Anisotropic magneto-thermoelectric power of ferromagnetic thin films

M. S. Anwar*, B. Lacoste, and J. Aarts

[1]Kamerlingh Onnes Laboratory, Leiden University, P.O. Box 9504, 2300 RA Leiden, the Netherlands

*E-mail: anwar@physics.leidenuniv.nl, m.s.anwar476@gmail.com

Abstract

Magnetothermoelectric power (MTEP) in metallic ferromagnetic films of $Ni_{80}Fe_{20}$ (Permalloy; Py), Co and CrO_2 was measured at temperatures in the range of 100K to 400K. In Py and Co both the anisotropic magnetoresistance (AMR) and MTEP show a relative change in resistance and thermopower of the order of 0.15%. The CrO_2 films were grown on TiO_2 and on sapphire. Where MTEP behavior at low fields shows peaks similar to the AMR, with variations up to 0.9%. With increasing field both the MR and the MTEP variations keeps growing, with MTEP showing relative changes of 1.5% with the thermal gradient along the b-axis and even 20% with the gradient along the c-axis, with an intermediate value of 3% for the film on sapphire. It appears that the low-field effects are due to the magnetic domain state, and the high-field effects are intrinsic to the electronic structure of CrO_2.

Thermal transport phenomenon

$$\left.\begin{aligned} J &= e^2 K_o.E + \frac{e}{T}K_1.(-\nabla T) \\ w &= e\ K_1.E + \frac{1}{T}K_2.(-\nabla T) \end{aligned}\right\} \kappa = \frac{\pi^2}{3}\frac{k^2 T}{e^2}\sigma$$

Charge and heat flux transport under the influence of electric field E and temperature gradient ∇T.

Electrical and thermal Conductivities in metals

If J = 0, E induced because of ∇T and resulted into Seebeck Effect, S=Seebeck coefficient

$$E = \frac{1}{eT}K_o^{-1}K_1.(-\nabla T) = S(-\nabla T)$$

Semi classical, Mott's formula of Seebeck coefficient, ratio of derivative of density of states and the density of states at Fermi level

$$S = -eL_oT\frac{N'(\varepsilon_F)}{N(\varepsilon_F)}$$

S in ferromagnetic material, electron magnon scattering, spin dependent S with opposite sign

$$S = -eL_oT\left\{\frac{N'\uparrow(\varepsilon_F)}{N(\varepsilon_F)} - \frac{N'\downarrow(\varepsilon_F)}{N(\varepsilon_F)}\right\} = (S\uparrow - S\downarrow),\ N = N\uparrow + N\downarrow$$

Influence of magnetic domain structure on thermoelectric power TEP?

Experimentation

Thermopower was measured using a home built sample holder based on PPMS puck, as shown in fig. 1

MTEP was probed with parallel configuration of temperature gradient and externally applied magnetic field.

Temperature dependent Seebeck coefficient was measured via dynamic technique in the temperature range of 100 K-400 K

Py films were deposited in UHV magnetron sputtering system with background pressure 10^{-9} mbar, Co films were deposited in Z-400 background presure of 10^{-6} mbar.

CrO_2 thin films were deposited on TiO_2 and sapphire substrates utilizing the Chemical Vapor Deposition technique at atmospheric pressure

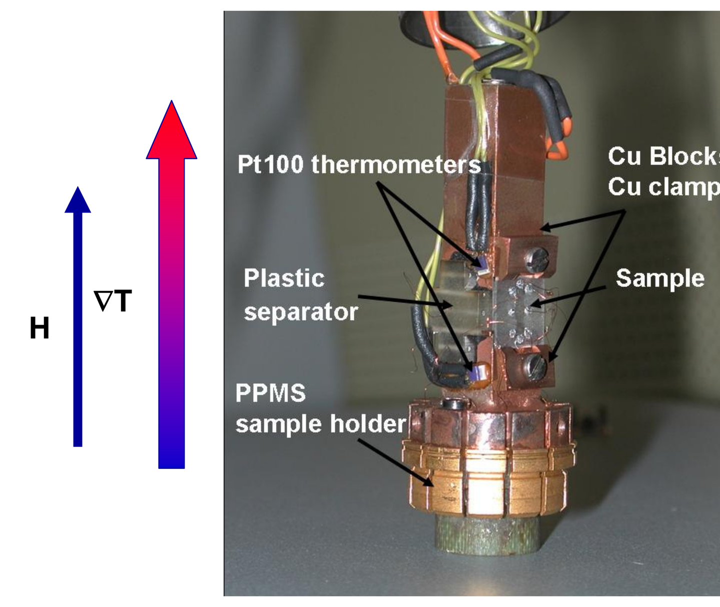

Figure 1. Home build thermal transport sample holder, based on PPMS puck.

