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Cr magnetism in Fe/Cr thin films

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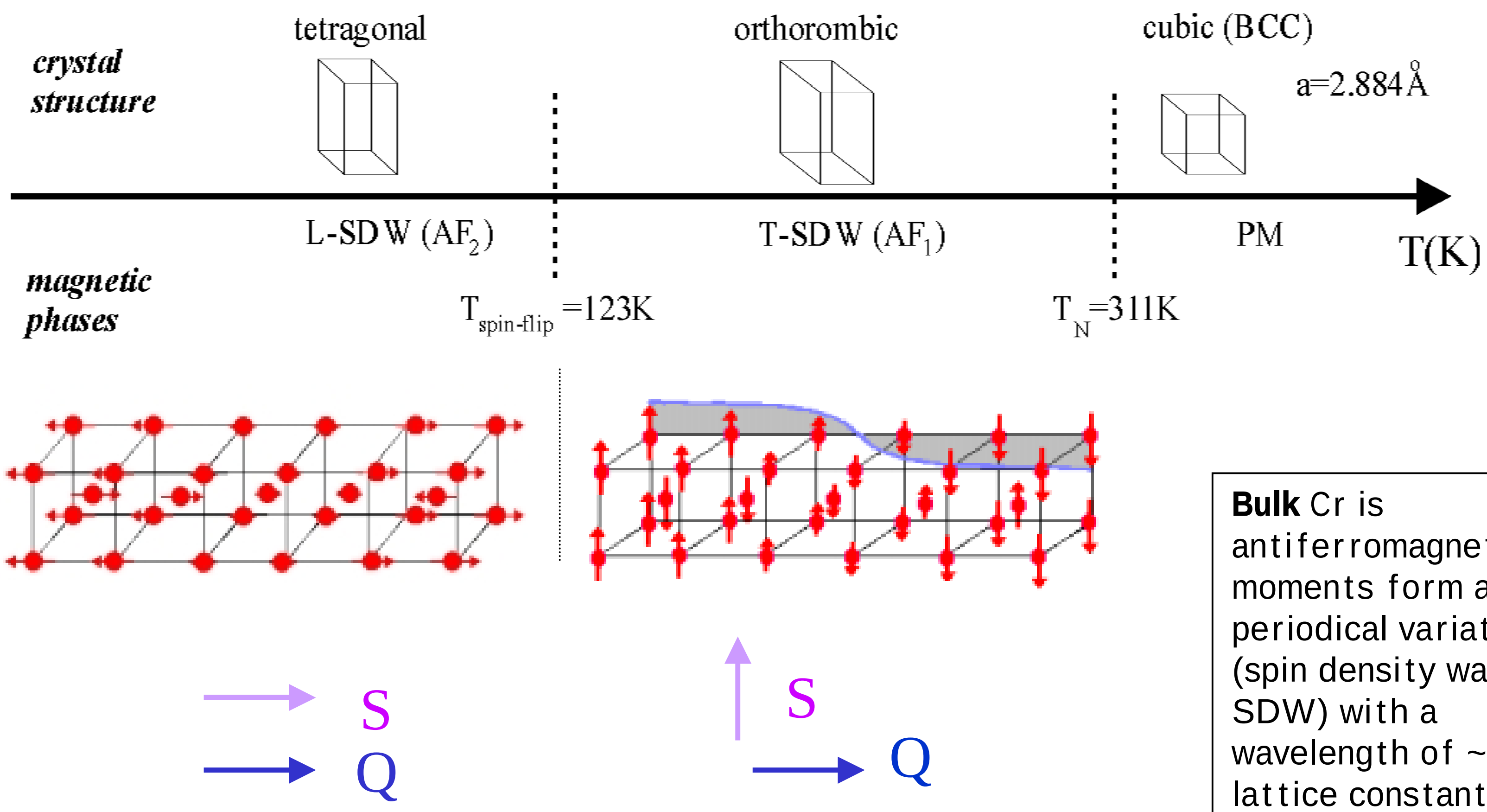
Cr magnetism in bulk

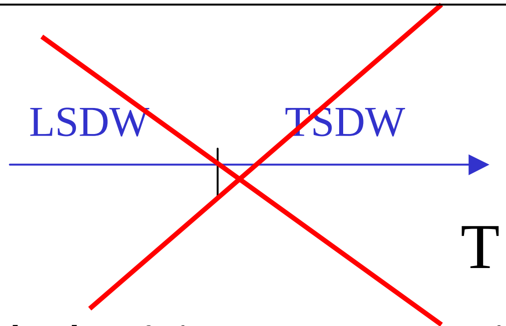


Bulk Cr is antiferromagnetic. The moments form a periodical variation (spin density wave, SDW) with a wavelength of ~ 20 lattice constants below Néel temperature, T_N=311K.

Cr magnetism in thin Cr layers

T_N=f(thickness)

T_N depends on the sample **thickness**
*Fullerton et al. PRL **75**, 2 (1995) 330*

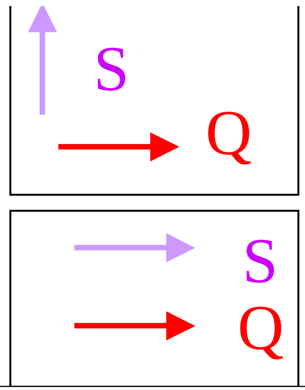


Once a thin film is prepared, the **polarization** of the SDW was seen to be **determined** and to remain until **T_N**. At this temperature, **different from Bulk** value, the Cr changes to the paramagnetic phase.

