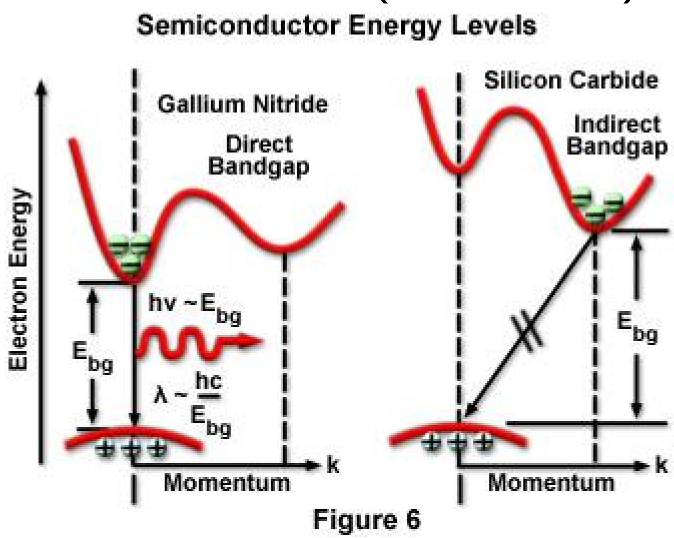
Spin flip lasers

Tim Verhagen

Groupmeeting, October 6th 2010

Spin flip laser

Semiconductor (laser diode)



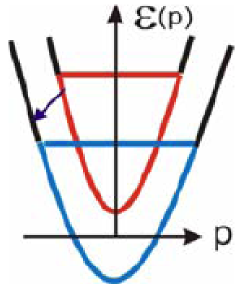
$\Delta k = 0$

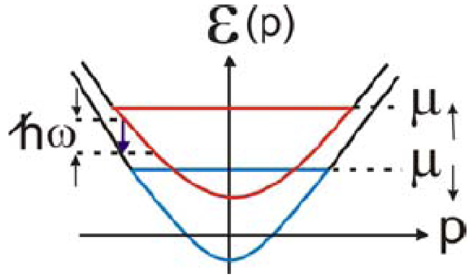
photon

$\Delta k \neq 0$

phonon

Magnetic (spin flip laser)





$\Delta k \neq 0$

magnon

↓

High frequency oscillators

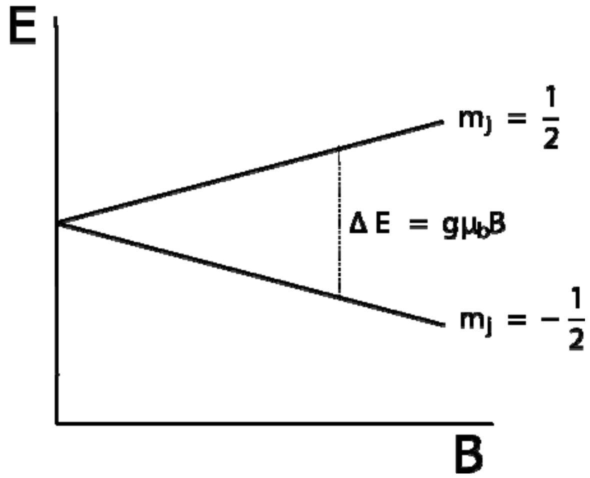
$\Delta k = 0$

photon

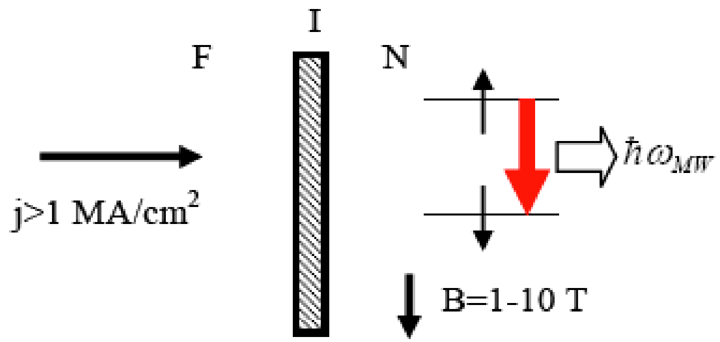
↓

High frequency lasers

Zeeman split transition



Zeeman effect



$$h\nu = g\mu_B m_s B$$
$$\nu = 0.007 gB[\mathrm{THz}]$$

Devices, Majority F

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

($SmCo_5, AlNiCo, Nd_2Fe_{14}B$)

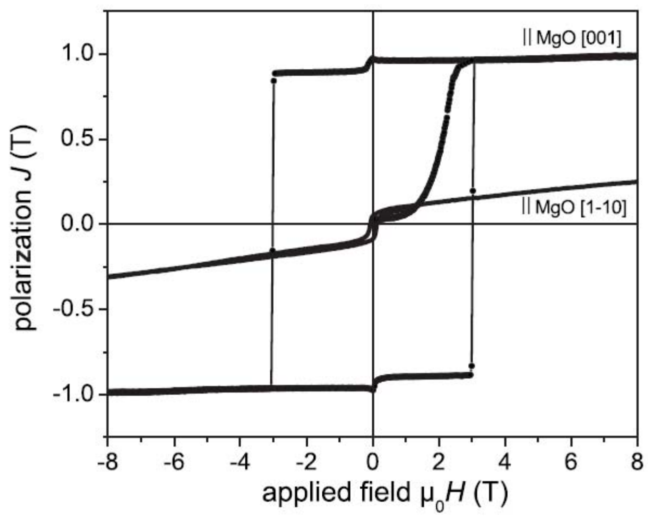
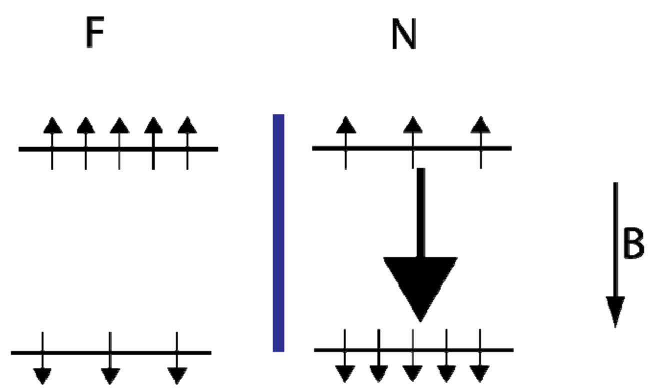
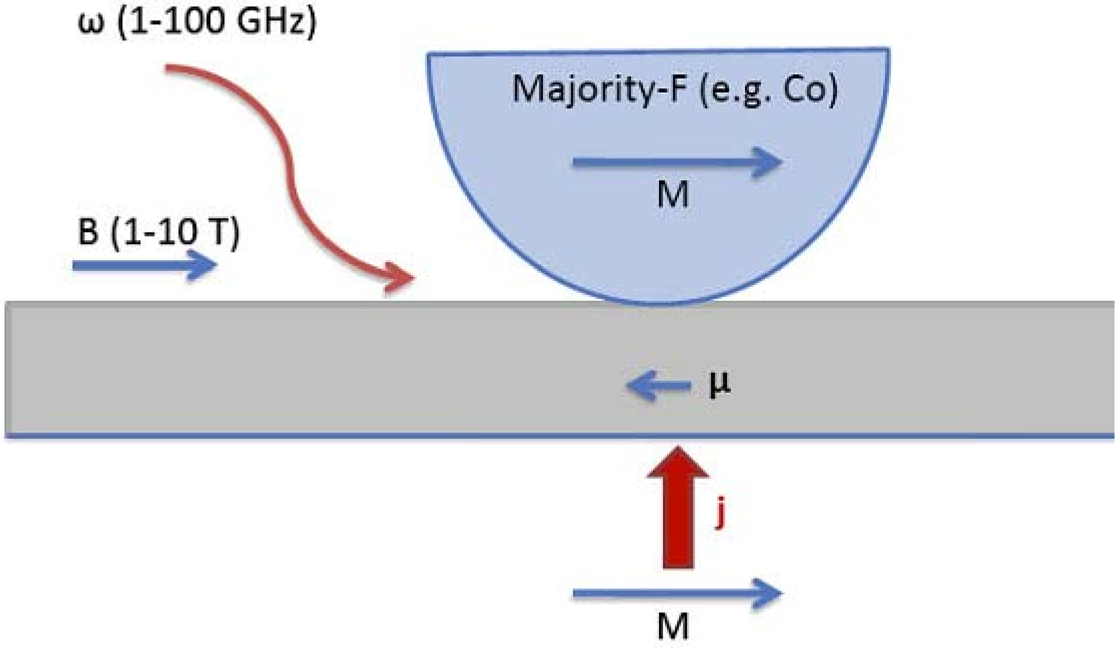


FIG. 2. Magnetic hysteresis of a $SmCo_5$ film measured along the easy magnetization axis (‖MgO[001]) and along the in-plane hard axis (‖MgO[1−10]).



