Structural properties and static- and dynamic magnetization in soft ferromagnetic materials

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Abstract

We study ferromagnetic thin films, and patterned devices. In particular, we are interested in their properties regarding magnetic field sensing and magnetic memory applications. These include magnetostatic properties such as magnetic anisotropy, coercivity and saturation magnetization, and dynamic properties such as resonance frequency and magnetization damping. The latter determine e.g. how quickly the magnetization responds to an external field. Magnetoresistive properties are also very important, i.e. how resistivity depends on current direction with respect to magnetization (AMR effect, anisotropic magnetoresistance) or relative magnetization orientation in heterostructures (GMR and TMR, giant and tunneling magnetoresistance).

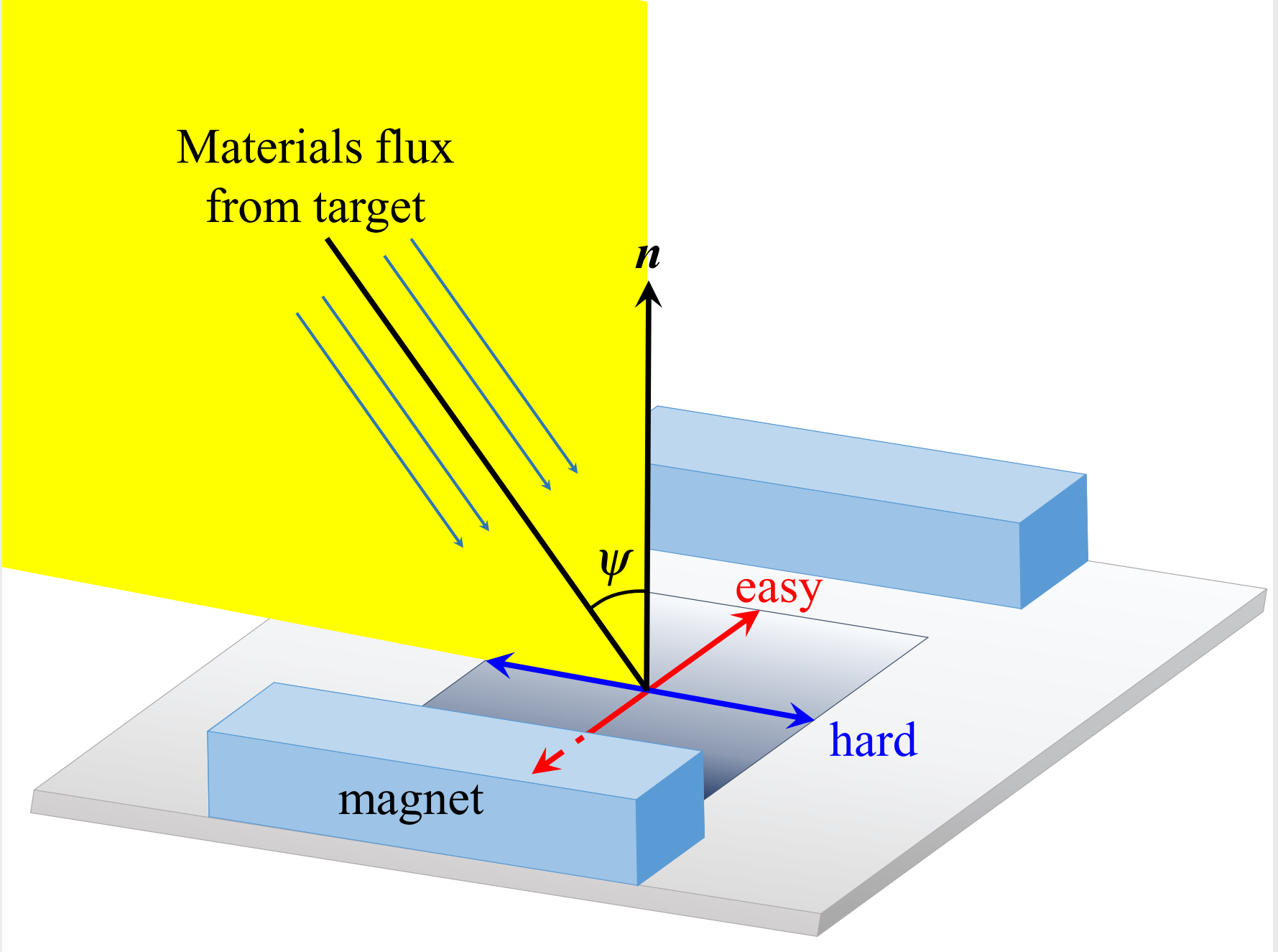
Our work includes thin film deposition and structural characterisation of many sorts, magnetostatic measurements (VSM, vibration sample magnetometry), MOKE (magneto-optic Kerr effect magnetometry), and dynamic measurements such as FMR (ferromagnetic resonance).