Meersschaut et al. PRL 75, 8 (1995) 1638
Bödecker et al. PRL, 81, 4 (1998) 914

How to produce T or L???

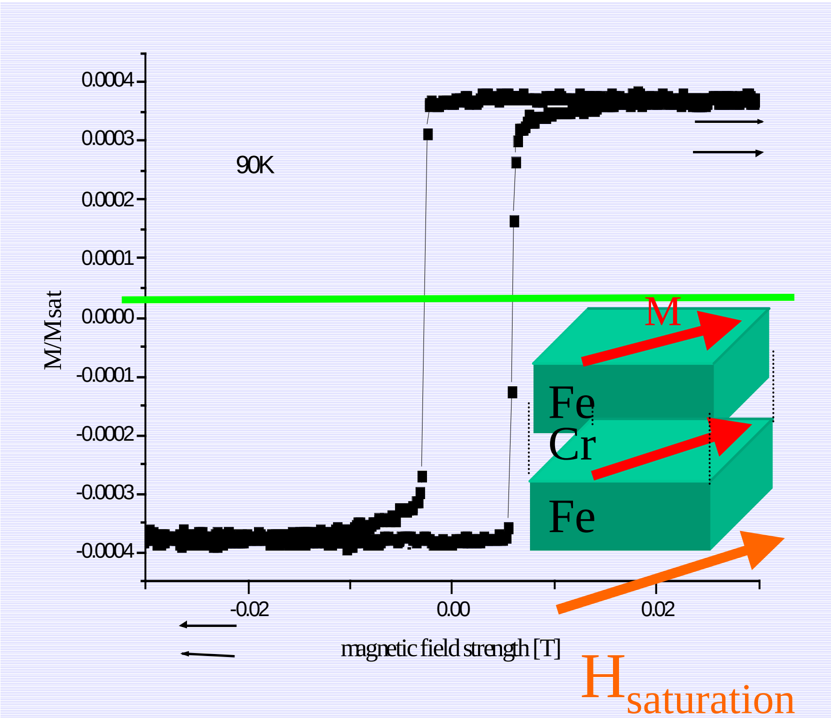
The appearance of T or L polarization is due to the **sample preparation method**, but it is up to now not clear how to produce the desired T or L polarization.



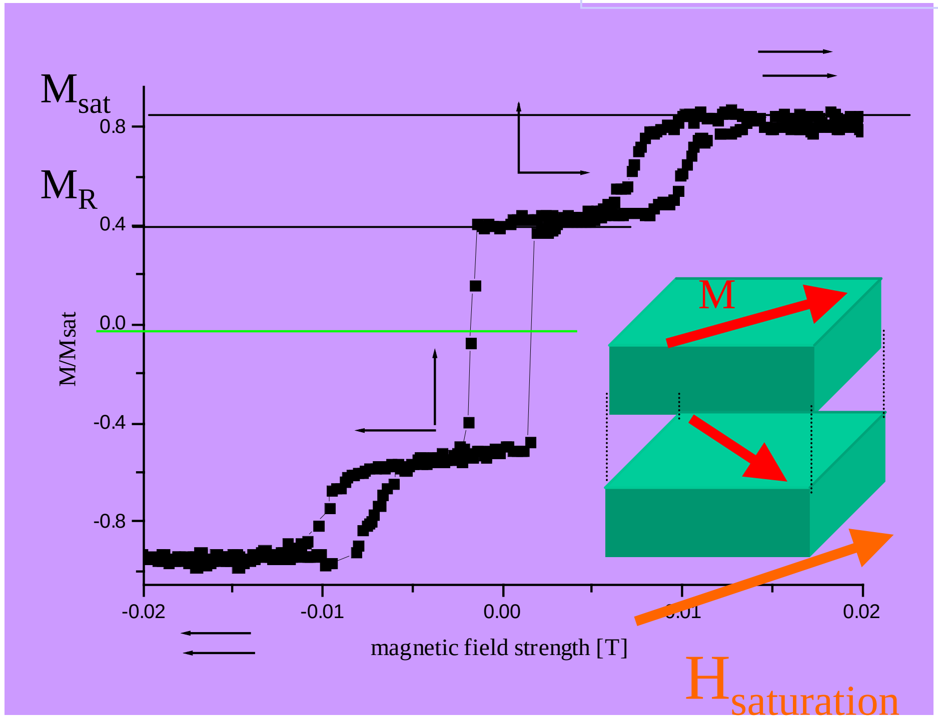
Cr as spacer layer induces coupling between adjacent Fe layers. In particular: biquadratic BQ coupling, strongly influenced by the magnetic state of Cr.

✓**BQ,** first observed by Rührig et al. it's origin is still being debated. Phys. Stat. Sol. A **125** (1991)635.

✓**no coupling**



✓**BQ coupling**



Magnetization loop at 90K of the trilayer Fe/Cr/Fe grown at 575K (ferromagnetic).

Magnetization loop at 260K of the trilayers TG= 575K. The value of the remanence (M_R) is half the saturation value, consistent with a 90º alignment of Fe layers.

Growing trilayers at different temperatures, can we change the magnetic properties of the Cr thin layer?

It is known that:

✓The growth temperature (TG) of Fe/Cr trilayers affects strongly the temperature dependence of the BQ coupling of Fe layers

In the work

Dekoster et al. JMMM 198-199(1999)303.

The strain in the Cr layers was measured with RBS concluding that it was not the reason of the coupling dependence on TG.

epitaxially grown Fe/Cr/Fe trilayers on MgO(001).