PRB 77 104443

Experimental Zeeman lasing



- Spin flip laser
- **Point contact spectroscopy**
- $SmCo_5$
- Radiation setup

What is a good point contact?

1. For pure metals, the contact resistance is within 1 to 100 Ω and the short has the metallic conductivity; i. e., its resistance increases with the voltage rise so that $d^2V/dI^2 > 0$ over the whole energy range.
2. Distinct maxima are observed in the PC spectrum at energy between zero and maximal one $\hbar\omega_{max}$. They are reproducible for different contacts of the particular metal. At energy $eV > \hbar\omega_{max}$, the spectrum contains a certain constant background value. The background parameter $\gamma = B/A$ (Fig. 4.2) is different for each metal, but as a rule, it should not be greater than 0.5.
3. Relative variation of the differential resistance within the spectrum has to be maximal among the spectra with the same other characteristics. Around zero-bias at $eV \ll \hbar\omega_{max}$, the d^2V/dI^2 curve behaves monotonously as V^n (see Table 3.1) or zero-bias anomaly should be as weak as possible.

Yansson & Naidyuk, Point Contact Spectroscopy

What is a good point contact?

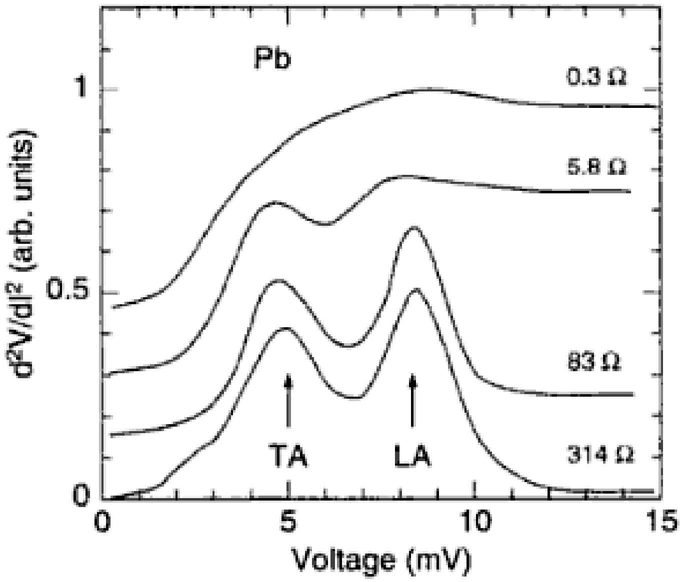


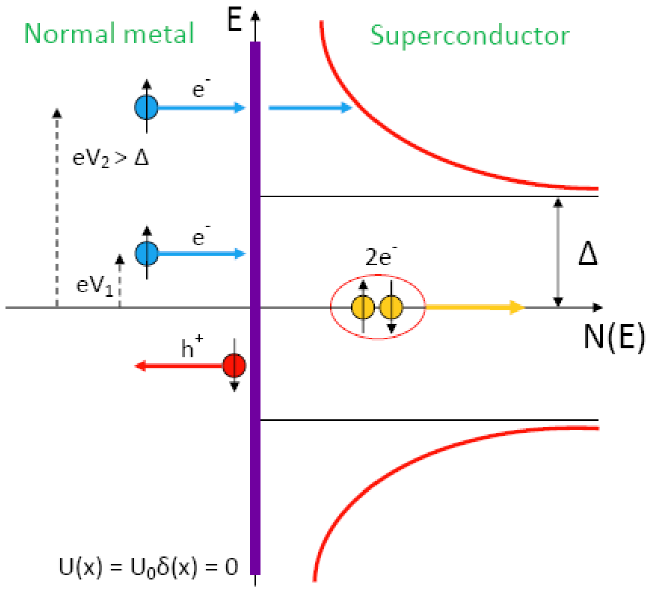
Fig. 2.3. Second derivative of $I - V$ curves for a Pb tunnel junction with micro-constriction at helium temperature in the process of successive decreasing of the resistance of the constriction from 314 Ω (bottom curve) to 0.3 Ω (top curve). The positions of longitudinal acoustic (LA) and transverse acoustic (TA) phonon peaks in Pb are indicated by arrows. The curves are offset vertically for clarity. Data taken from Yanson (1974).

Yansson & Naidyuk, Point Contact Spectroscopy

Add a superconductor

Create a normal metal – superconductor interface,

so Andreev reflection

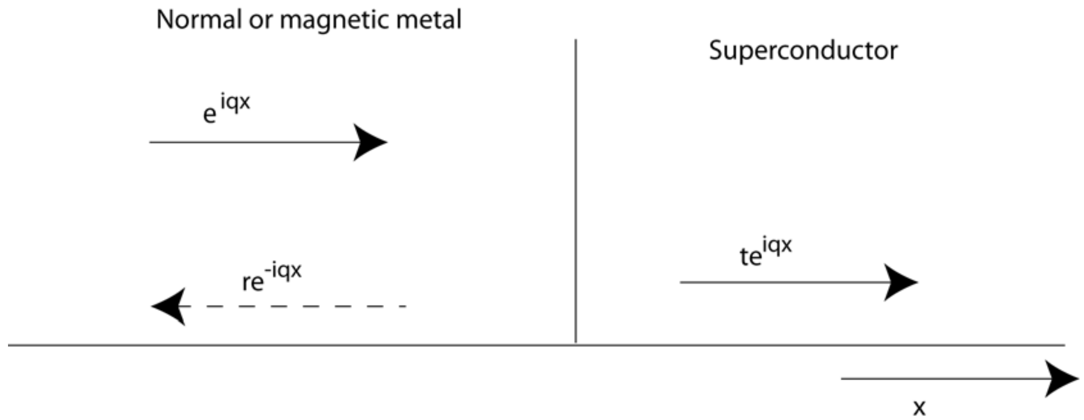


Daghero & Gonnelli, arxiv:0912.4858v1

Add a superconductor

Bogoliubov de Gennes equation

$$\begin{cases} i\hbar\dfrac{\partial f(x,t)}{\partial t} &= \left[-\dfrac{\hbar^2\nabla^2}{2m} - \mu(x) + V(x)\right] f(x,t) + \Delta(x) g(x,t) \\ i\hbar\dfrac{\partial g(x,t)}{\partial t} &= \left[\dfrac{\hbar^2\nabla^2}{2m} - \mu(x) + V(x)\right] g(x,t) + \Delta(x) f(x,t) \end{cases}$$