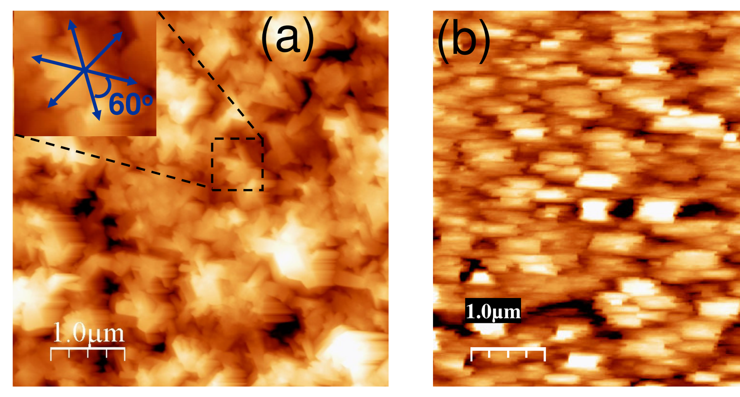

Figure 2. AMF images of CrO_2 thin films deposited on (a) Sapphire (b) TiO_2 substrates. Films grow in the form of rectangular grains.

Results

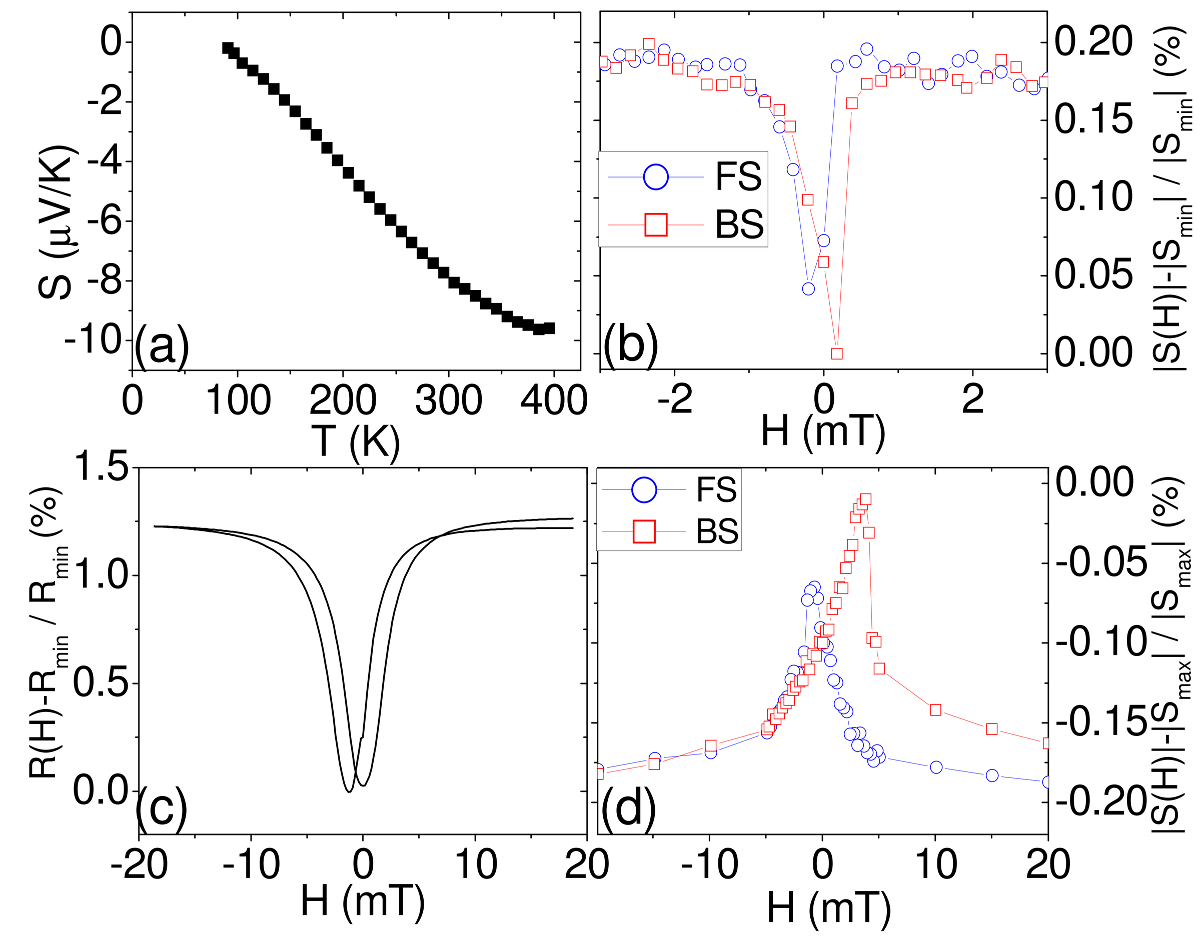

Figure 3, (a) S(T), (b) MTEP, and (c) AMR for Py, (d) MTEP of Co.