Thin film growth and characterisation

Thin film deposition

We use mostly dc magnetron sputtering for metals or HiPIMS (high power impulse magnetron sputtering, i.e. bursts of plasma with a low duty cycle) to deposit thin ferromagnetic films.

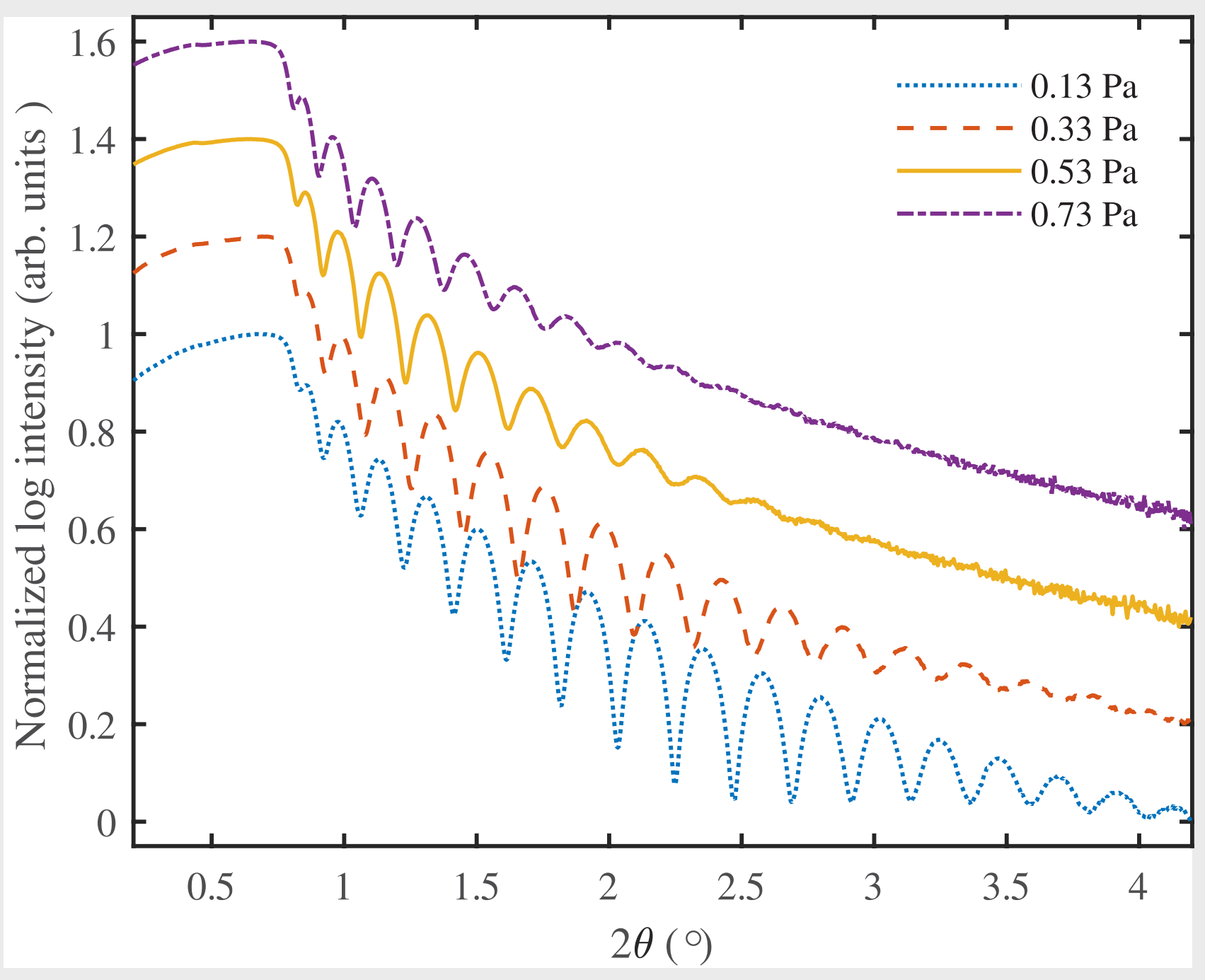
A very common method to affect the direction of magnetic anisotropy after deposition is to apply a static magnetic field in situ, during growth. Another method, less commonly used, is to change the incident angle of the sputter flux, i.e. sputter at an angle other than 90 degrees. Both methods can help define the anisotropy axes, and we study both, separately and together. Neither of them is well understood yet!



