NON-LINEAR SPIN-WAVES RADIATED IN SPIN-TORQUE NANOCONTACT DEVICES

H. Schultheiss[1], F. Ciubotaru[1], A. Laraoui[1], S. Hermsdörfer[1], M. Manfrini[2], M. van Kampen[2], L. Lagae[2], B. Leven[1], A.N. Slavin[3], and B. Hillebrands[1]

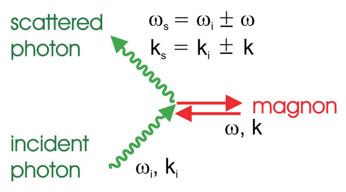
[1]Fachbereich Physik and Forschungszentrum OPTIMAS, TU Kaiserslautern, 67663 Kaiserslautern, Germany
[2]IMEC, 3001 Leuven, Belgium,
[3]Department of Physics, Oakland University, Rochester, MI-48309, USA

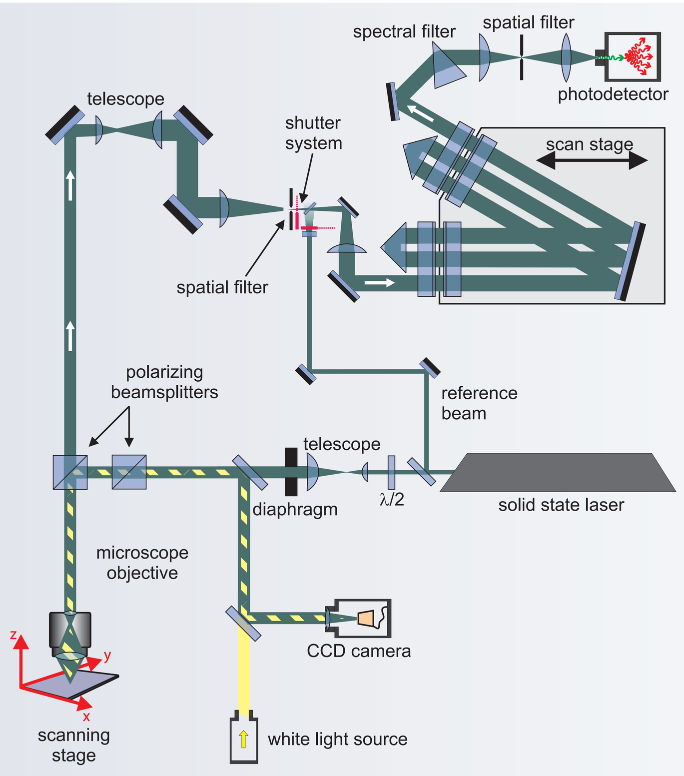
Motivation:

- Investigation of the dynamic magnetic excitation spectrum in nanocontacts
- Studies of spin-wave radiation in spin torque devices
- Understanding the influence of a dc current on magnetization dynamics

Microfocus Brillouin Light Scattering:

Inelastic scattering between photons and magnons with conservation of energy and momentum





- Optical spatial resolution: 250 nm
- Frequency range: 1 GHz - 500 GHz
- Spectral resolution: 100 MHz
- Large dynamic range due to contrast better than 1:10^{10}
- High sensitivity, i.e., investigation down to thermally excited spin waves
- 2D scanning stage for sample positioning
- Integrated observation system for monitoring the sample even while spectroscopic measurements are running