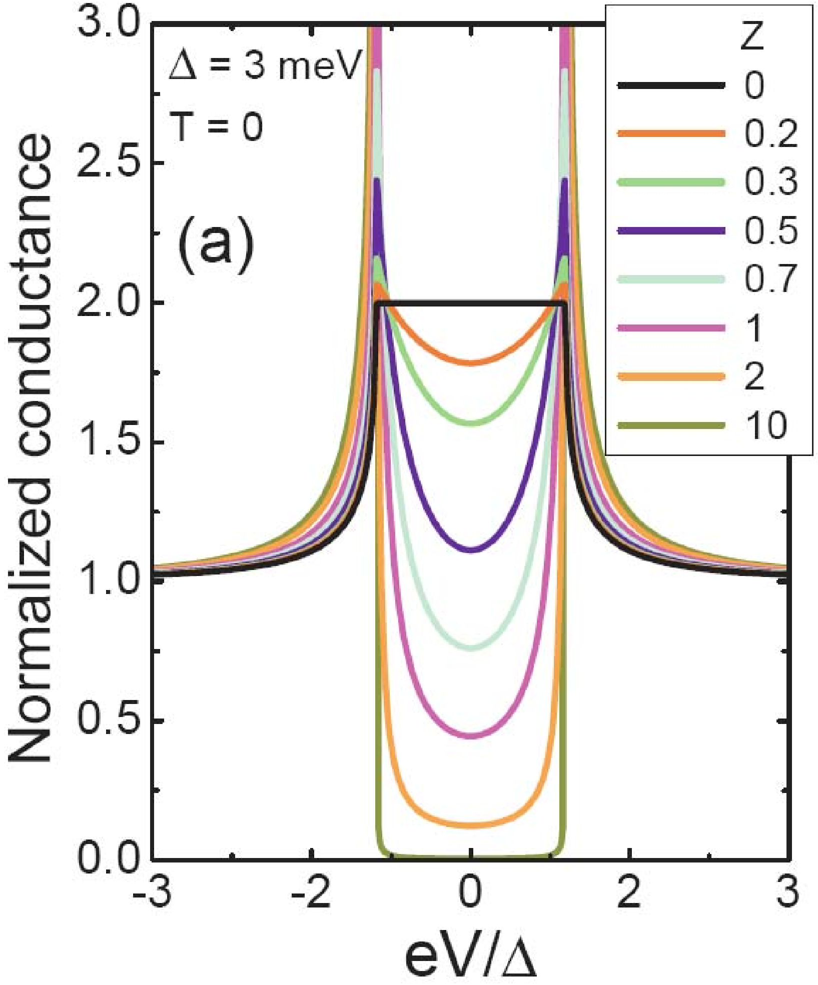


Solve -> Transmission coefficient @ 0K: $T(\varepsilon) = 1 + A(\varepsilon) - B(\varepsilon)$

Probability Andreev reflection

Probability normal reflection

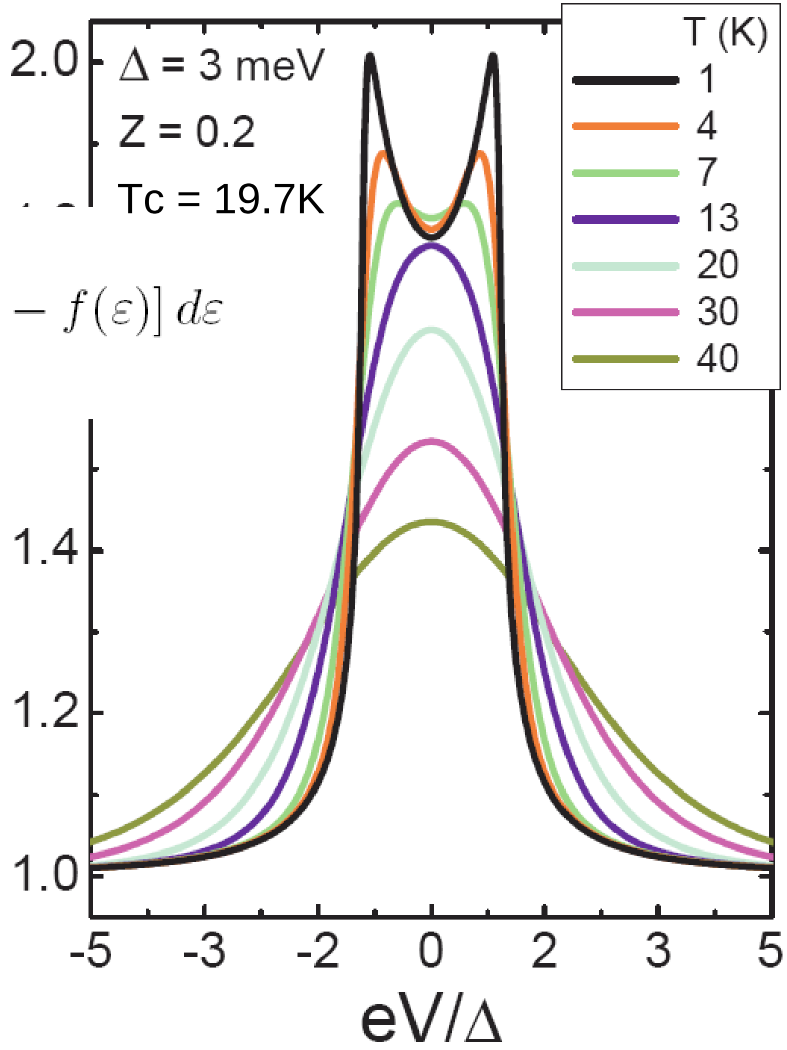
Add a superconductor



Daghero & Gonnelli, arxiv:0912.4858v1

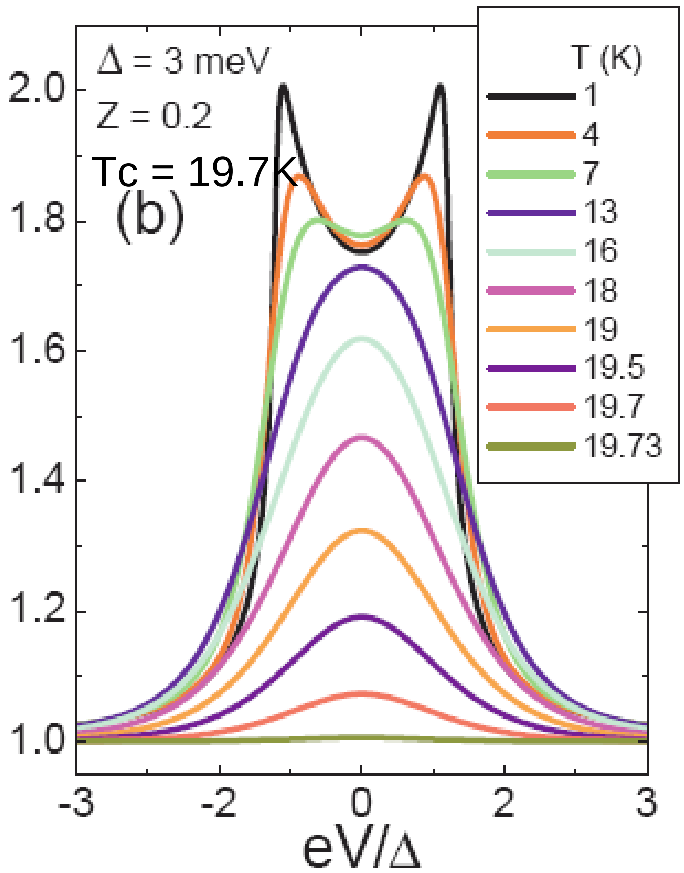
Add temperature

$$I = \int_{-\infty}^{+\infty} [1 + A(\varepsilon) - B(\varepsilon)] \, [f(\varepsilon - eV) - f(\varepsilon)] \, d\varepsilon$$



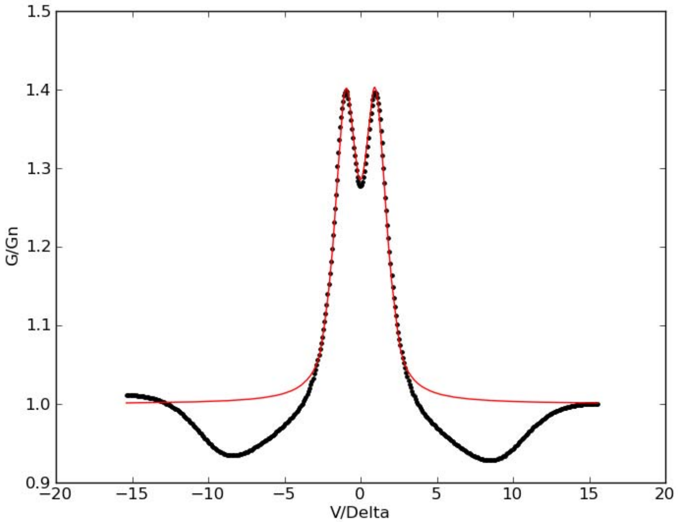
Daghero & Gonnelli, arxiv:0912.4858v1

Include gap(T)



Daghero & Gonnelli, arxiv:0912.4858v1

Too low temperature?