Sample arrangement during sputter deposition. The sample is enclosed by permanent magnets and we change the angle of incident flux.

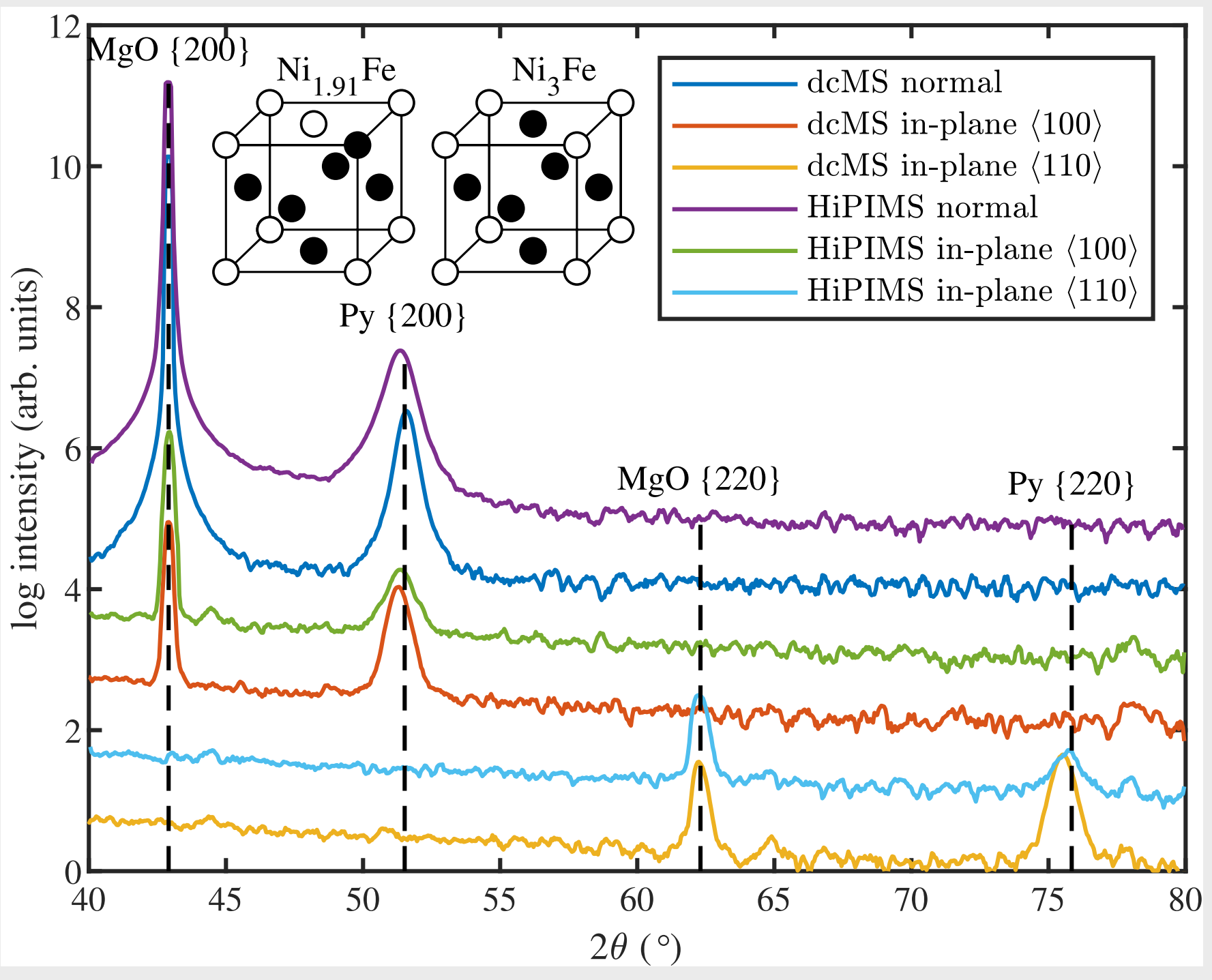
Structural properties

The crystal structure, epitaxy (or not), grain size, density, defects and film thickness are very important to know. These are obtained by x-ray measurements, (XRD: x-ray diffraction, XRR: x-ray reflection, AFM: atomic force microscopy).