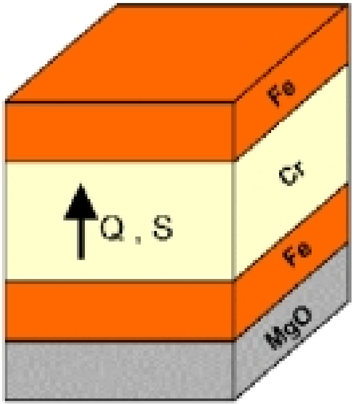
Fe thickness 3 nm

Cr thickness 7 nm

Au capping layer 3 nm.

Growing temperature:

TG=290K, 450K, 575K.

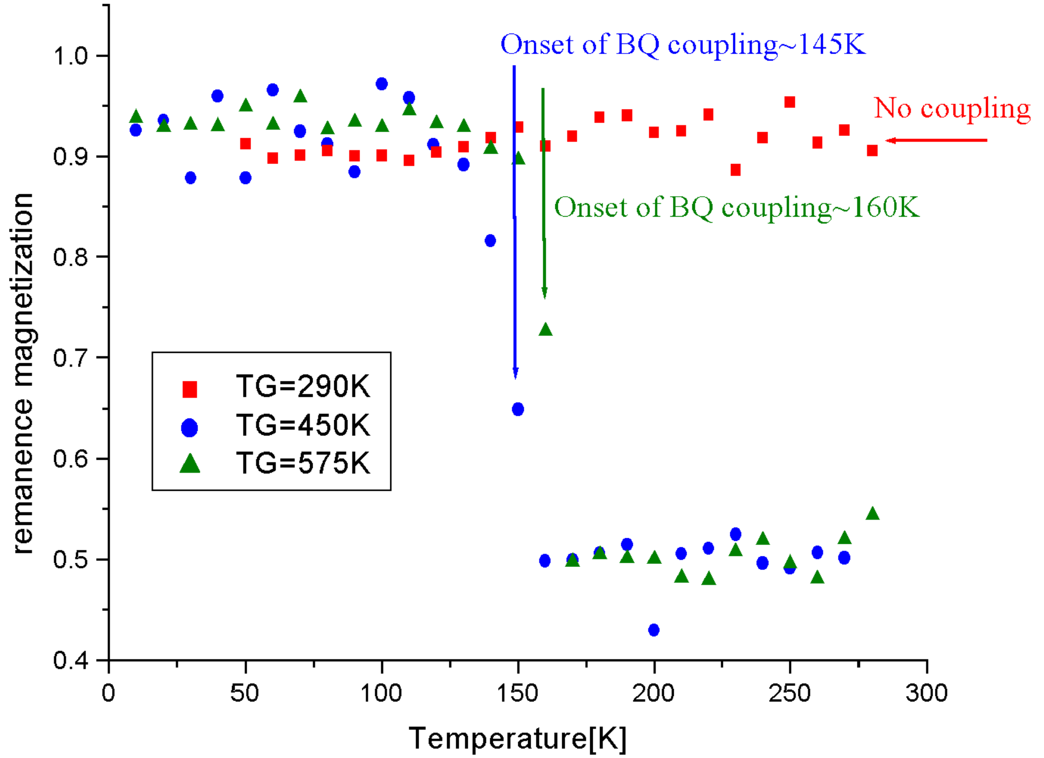


samples characterization:

The epitaxial growth was characterized by RHEED (reflecting high energy electron diffraction)

The thickness of the layers and the quality of the interfaces by X-ray reflectivity.

Results 1: remanence magnetization.



* BQ coupling appears abruptly at a critic temperature. From Fullerton et al. it was found to be the T_N

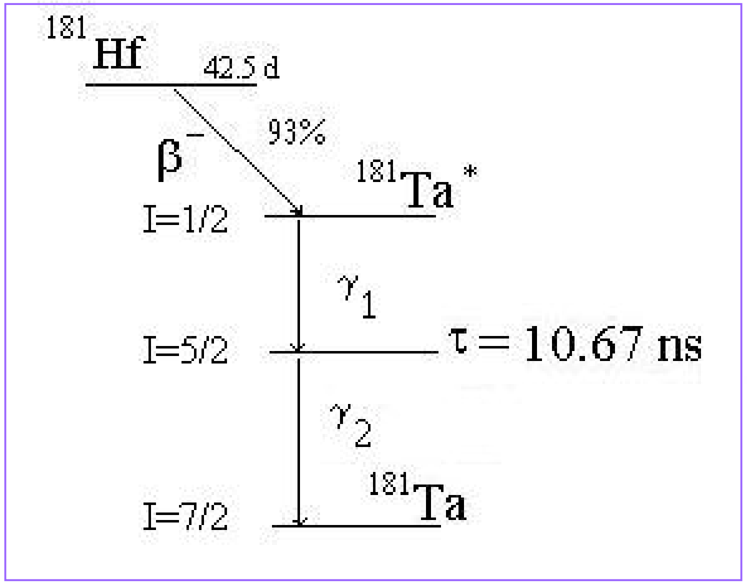
Fullerton et al. Phys. Rev. Let. 75,2,1995.