MTEP measurements were done at
T = 200K
T_{ave} = 178 K
ΔT = 45 K

AMR measurements were done at
T = 4.2 K
I = 100 μA

H_{ext} is parallel to current and the in-plane

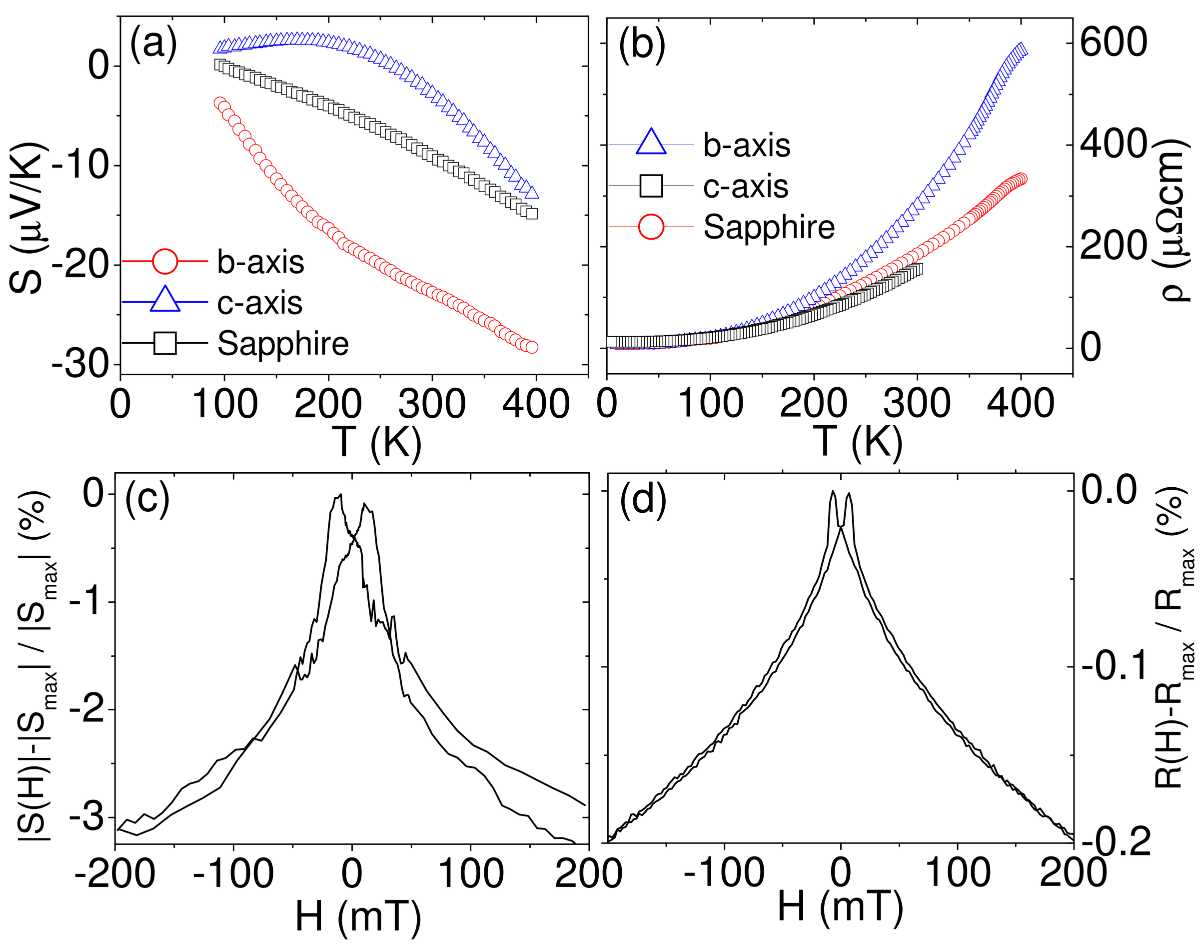

Figure 4, (a) S(T) for CrO_2 films deposited on TiO_2 and Sapphire substrates, (b) R(T) for CrO_2 for both of these films, (c) MTEP for CrO_2 deposited on Sapphire (d) and corresponding AMR.