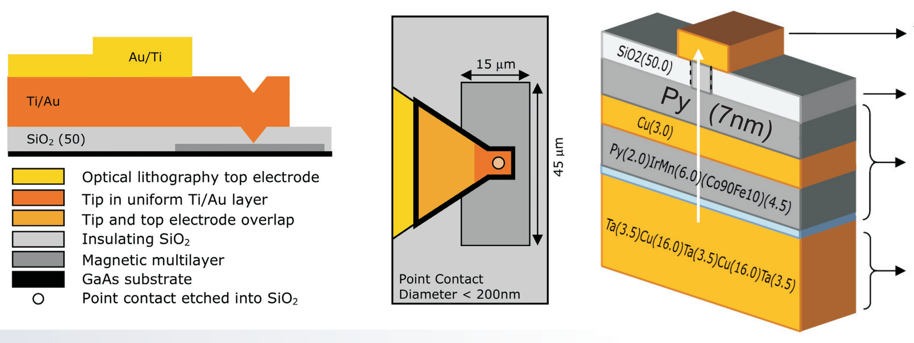
Active stabilization and positioning

- Automatic stabilization of sample below laser spot
- Enables reproducible measurements of arbitrary duration
- Precise laser positioning (15 nm resolution)
- Flexible programming of scan regions directly in the CCD-camera image of the sample

Spin torque nanocontacts:

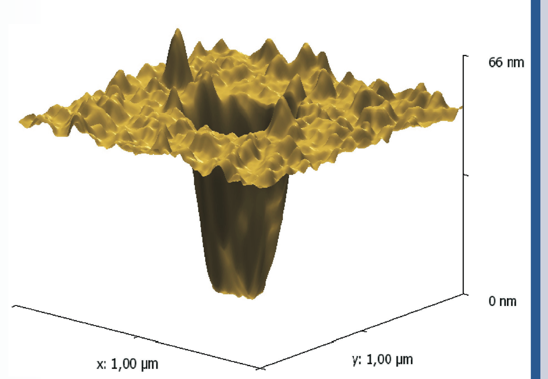
The spin torque nanocontacts presented here are prepared for investigations of the magnetization dynamics with optical methods. Hence, the top-electrode of the nanocontacts are "tip-shaped" to have optical access to the magnetic free layer.

Contact Design:



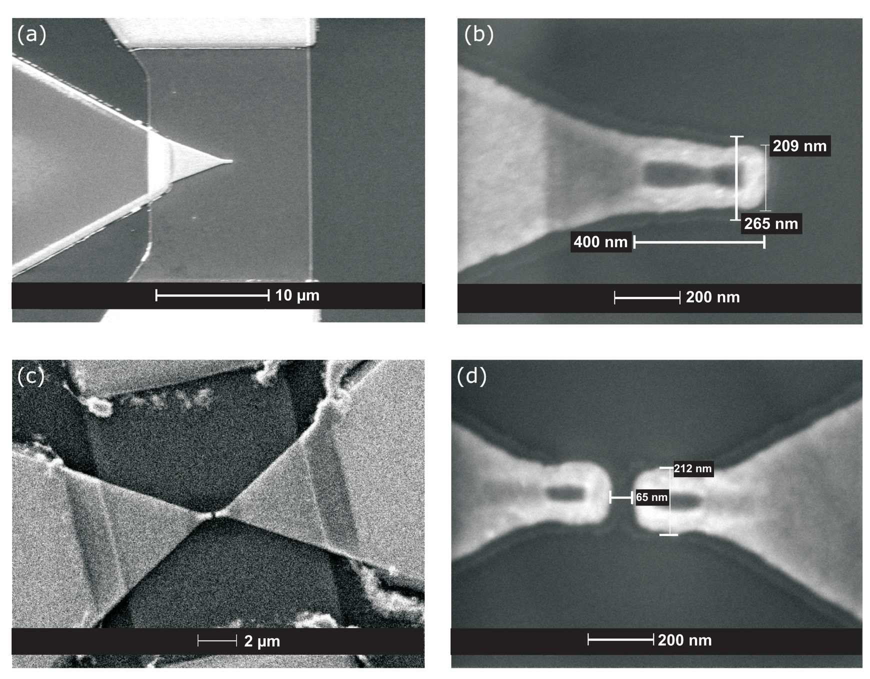
Point contacts with diameters ranging from 80 nm to 200 nm are etched into the SiO_2-layer.

The "tip-shaped" top electrode is patterned in two steps. The fine structure is prepared with electron beam lithography. The coplanar waveguides for the rf-measurements are made by optical lithography.