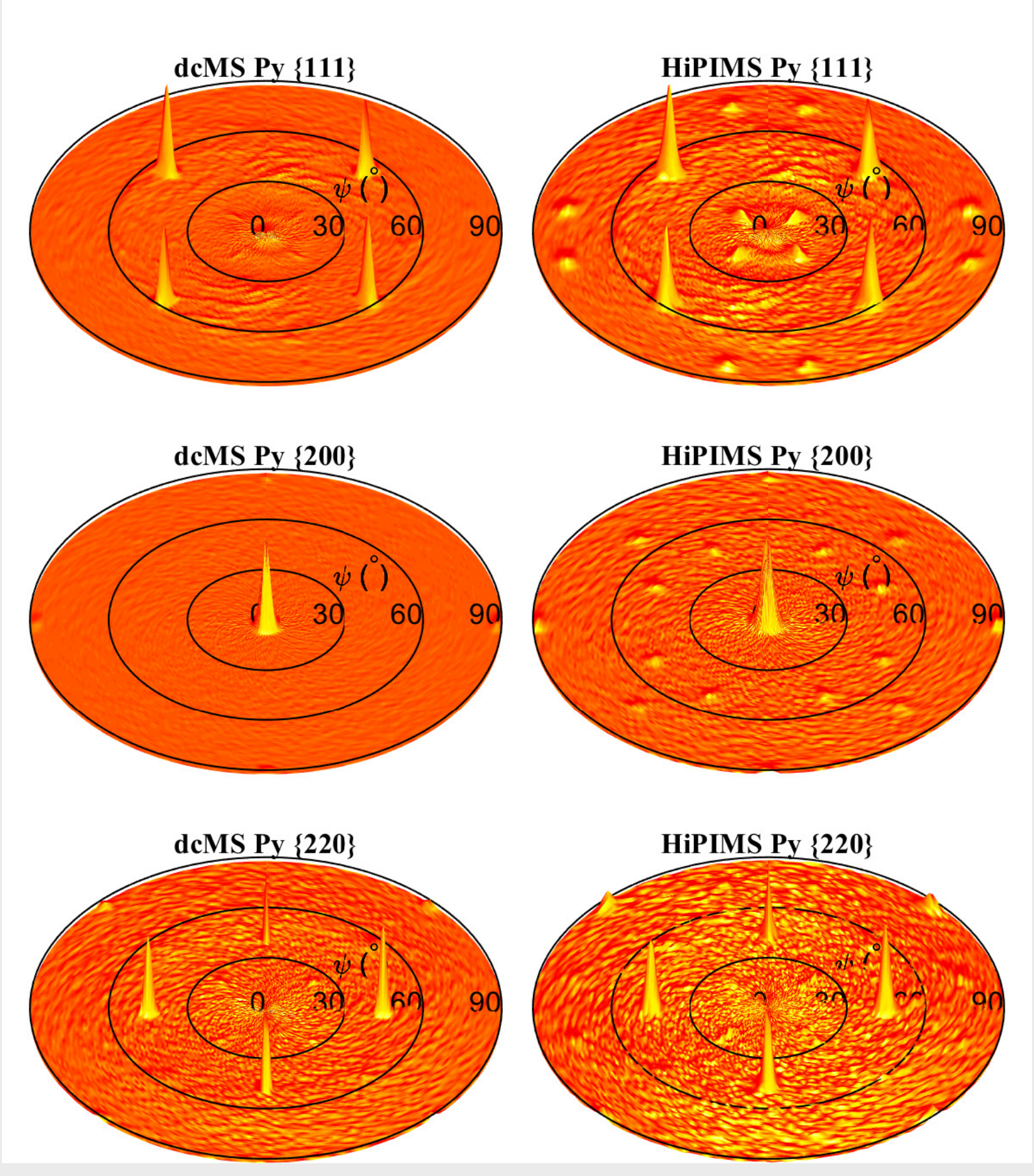


Fitting XRR results, the decaying fringes in the figure, yields film thickness, surface or interface roughness, and film density.