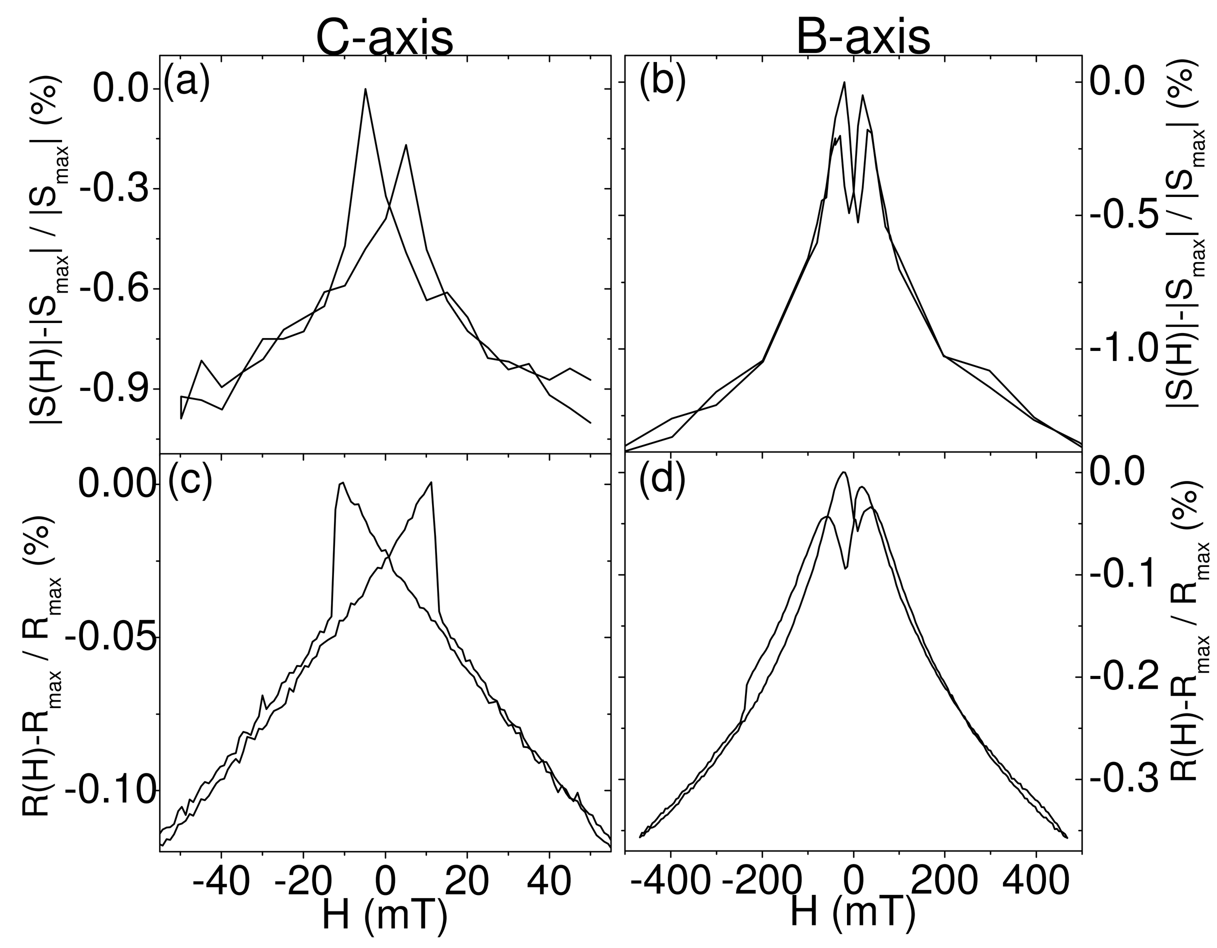

Figure 5, (a) MTEP along c-axis of CrO_2 thin films deposited on TiO_2 substrate, (b) MTEP along b-axis. (c) and (d) are illustrating AMR signal along c-axis and b-axis respectively.

Both R and S are increasing in domain state but opposite for Py.