Best T<4.2K

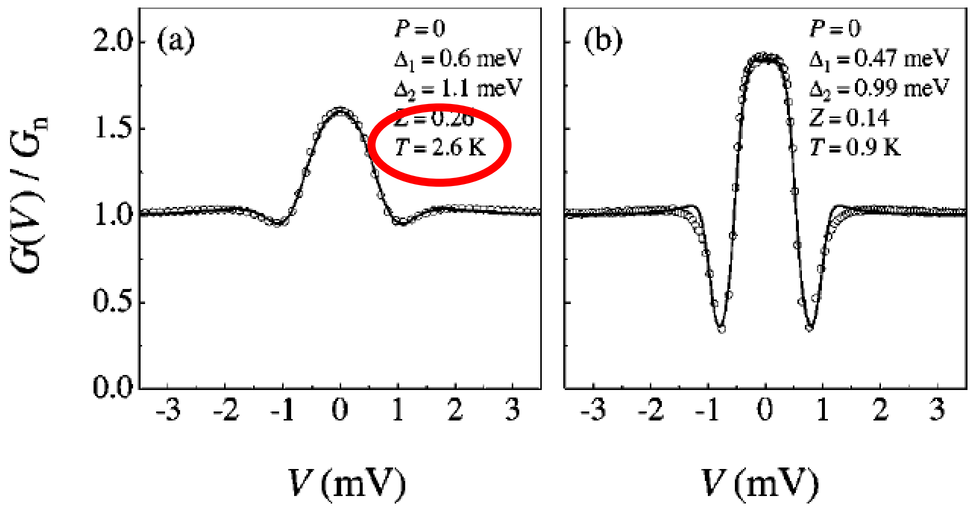


FIG. 4. Representative conductance versus voltage curves for Cu/Nb at $T=4.2$ K (open circles) with a contact resistance of (a) $R=7.6\ \Omega$ and (b) $R=2.4\ \Omega$. The solid lines are fits using the model of Sec. II, resulting in P, Δ_1, Δ_2, Z, and T as indicated in the figure.

the proximity effect in the Cu plays an important role. Since temperature is included in our model by an equilibrium Fermi-Dirac distribution function, the fitted temperature is considerably lower than 4.2 K, as shown in Fig. 4. Formally

Strijkers, PRB **63** 104510

Add inelastic scattering

$$i\hbar\frac{\partial f(x,t)}{\partial t} = \left[-\frac{\hbar^2\nabla^2}{2m} - \mu(x) - i\Gamma_i + V(x)\right] f(x,t) + \Delta(x) g(x,t)$$
$$i\hbar\frac{\partial g(x,t)}{\partial t} = \left[\frac{\hbar^2\nabla^2}{2m} - \mu(x) + i\Gamma_i + V(x)\right] g(x,t) + \Delta(x) f(x,t)$$

Inelastic scattering

$$u_0^2 = \frac{1}{2}\left[1 + \frac{\sqrt{\varepsilon^2 + \Delta^2}}{\varepsilon}\right] \xrightarrow{\text{Dyson}} u_0^2 = \frac{1}{2}\left[1 + \frac{\sqrt{(\varepsilon + i\Gamma)^2 + \Delta^2}}{\varepsilon + i\Gamma}\right]$$

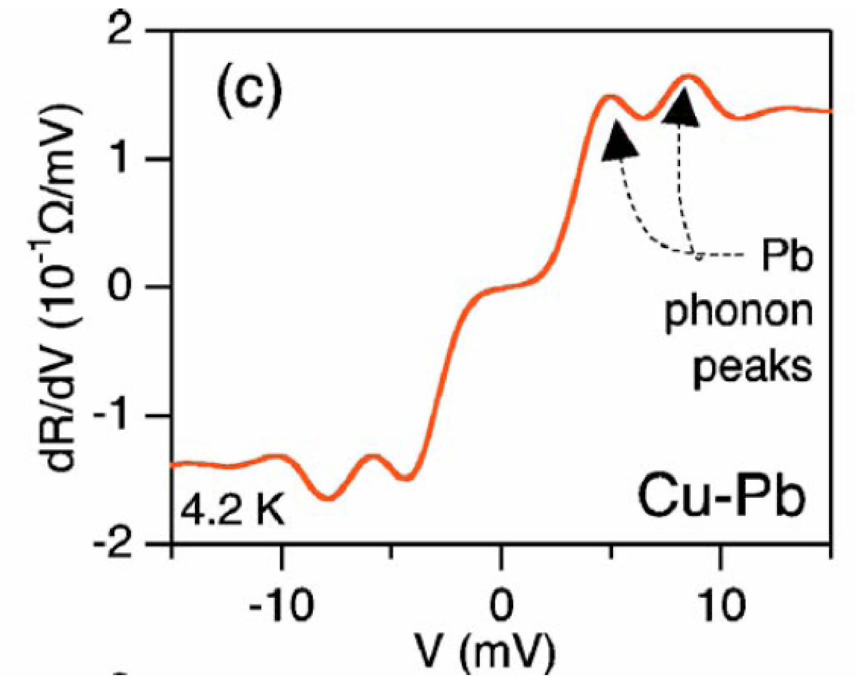
Solve -> Transmission coefficient @ 0K: $T(\varepsilon) = 1 + A(\varepsilon) - B(\varepsilon)$

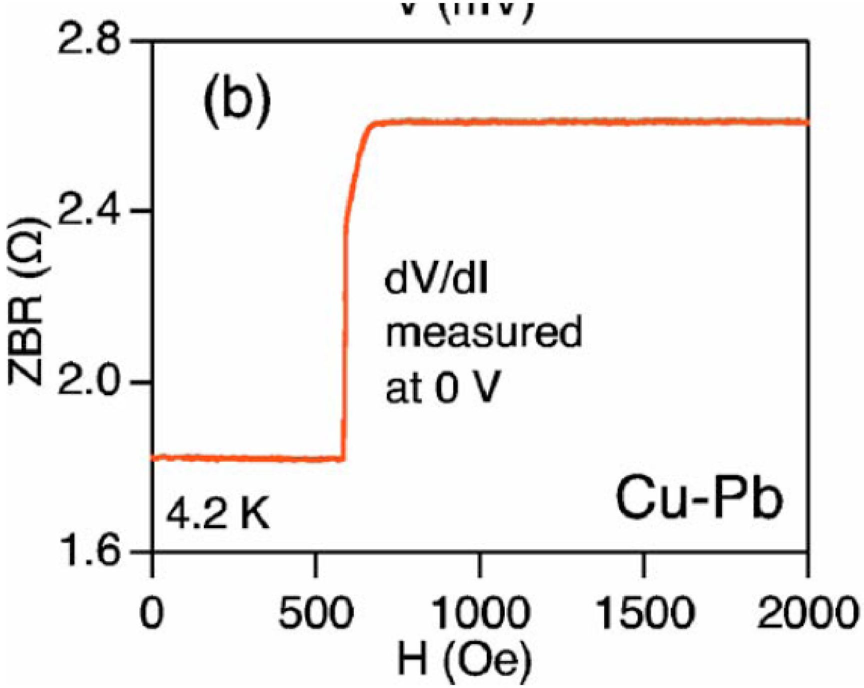
Probability Andreev reflection

Probability normal reflection

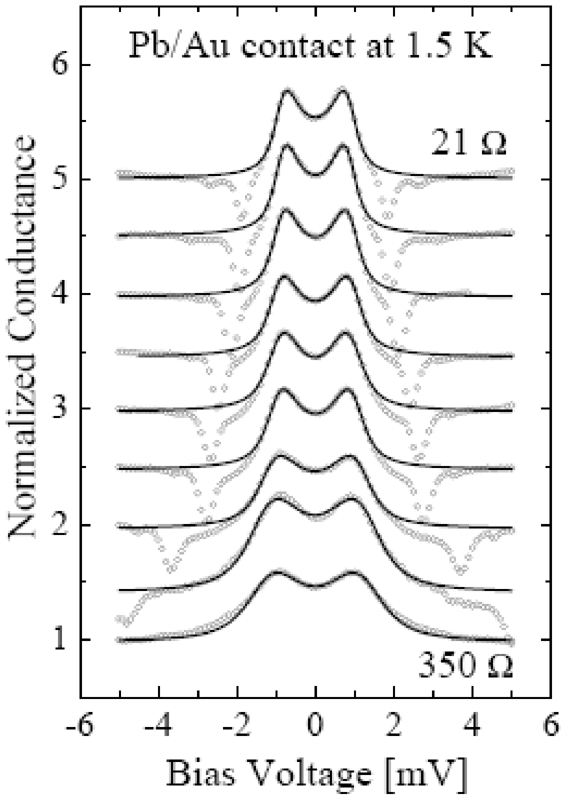
Plecenik et al, Prb **49** 10016

What to expect?