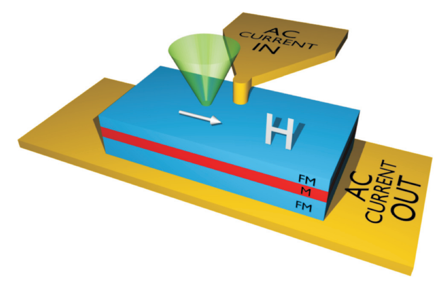
AFM-image of the nanocontact

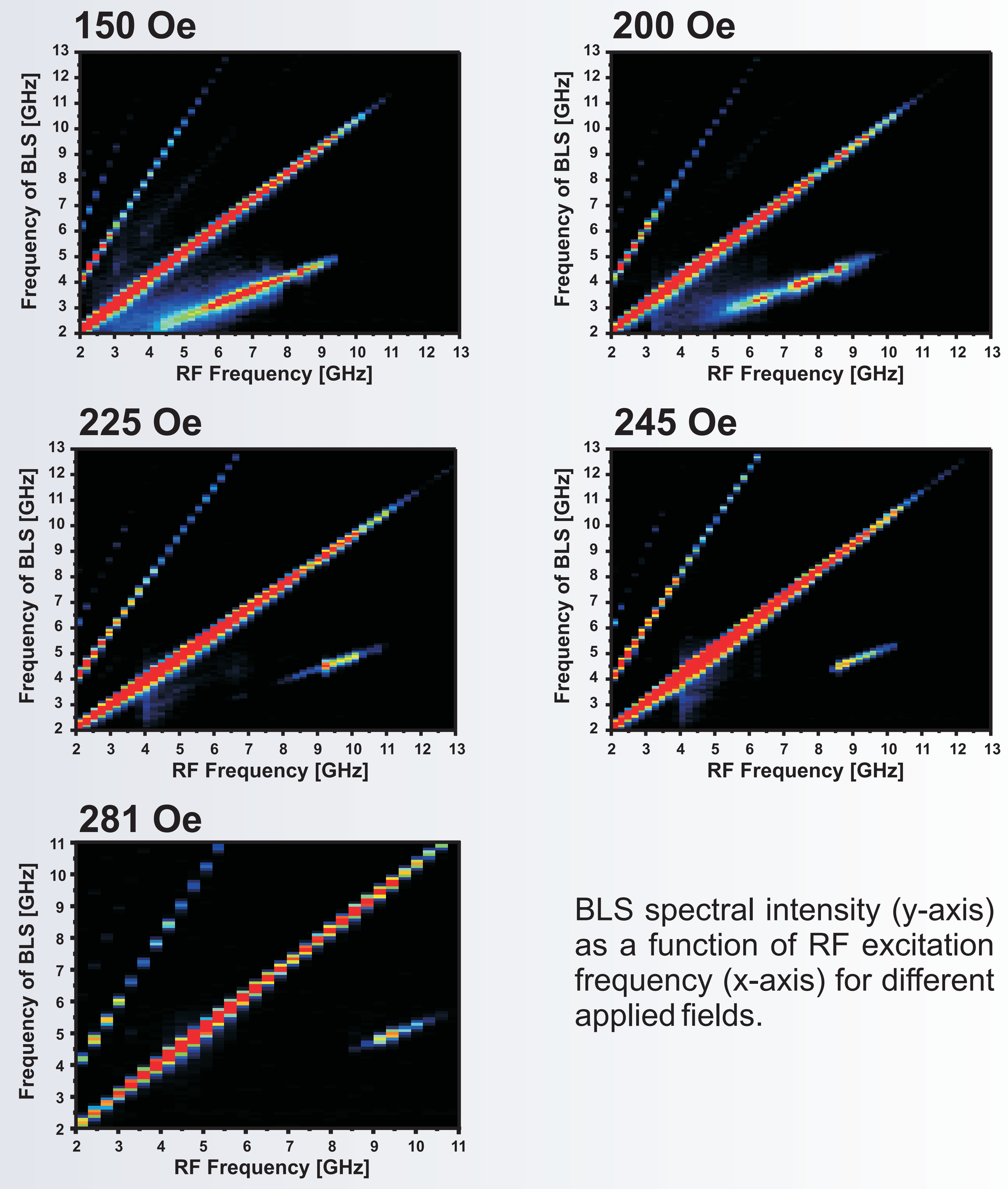
SEM-images of the nanocontacts:



Investigation of the resonances in external applied fields:

To determine the resonance frequencies of the nanocontacts we applied a microwave current with different frequencies and measured the BLS response at a fixed position.