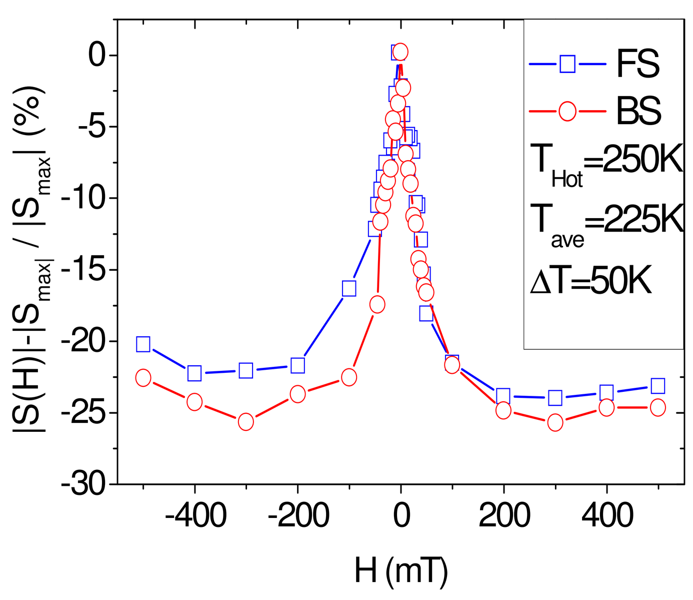

Figure 6. MTEP with relative change of 20% along c-axis of CrO_2 thin films deposited on TiO_2 substrate.

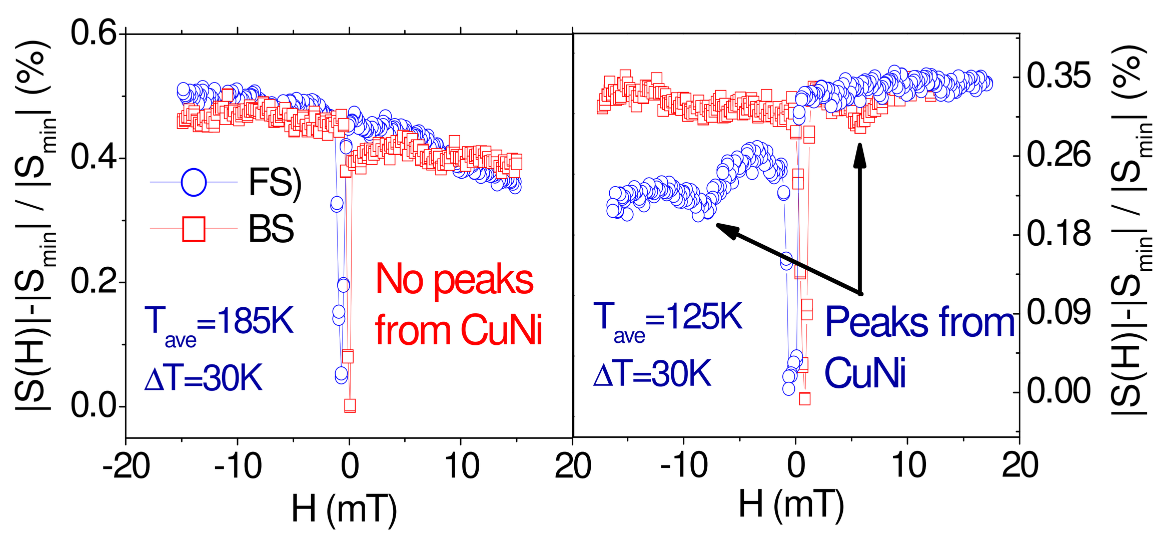

Figure 7. MTEP for a multilayer ferromagnet sample Py(25nm)/CuNi(50nm), No peak from CuNi at T_{ave}=185>Tc of CuNi (a) and appearing at T<Tc (b).

Conclusion

Magnetothermopower (MTEP) is strongly related with anisotropic magnetoresistance (AMR)

MTEP is increasing in the domain state.

Py and Co have opposite behaviour although their AMR have the same behaviour.

CrO2 shows a huge TEP variation when measured along its c-axis.'

S(T) of CrO2 thin films has anisotropic behavior.

References

1. J. M. Ziman, Principles of the theory of solids, Cambridge University Press-London, (1964).
2. L. Piraux, A. Fert, P. A. Schroeder, R. Loloee, and P. Etienne, J. Magnetism and Magnetic Materials, **110,** L247 (1992).
3. Y. Pu, D. Chiba, F. Matsukura, H. Ohno, and J. Shi, Phys. Rev. Lett. **101,** 117208 (2008).
4. M.S. Anwar, and J. Aarts, Supercond. Sci. Technol. **24,** 024016 (2011).