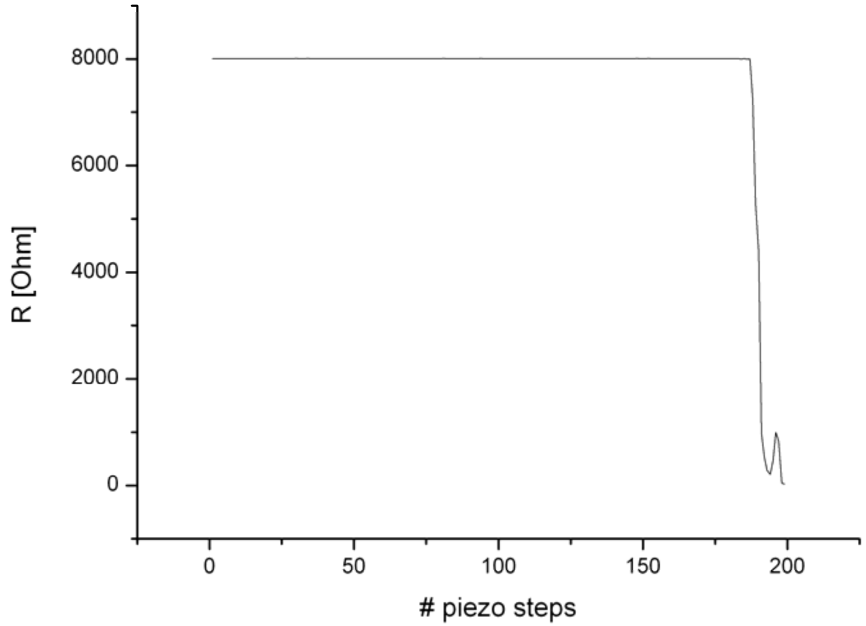


What to expect?

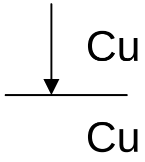


Thesis Kant

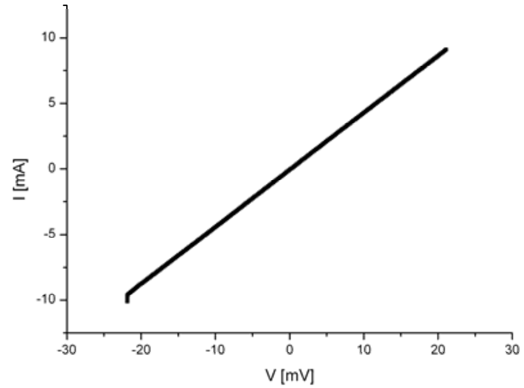
Making a point contact with attocube

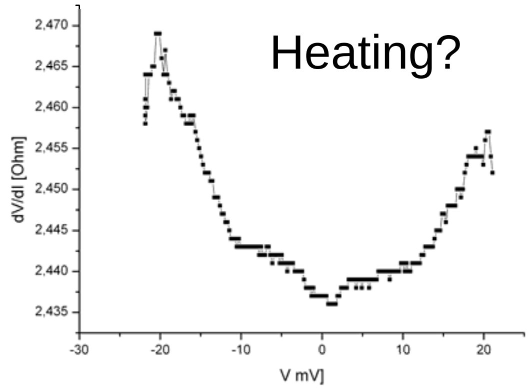


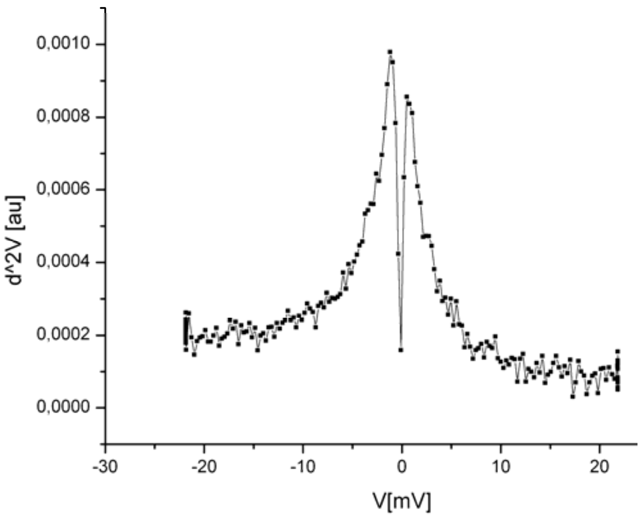
Together with A.Naylor, Leeds



Phonon peaks?







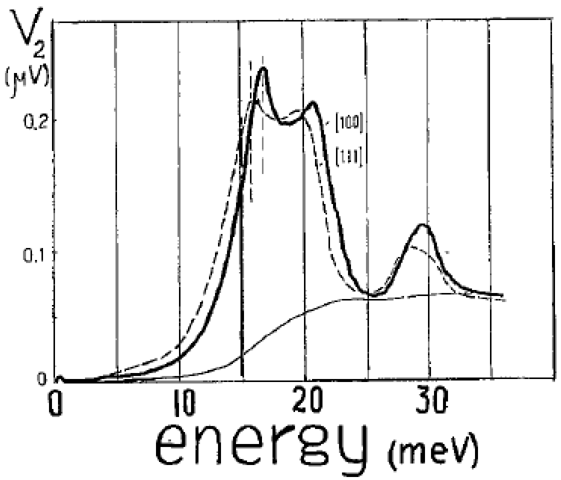


Fig. 1. Point-contact spectra of Cu single crystal in the orientation [100] (contact resistance $R_0 = 2.75\ \Omega$) and [111] ($R_0 = 4.45\ \Omega$). Temperature $T = 1.6$ K; the modulation amplitude $V_1 = 0.2$ mV in the first case and $V_1 = 0.3$ mV in the second case. The lower curve shows the expected energy dependence of the background of the PC spectrum.