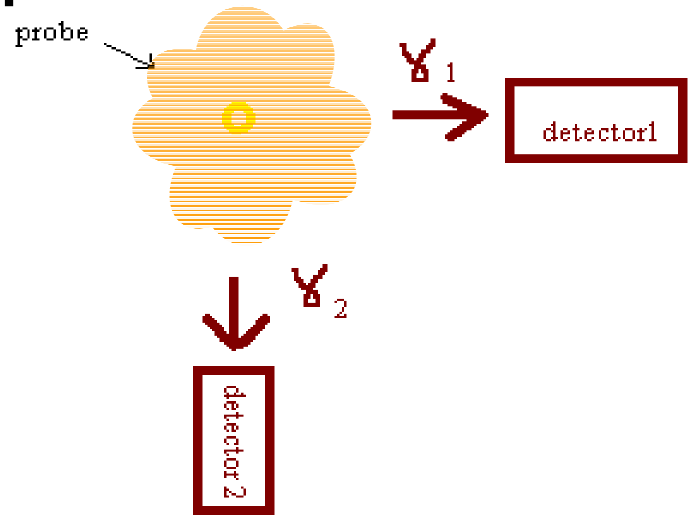
✓For the samples TG=450K and TG=575K, the onset of BQ coupling is clear. T_N is expected to be ~150K according to the work of Fullerton*.

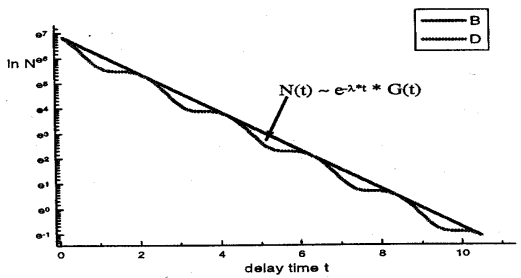
✓TG=RT sample, no sign of BQ coupling. Which is the magnetic state of Cr here? Do we expect to have coupling for a much different temperature range?

How can we understand such a difference?

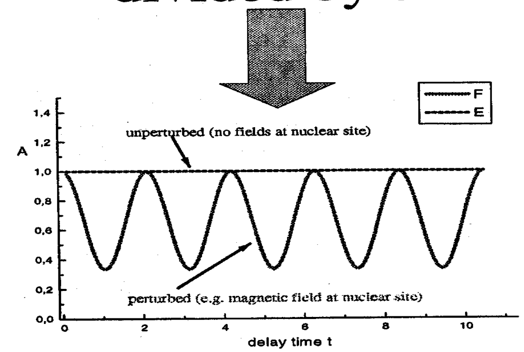
Introduction to perturbed angular correlations (PAC) technique

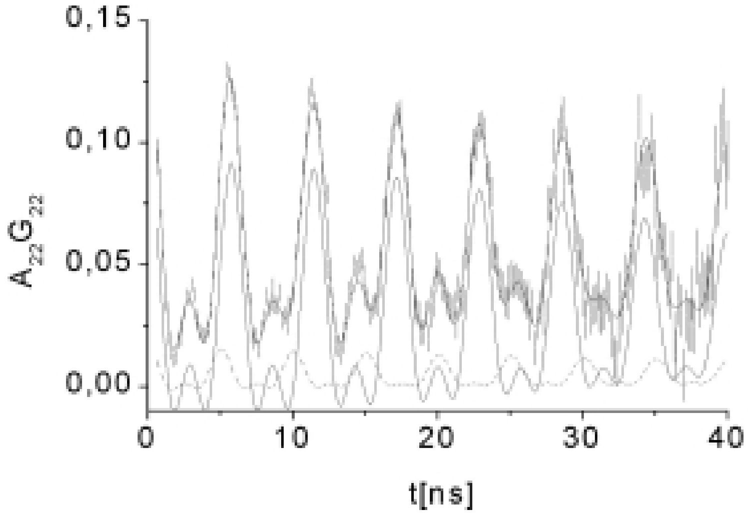






divided by $e^{-\lambda t}$





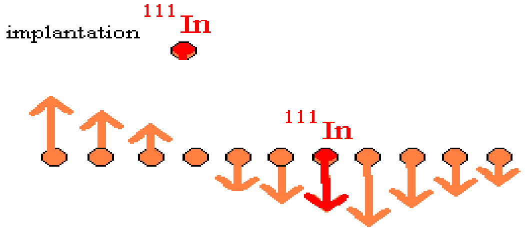
$[^{181}Ta]ErFe_2$

$$R(t) = s_{k0} + \Sigma\, s_{kn} \cos(\omega_n t)\ .\ \exp[-(\delta\omega_n t)^2/2]$$

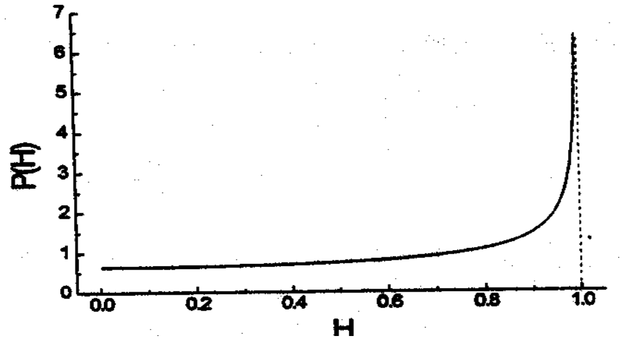
We use PAC technique to investigate Cr SDWs in the trilayers.

^{111}In was implanted at 60keV.

The range is 120 Å, the straggling is 56 Å, then most of the probes landed in the Cr and Fe layers.



