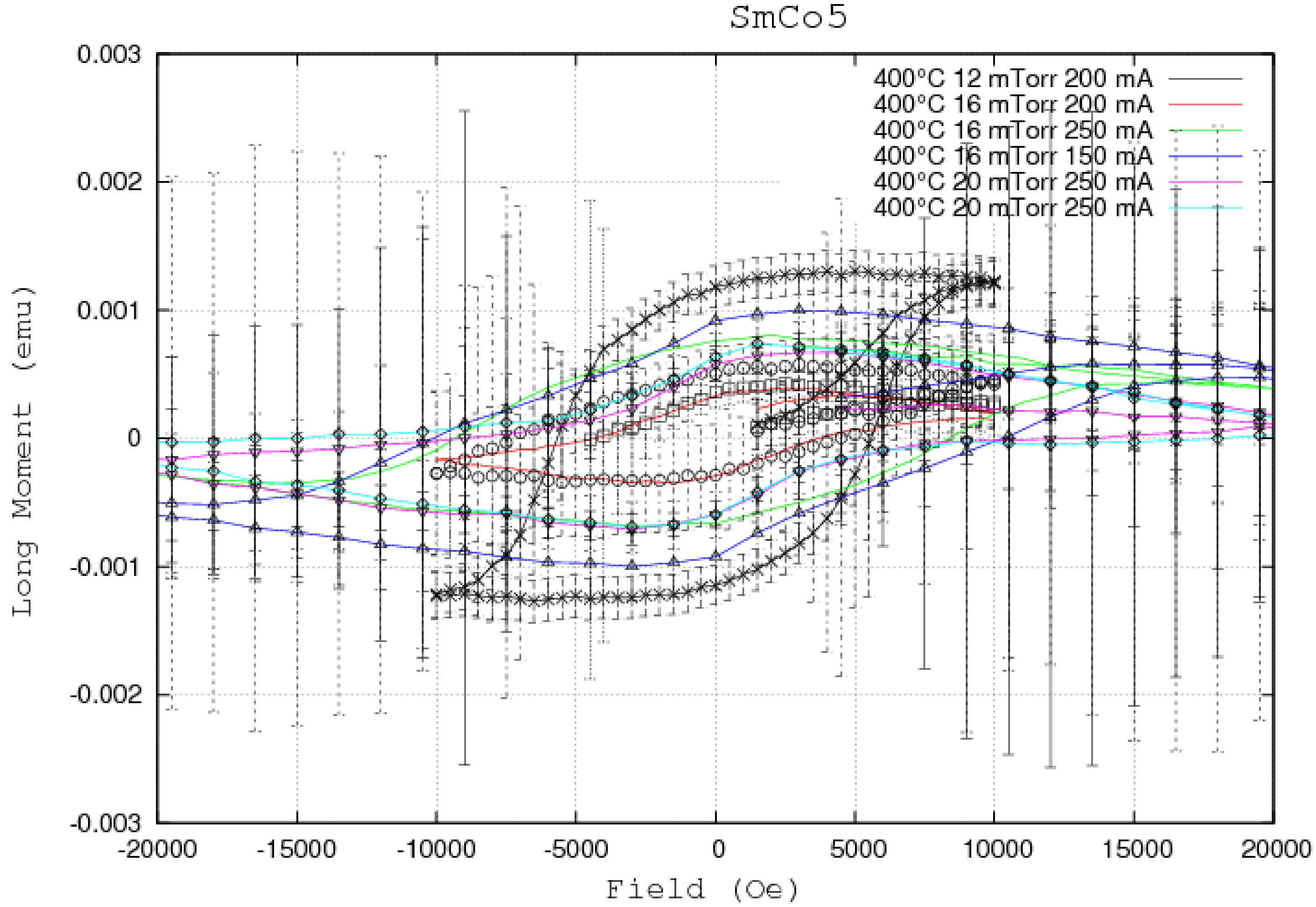
- Rapid thermal annealing
- Diffusion between layers
- Change crystallography

Zhang et al, JMMM 310, 1

Coercive fields grown $SmCo_5$



Coercive fields, with errorbar, grown $SmCo_5$



Outlook

- Grow $SmCo_5$ & measure with squid

- PCS FN structures and observe STT (Stefano)
- Apply radiation

- Measure V_{ish} during spin pumpings
- Spin pump GdNi (Hiske)

Hiske Overweg

Spin pumping