Mechanical Point contacts

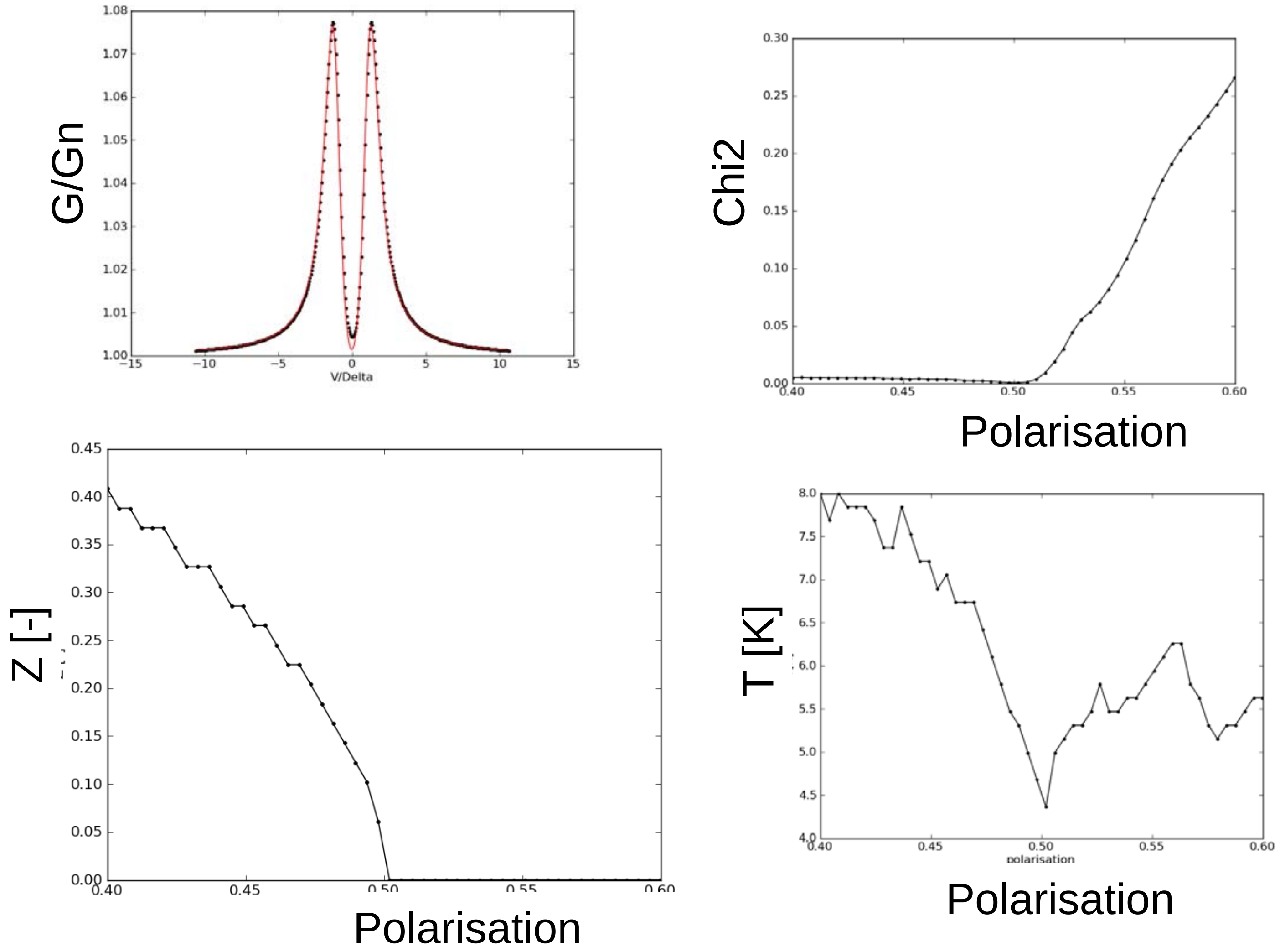
Fitting

- $$\chi^2 = \sum [G_{meas} - G_{fit}]^2$$

- 3 parameters (Z,T, gap) -> unique solution
- 4 parameters (Z,T, gap, P) -> no unique solution

- How to normalize?

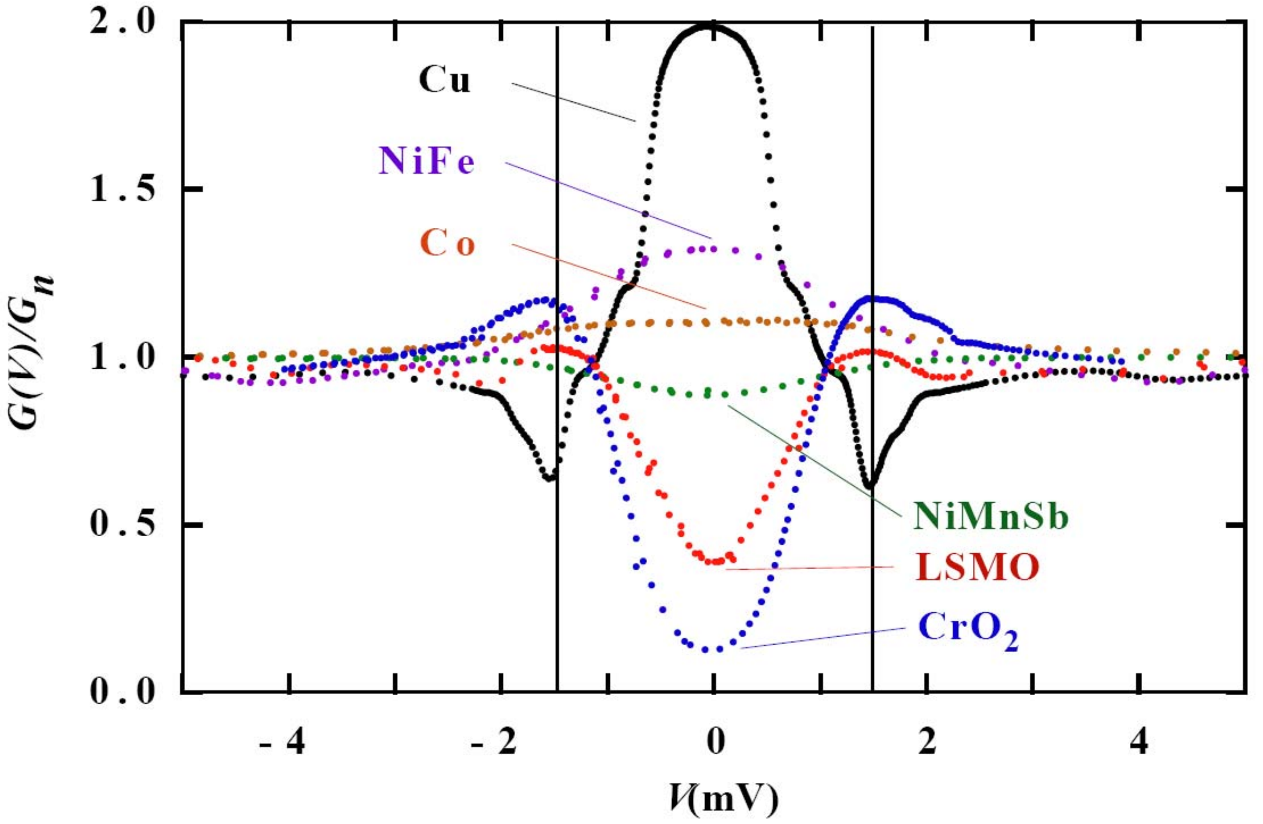
Fitting



G/Gn
V/Delta
Chi2
Polarisation
Z [-]
Polarisation
T [K]
polarisation
Polarisation

Add spin

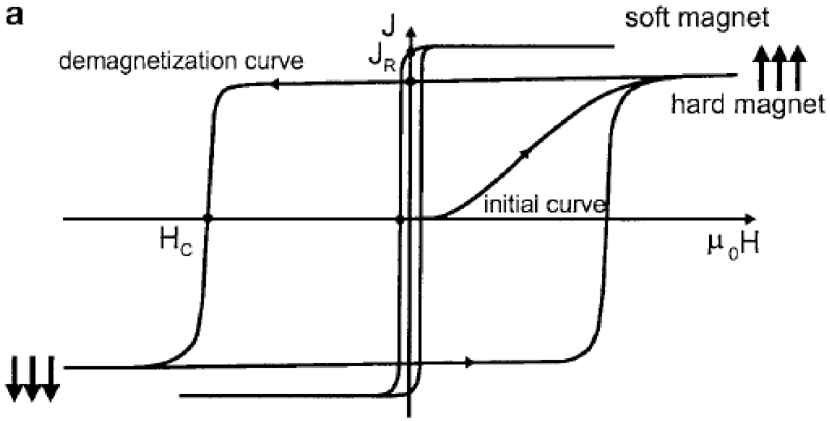
$$G = [1 - P]G_u(\Delta, Z, \omega) + PG_p(\Delta, Z, \omega)$$