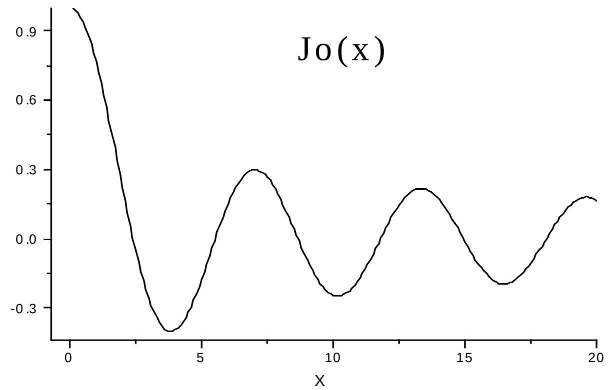
In case of a SDW, the distribution of the fields follows an *Overhauser* type

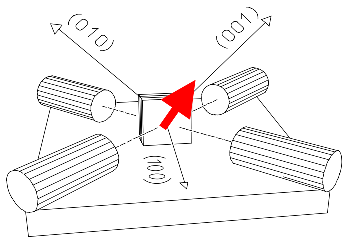


Then the PAC spectra is described by:

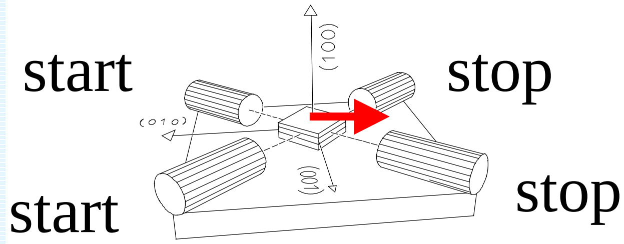
$$R_{Overh}(t) = a_0 + a_1 J_0(\varpi_{H_0} t) + a_2 J_0(2\varpi_{H_0} t)$$