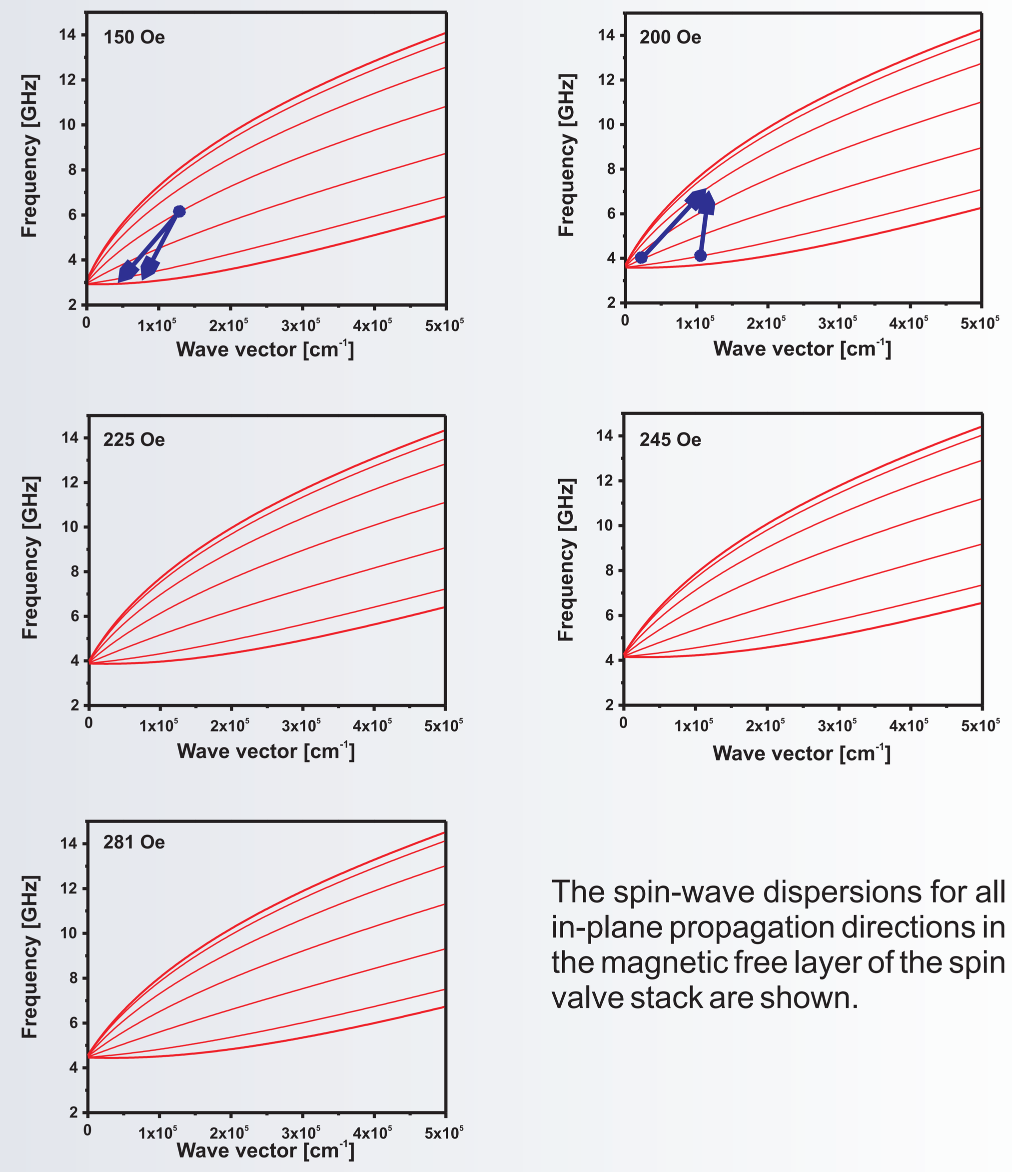
BLS spectral intensity (y-axis) as a function of RF excitation frequency (x-axis) for different applied fields.