Epitaxial $Ni_{80}Fe_{20}$ (permalloy)



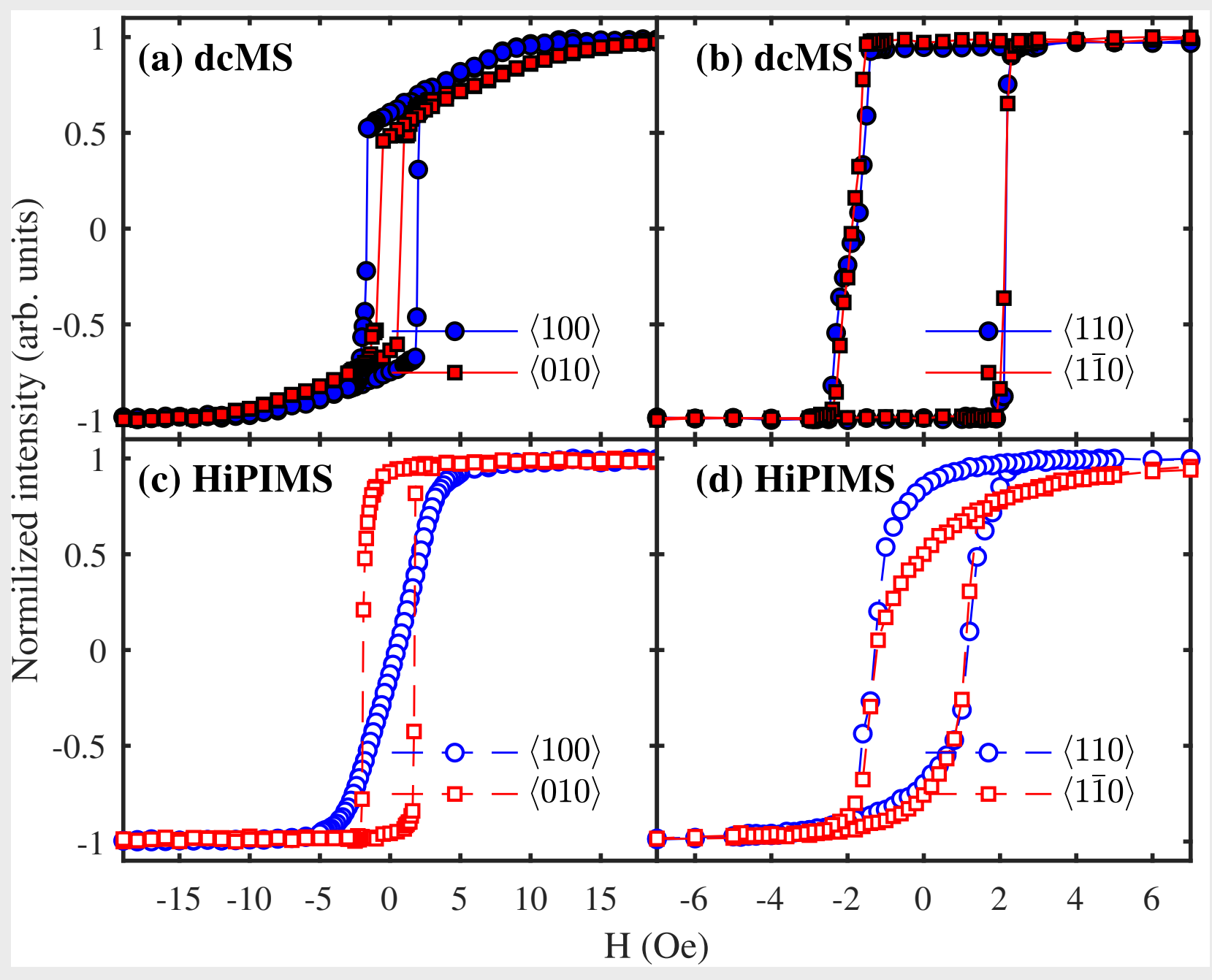
XRD spectra of dc magnetron sputtered and HiPIMS deposited permalloy. The interface with the MgO substrate is strained, but there is a perfect cube-on-cube epitaxial relationship between film and substrate.