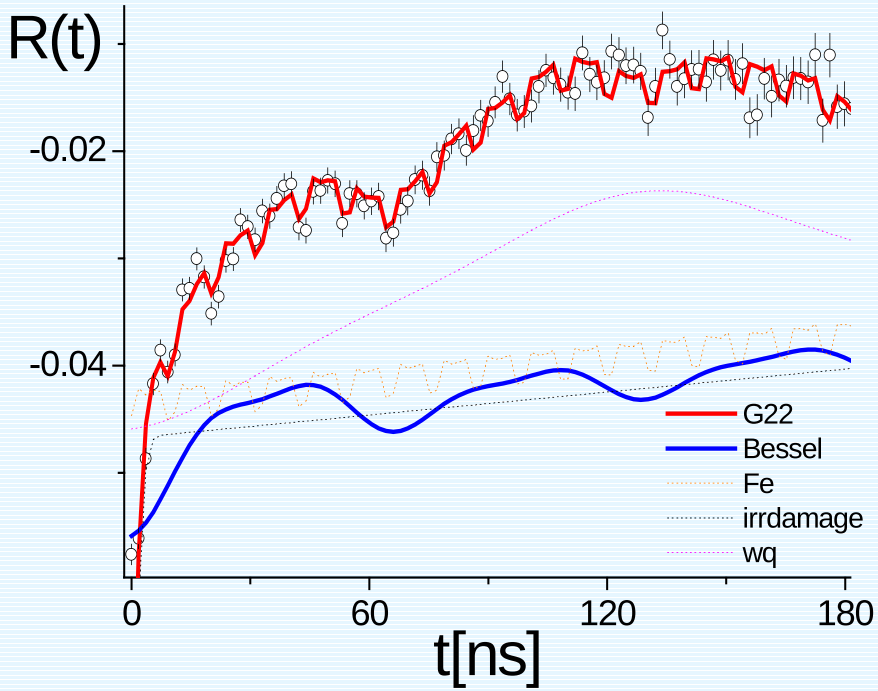
Being Jo the 0th order Bessel function

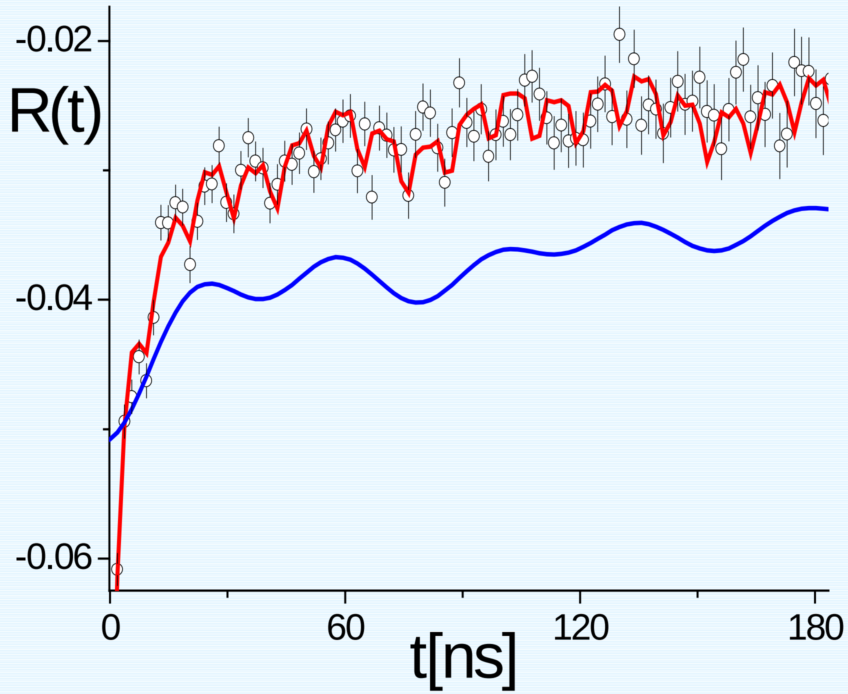




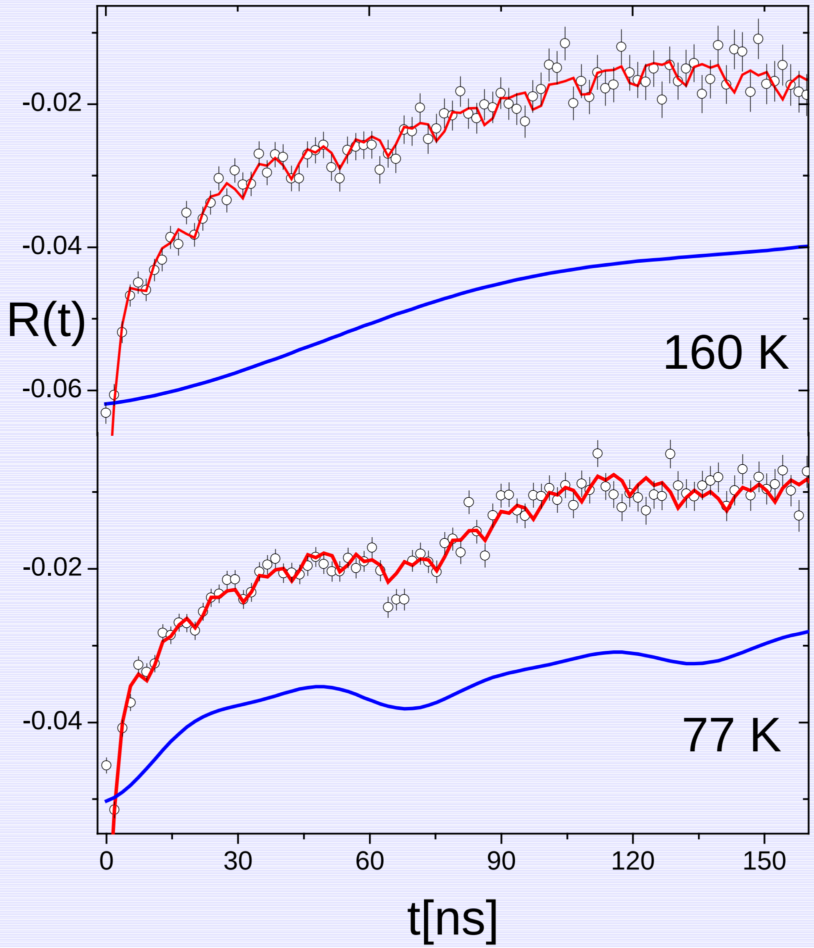
Results 2: PAC on 575 K grown sample. T=140 K





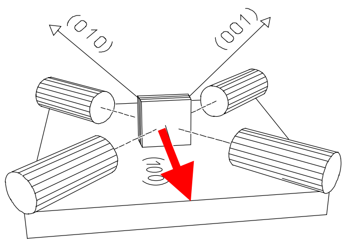


- ✓**SDW with Bhf=6.5 T at 140 K**
- ✓**Direction of the Bhf: in plane.**
- ✓**TSDW (from following Bhf value comparison)**

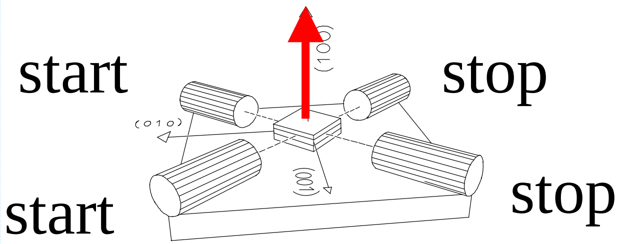


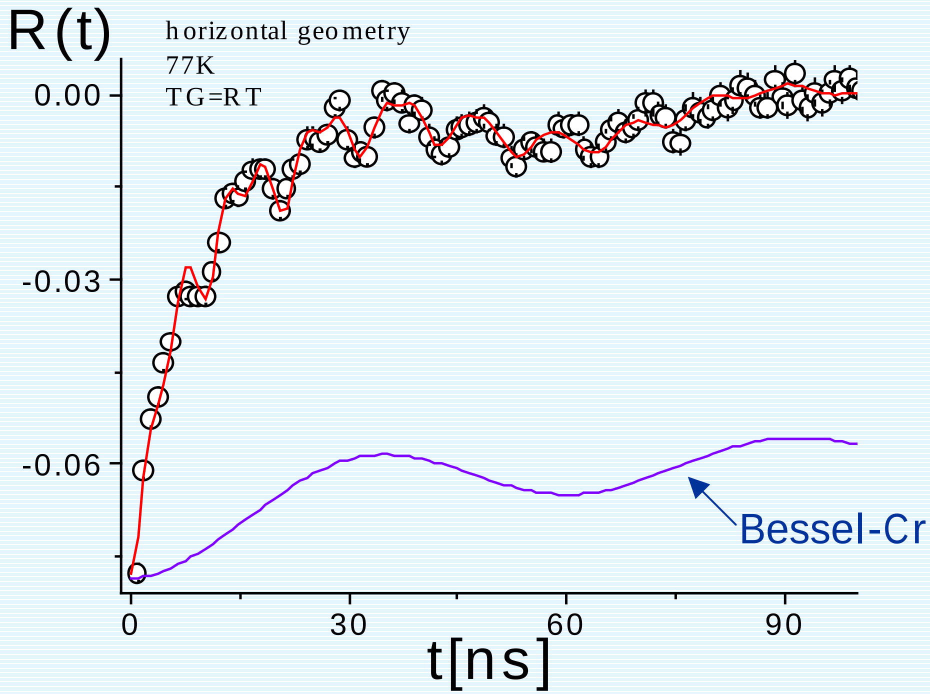
PAC on 575 K grown sample as a function of temperature.