- Spin waves with frequencies 0.5, and 2 times the excitation frequency are observed in the vicinity of the point contact
- In the measurement with an externally applied field a clear threshold frequency for the appearance of 0.5 of the excitation frequency is found

Nonlinear processes in nanocontacts:

The appearance of modes with twice and half the excitation frequency in the spatially resolved measurements described in the panel above motivated for a deeper investigation of these processes:

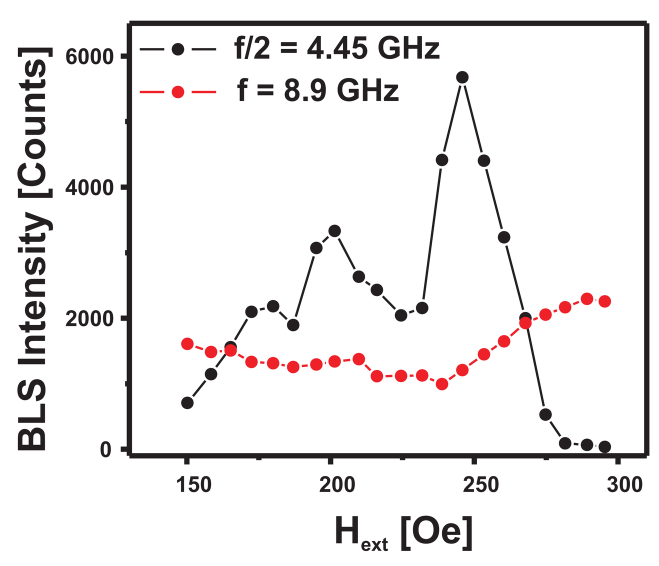
Spin-wave dispersions:



The spin-wave dispersions for all in-plane propagation directions in the magnetic free layer of the spin valve stack are shown.

- The threshold frequency for the half frequency generation can be explained due to three-magnon-scattering when conservation of energy is taken into account
- Splitting of a magnon in two magnons is possible only in the case of an externally applied field if the excitation frequency is twice the bottom of the spin-wave band