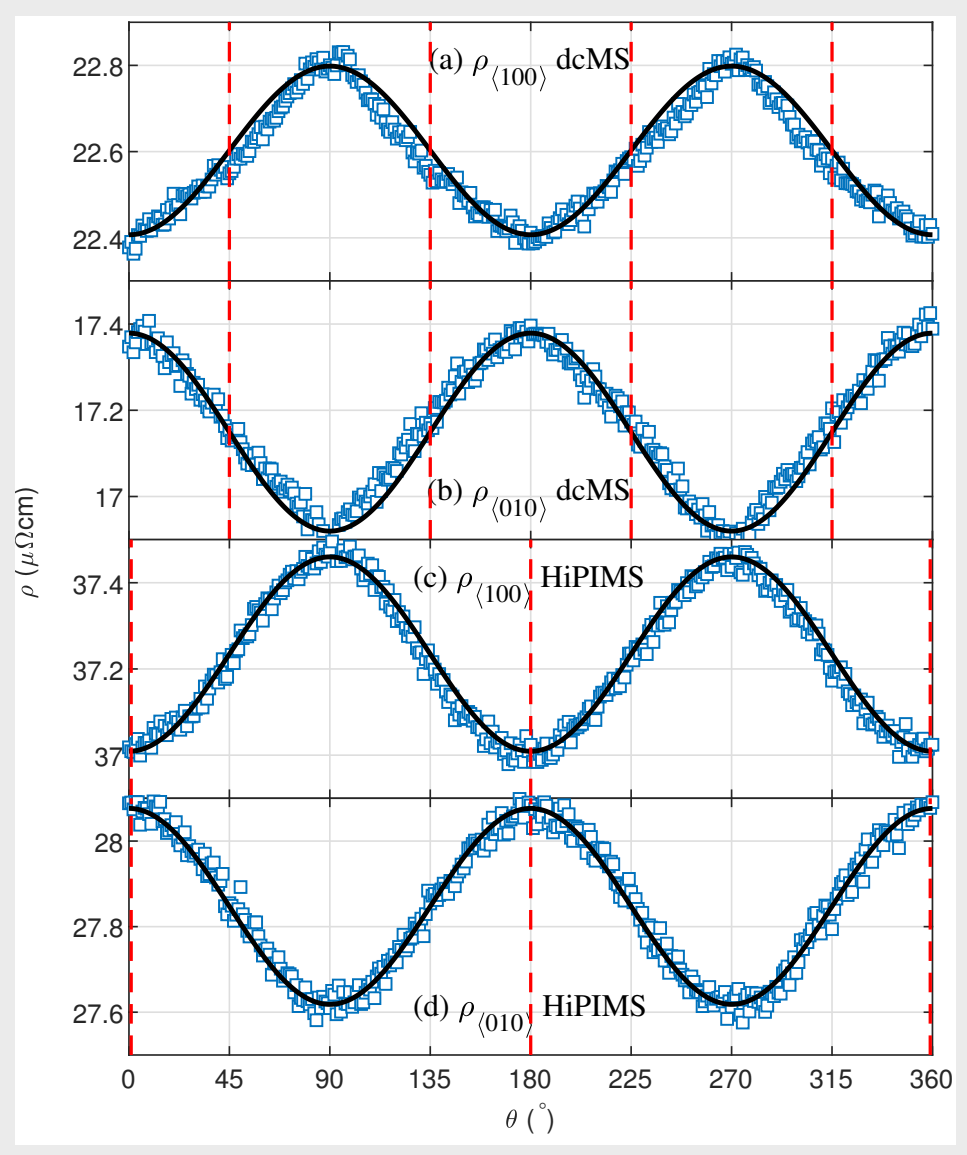


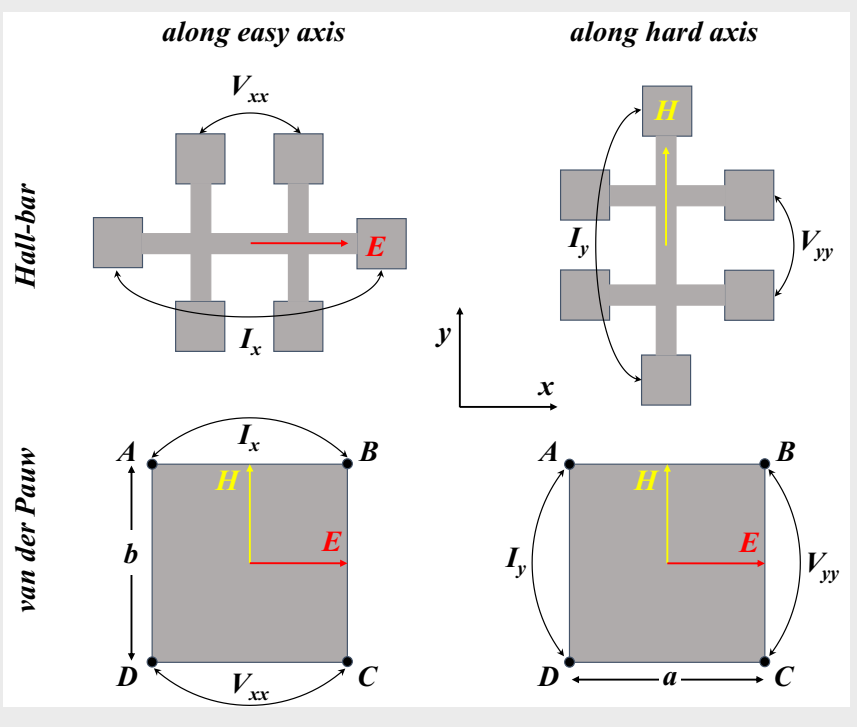
Subtle differences in the pole figures of films made by different deposition methods.

Magnetic properties differ dramatically between the two deposition techniques:

- dc magnetron sputtered films have cubic in-plane symmetry, with two equivalent easy axes along the <110> directions and have "hard axes" in-plane along the <100> directions.