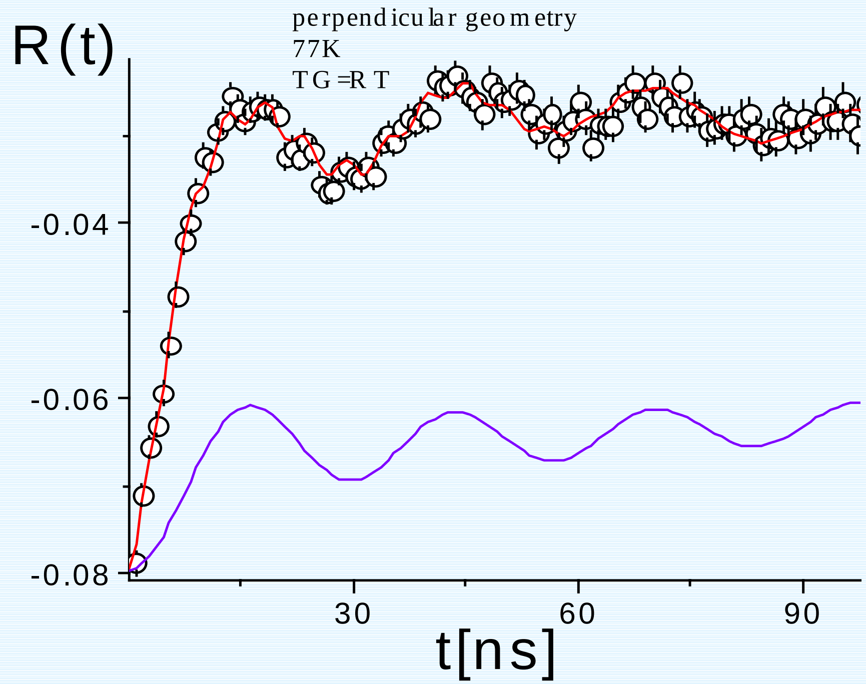
Measurements were taken between 13 K and 300 K. The Bessel contribution was seen up to T~160K, pointing out a T_N near160 K.