Field dependence of a ½ *f* mode

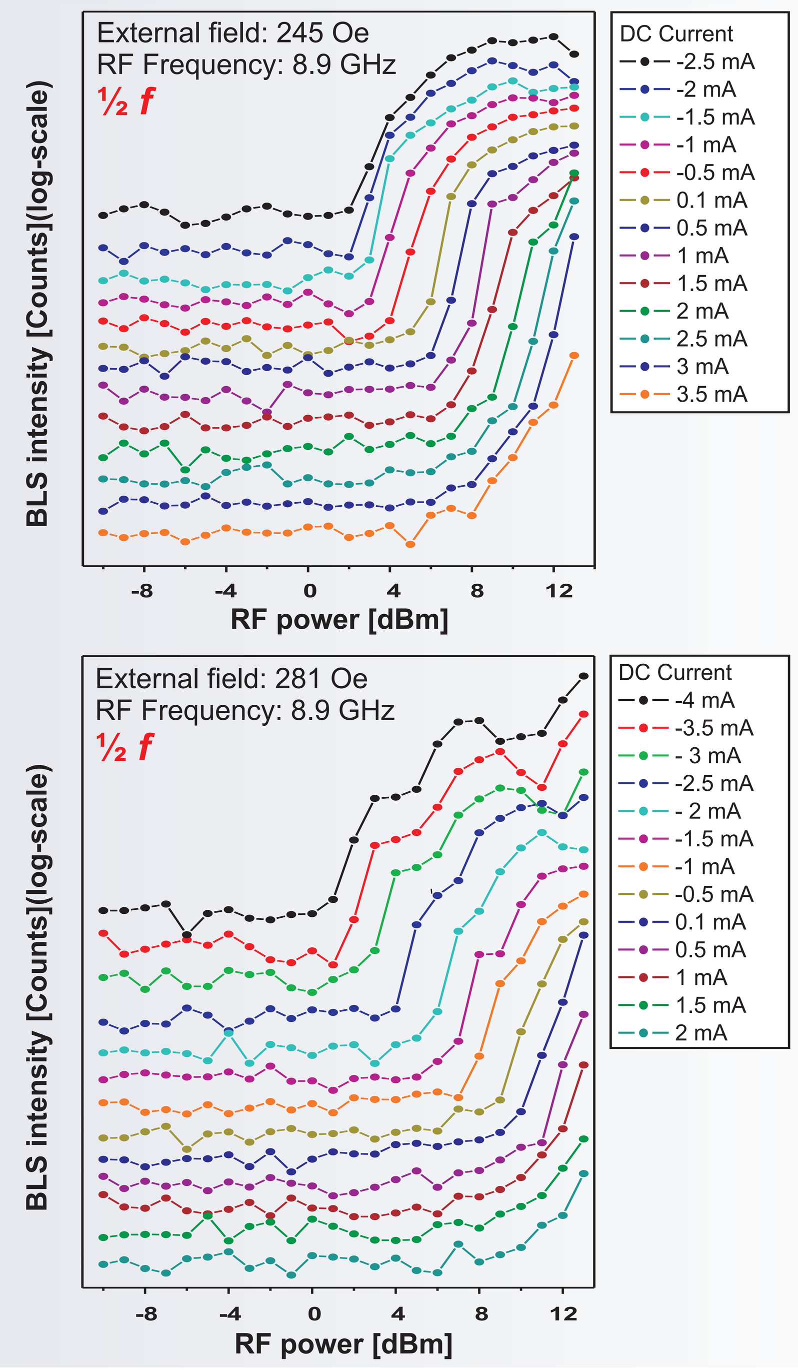


Sweeping the magnetic field for a fixed RF power and RF frequency of 8.9 Ghz → know the magnetic field witch corresponds to the maximum of BLS intensity for the half excitation frequency

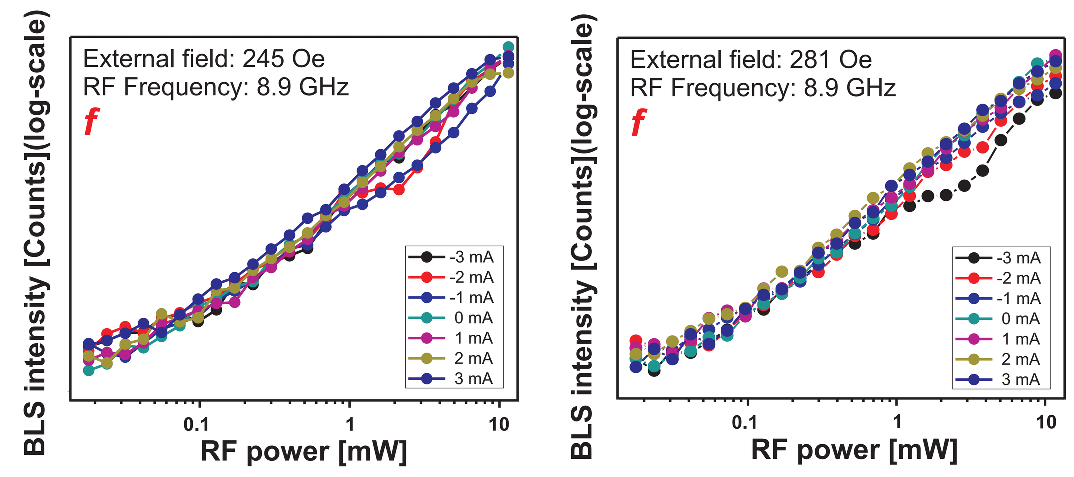
Power dependence of the nonlinear processes found in the nanocontacts:

For investigating the nonlinear behavior of the spin waves with half of the excitation frequency, the BLS intensity of the spin waves is measured as a function of the applied microwave power and as a function of the DC current.