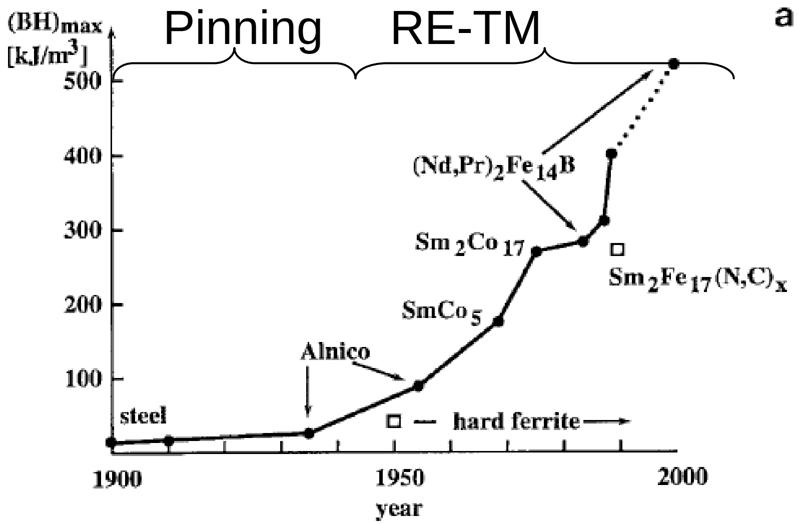


Soulen, Science **282**, 85

- Spin flip laser
- Point contact spectroscopy
- **$SmCo_5$**
- Radiation setup

Hard magnets





Rare earth transition metals

- Nd
- Pr
- Sm

- Fe
- Co

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

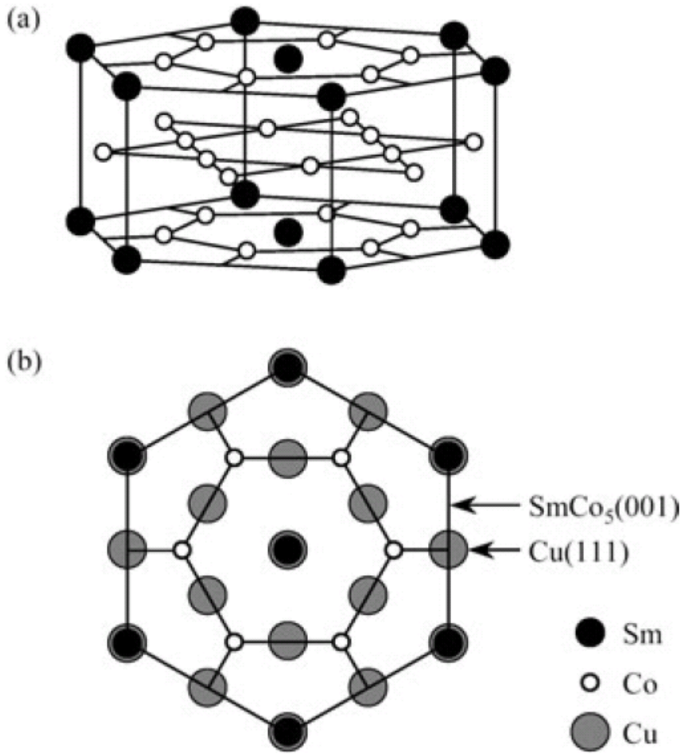
J. J. BECKER
General Electric Research and Development Center, Schenectady, New York

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.

Combine

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

SmCo5



P6/mmm-structure

Sayama et al.J Phys D. **37** L1

Growing SmCo5

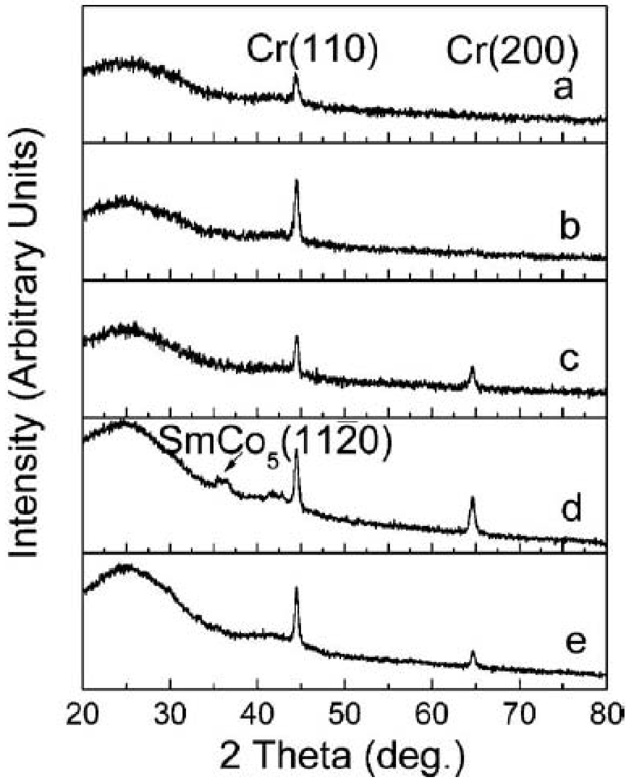
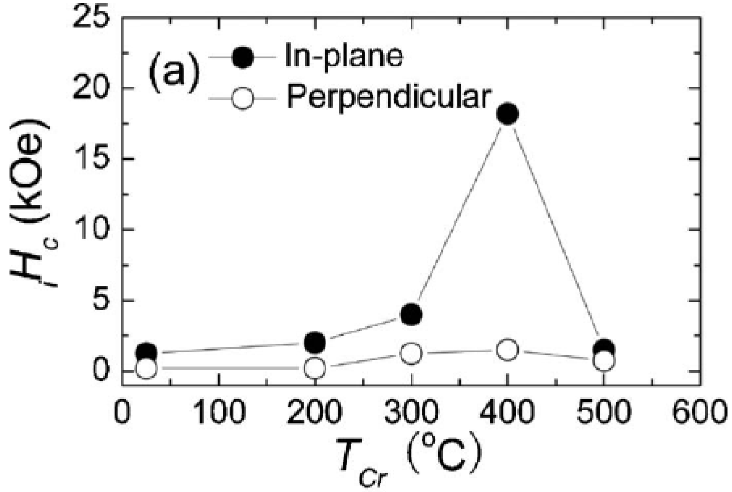


FIG. 2. The XRD spectra of Cr/SmCo/Cr thin films with the Cr underlayers deposited at different temperatures: (a) room temperature, (b) 200 °C, (c) 300 °C, (d) 400 °C, and (e) 500 °C.



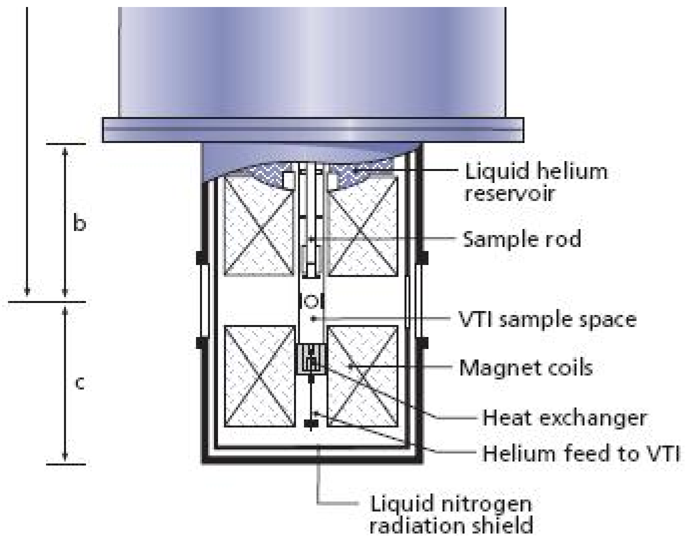
* Claims Hc can be >6T @10K

Zhang et al. J.Appl Phys **103** 113908

*Journal of Physics: Conference Series **234** (2010) 012012

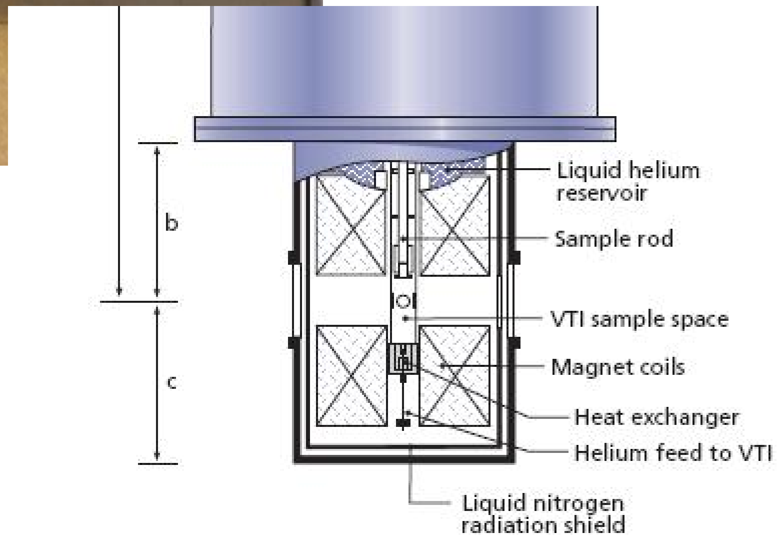
- Spin flip laser
- Point contact spectroscopy
- SmCo5
- **Radiation setup**