Results 3: PAC on RT grown sample. T=77 K

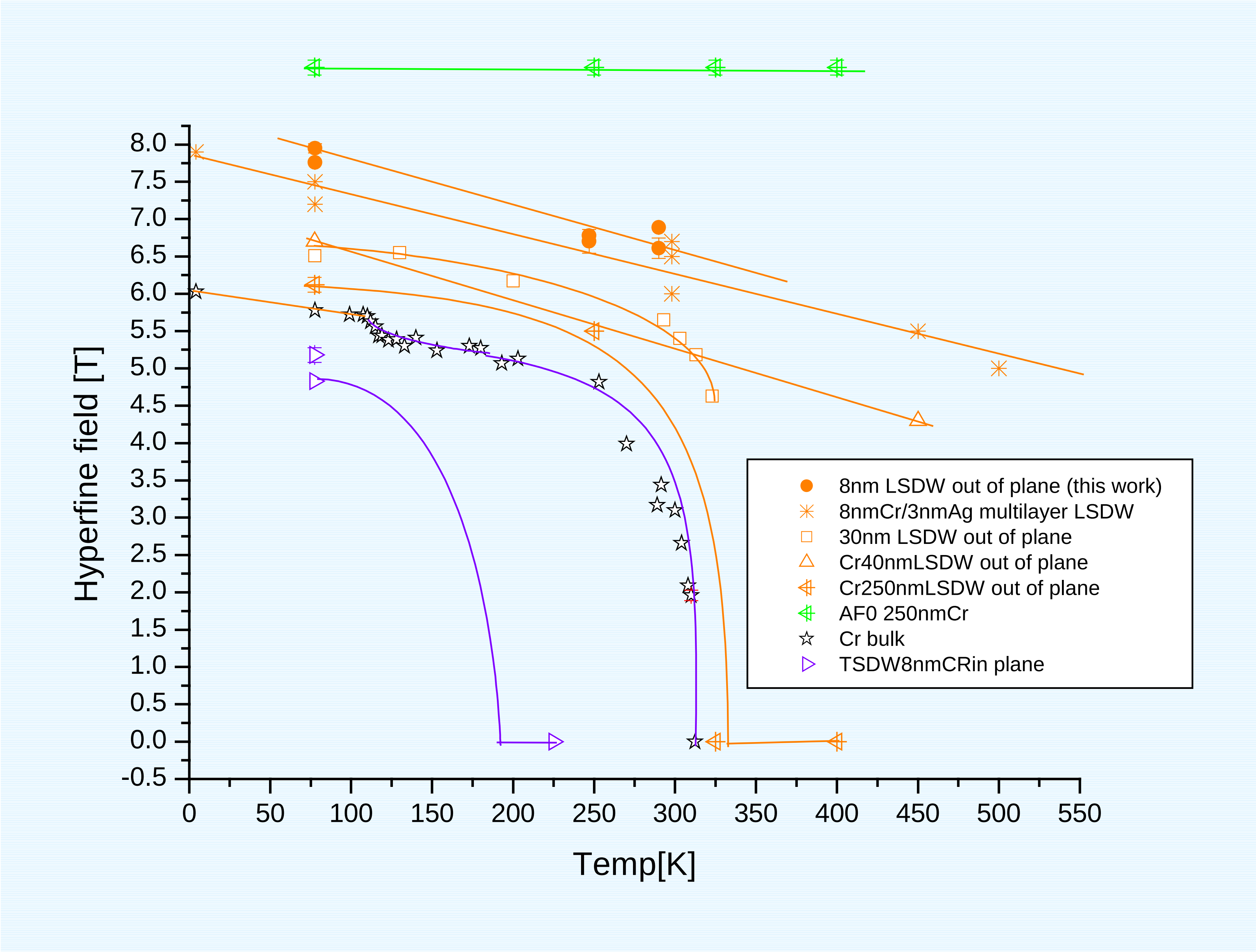






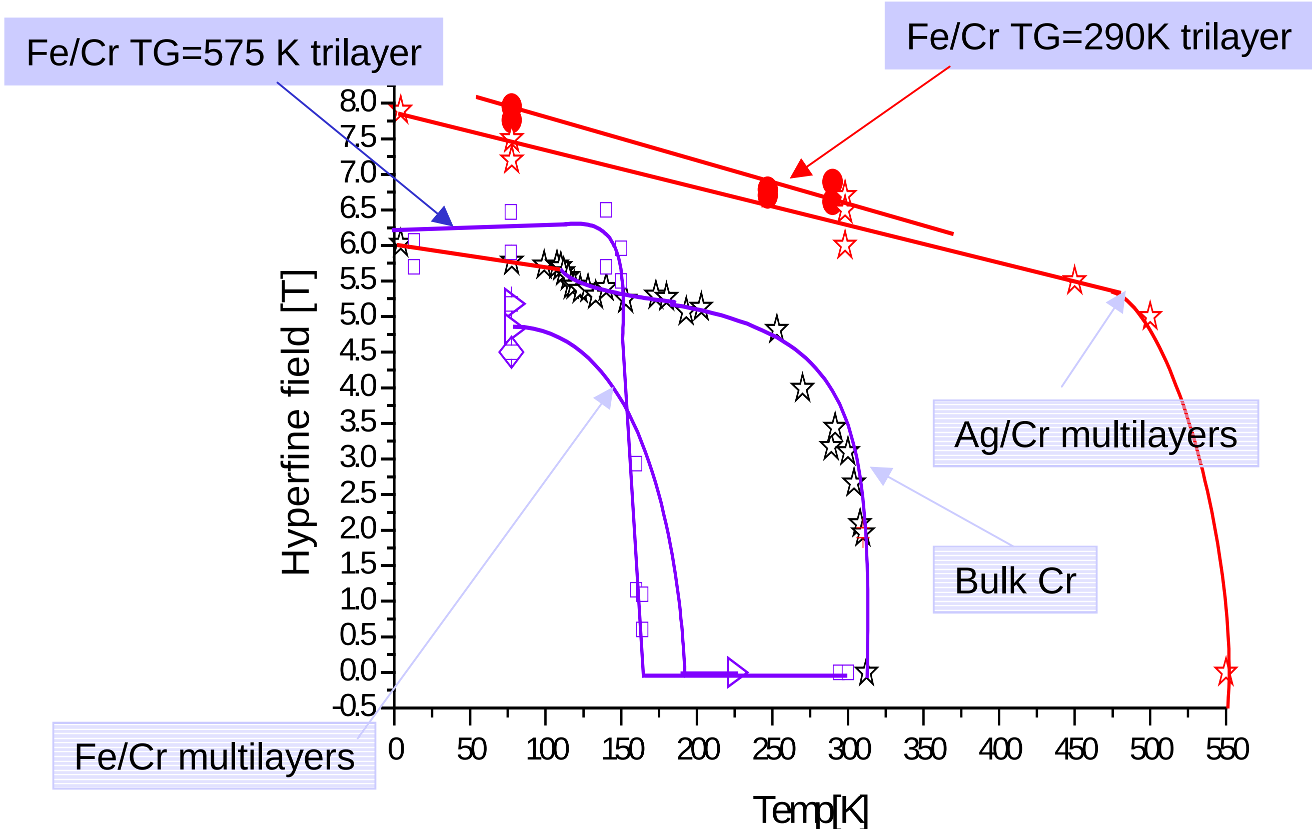
- ✓**SDW with Bhf=7.8(2)T at 77K**
- ✓**Direction of Bhf is out of plane for the range measured: between 77K and 290 K.**
- ✓**LSDW (from Bhf value comparison)**

PAC results compared for different Cr thickness



The dependence with temperature

Hyperfine field compared with data from other PAC measurements on samples of similar Cr thickness and with bulk Cr.



- 7nm Cr/ 3nm Fe trilayer, TG=RT. LSDW out of plane (this work).
- 7nm Cr/ 3nm Fe trilayer, TG=575 K. TSDW in plane (this work).
- 8nm Cr/ 3nm Ag multilayer LSDW from Demuynck et al. Phys. Rev. Let. 81,12(1998)2562.
- Cr bulk from Venegas et al. Phys. Rev. B, 21, 9(1980)3851.
- 8nm Cr/ 2nm Fe multilayer TSDW in plane, from J. Meersschaut, doctor thesis, 1998. TG= 585K.

The LSDW has an enhanced value of hyperfine field and of TN respect to the TSDW.

✓Red points are LSDW.

✓Violet points are TSDW.

The enhanced TN due to the presence of the LSDW polarization in the sample TG=RT explains why BQ coupling was not observed in this temperature range.

Conclusions

✓PAC spectra on trilayers Fe/Cr were obtained.

✓By changing the growing temperature we selected the polarization of the SDW.

✓Magnetization and PAC experiments in progress also above RT to check if the biquadratic coupling appears as expected above TN in the sample grown at RT.

✓Open subject: PAC experiments are showing a big enhancement of the LSDW and a diminishing of the TSDW hyperfine fields. Why?