- HiPIMS deposited films have "easy axis" anisotropy, that is one easy axis and one hard axis at right angles in the plane of the film. The easy axis in our case is along <100> while the hard is along <010>.







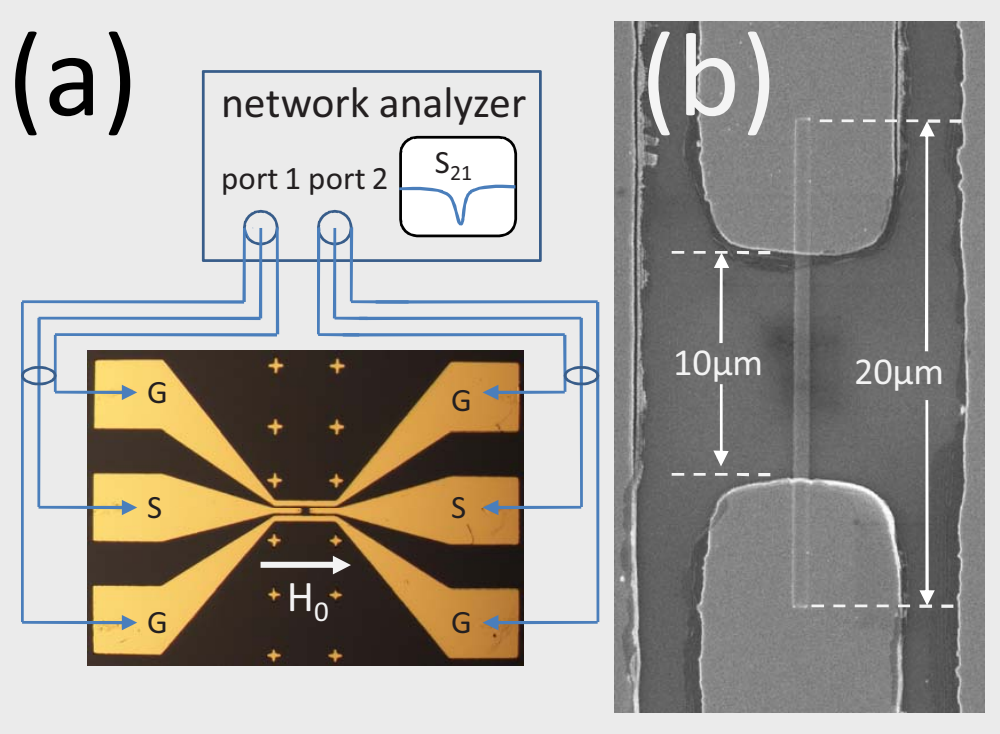
Measurement techniques for magnetoresistance, above. Left: AMR results for epitaxial permalloy films.