Build setup to irradiate PC



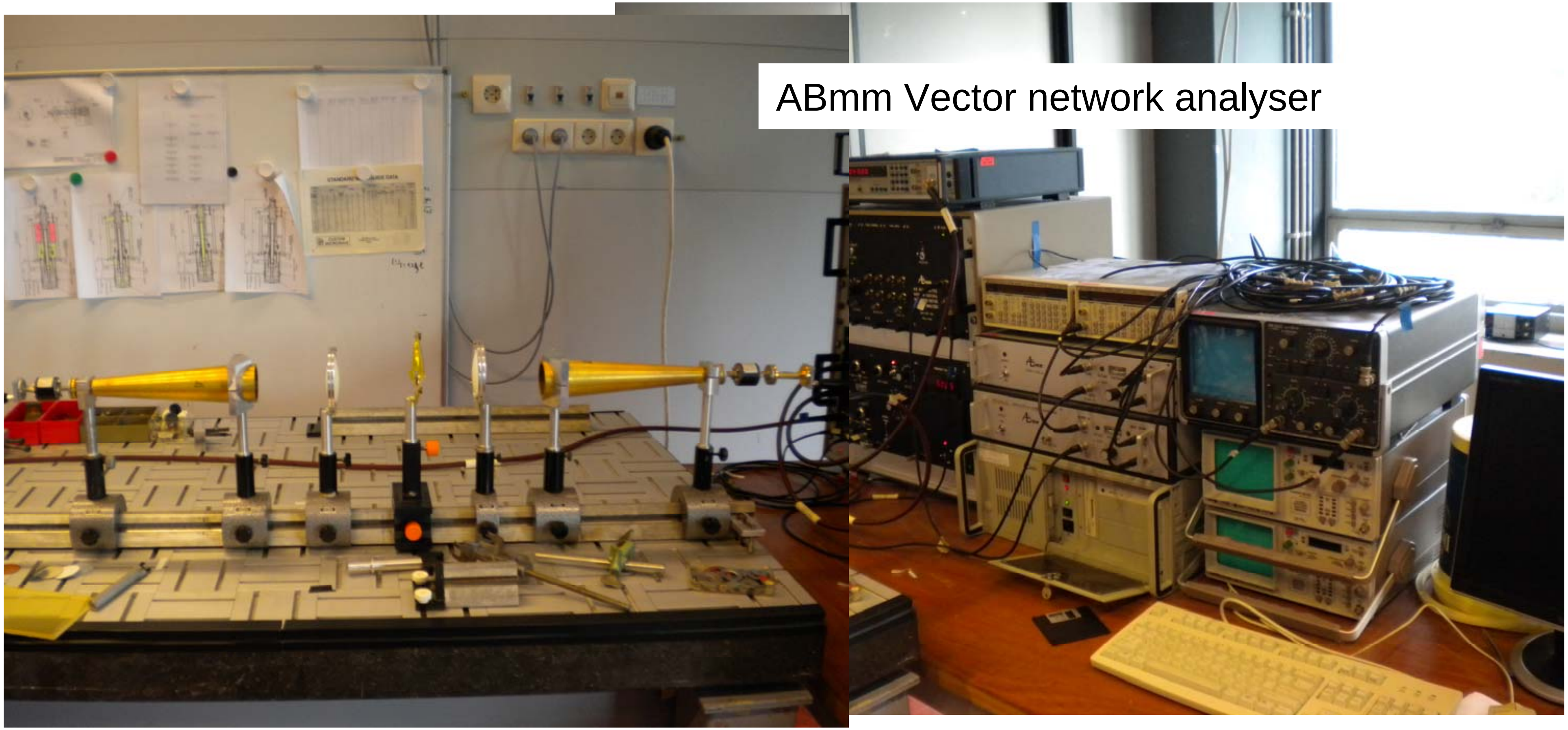
Basic spectromag SM4000 system configuration
Dimensions a, b and c are specified in the system configuration table.

Windows



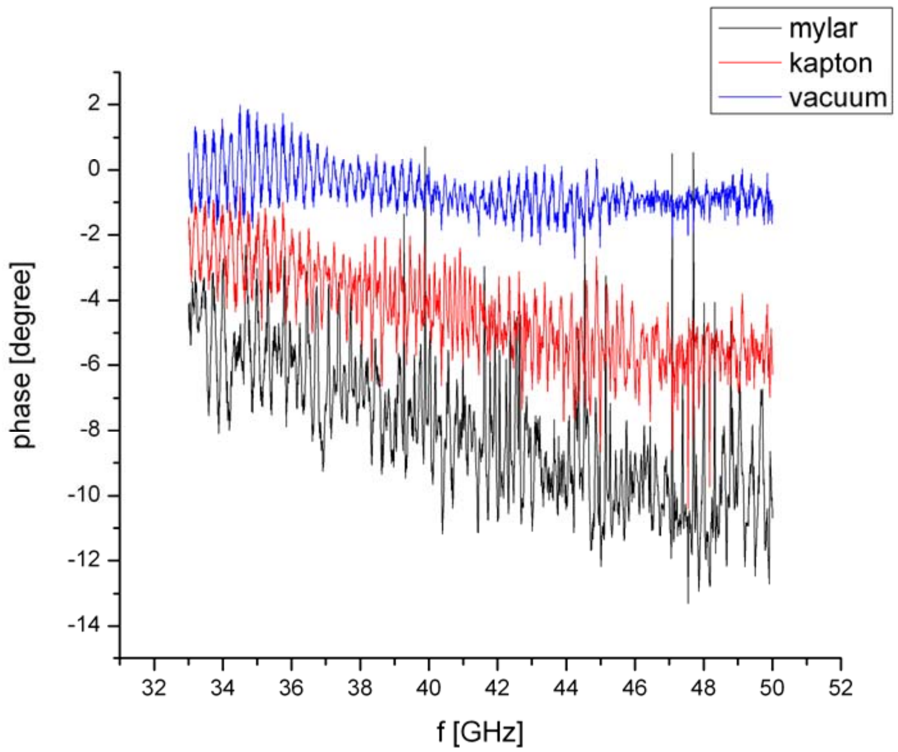
Basic spectromag SM4000 system configuration
Dimensions a, b and c are specified in the system configuration table.

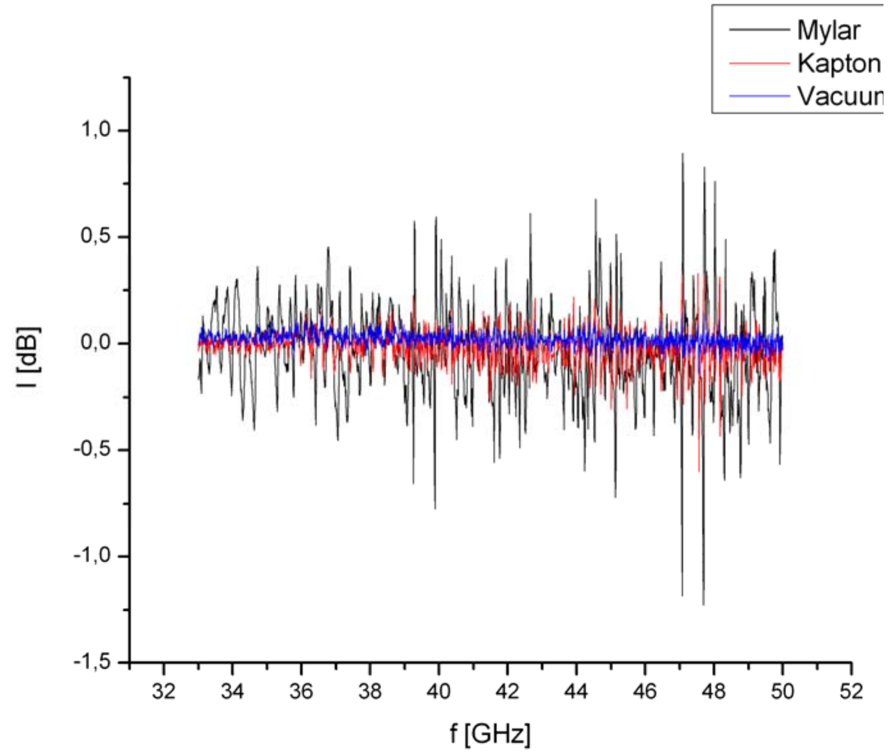
Add radiation / Transmission



ABmm Vector network analyser

Transmission window





Outlook / To Do

- Study possible materials using PCS
- Grow $SmCo_5$
- Measure PCS with radiation