A spin polarized dc current exerts a torque on the magnetization and will therefore influence the dynamics of the magnetization. The BLS response of spin waves excited by a microwave current as a function of an additionally applied dc current is investigated also.

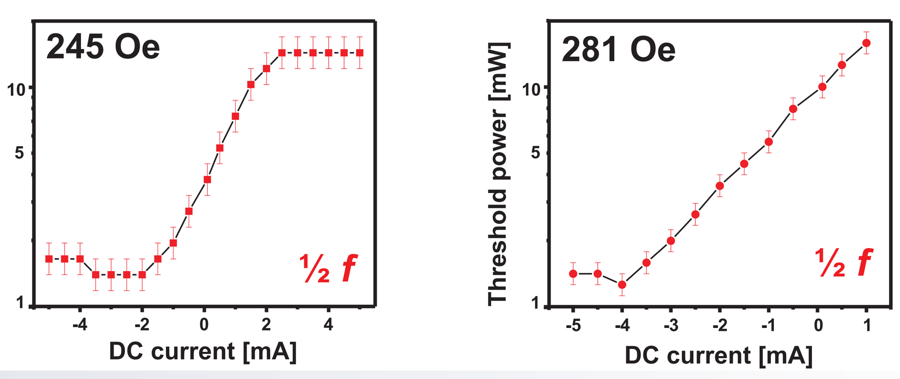


- All nonlinear processes show a clear threshold when the microwave power is increased



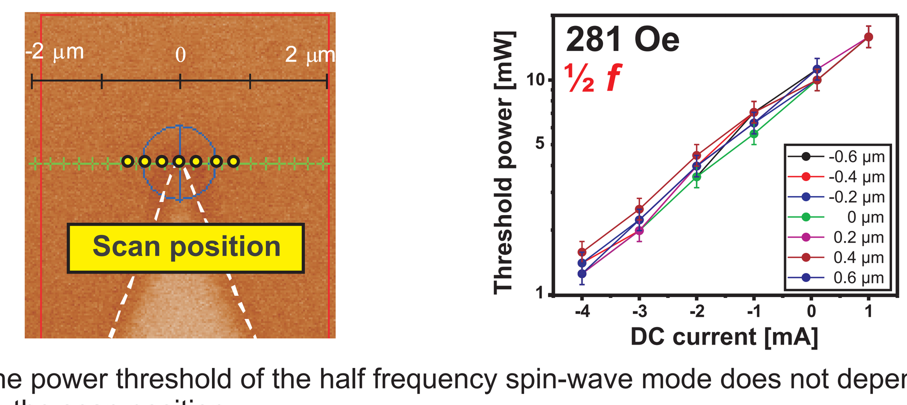
- When exciting at the resonance frequency (8.9 GHz) the directly excited spin waves show linear response as a function of the applied microwave power

Influence of a dc current on the three-magnon-scattering:



- The power threshold of the half frequency spin wave mode is clearly shifted when a dc current is applied
- Depending on the dc current direction the intensity of the half frequency mode is strongly enhanced or completely suppressed

dc current controlled three-magnon-scattering



- The power threshold of the half frequency spin-wave mode does not depend on the scan position

Acknowledgements:

- EC-MRTN SPINSWITCH (MRTN-CT-2006-035327) is gratefully acknowledged
- DFG within the priority program SPP 1133

email: helmut@physik.uni-kl.de, ciubotaru@physik.uni-kl.de
homepage: www.physik.uni-kl.de/hillebrands