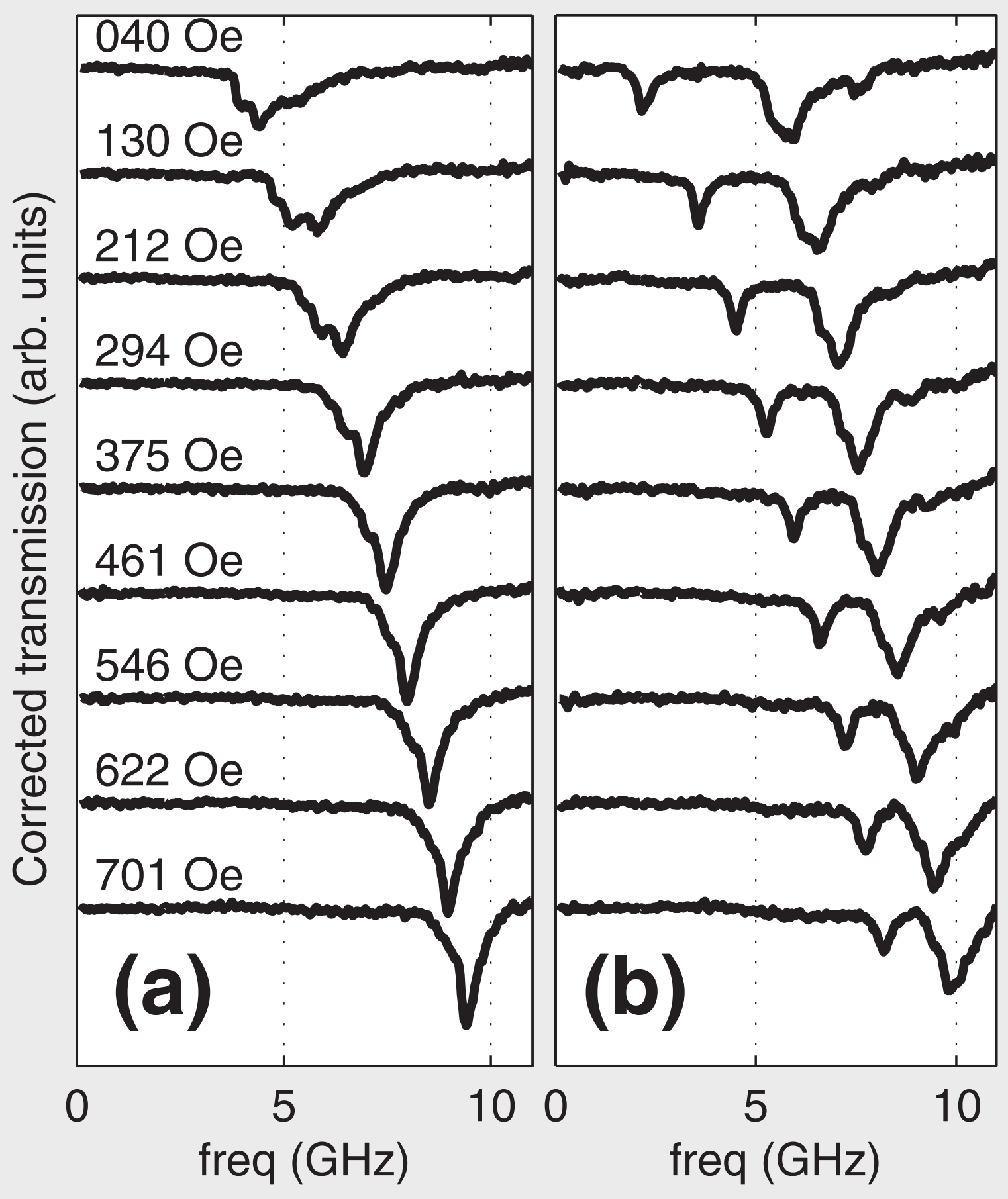
Magnetotransport

We employ either lithographic patterning or a technique named after van der Pauw that requires nothing but a simply connected region and knowledge of distance between electrical contacts. An extension of this technique provides the full 2x2 in-plane resistivity tensor. The resistivity variation in the epitaxial permalloy films above is shown left, as the saturated magnetization is rotated in the plane.

Magnetodynamics: Ferromagnetic resonance

We do ferromagnetic resonance measurements on thin films and patterned structures. Below is a schematic of an experiment done on 650 nm wide wires, in one case a single 15 nm thick layer of permalloy, in the other case two such layers separated by a 20 nm thick spacer layer of copper (non-magnetic). The results are shown in the figure on the right. The left panel is a single layer, while the right panel shows how the layers couple and split the resonant peak due to magnetostatic interaction.





Further information

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