PhaseFMR measurements

Key features
- Affordable turn-key FMR spectrometer
- Extracts $M_S$, damping, and gyromagnetic ratio
- Frequency 2 – 17 GHz
- Measures thin films down to 1.4 nm
- No external instruments needed
- Usable with any magnet with current source
- LabView interface

The PhaseFMR instrument is a magnetodynamic characterization tool, which brings affordable turn-key magnetodynamic characterization of thin magnetic films and magnetic nano-structures to the market.

The ferromagnetic resonance (FMR) of a magnetic thin film is a fundamental property for any high-frequency magnetic and spintronic application, such as hard drive read-heads, MRAM, spin torque MRAM, and spin torque oscillators. The PhaseFMR measures the ferromagnetic resonance at different applied magnetic fields and its analysis software extracts:
- Saturation magnetization ($M_S$)
- Intrinsic damping ($\alpha$)
- Inhomogeneous broadening ($\Delta H$)
- Gyromagnetic ratio ($\gamma/2\pi$)

In magnetic nanostructures, other higher spin-wave modes may dominate and a complete understanding of these modes is necessary for final device operation and reliability. The PhaseFMR measures the location and field dependence of such modes.

NanOsc’s PhaseFMR instrument offers coplanar waveguide ferromagnetic resonance (CPW-FMR). This is a spectroscopic technique that takes advantage of the coupling between an RF signal traveling in the CPW, and the oscillating magnetization of a sample sitting on top of it. When a ferromagnetic sample is placed in a constant uniform external field (HDC), its magnetization will align along the direction of the applied field. It is then possible to excite a precession of the sample magnetization by applying a small RF field at an angle to the direction of magnetization.

Cross section of a CPW with a sample on top. The magnetic field $h_{rf}$ will penetrate into the sample and excite spin precession.

Since the resonance frequency $f_{FMR}$ of the magnetization depends on the local field, sweeping the external field while holding the frequency of $h_{rf}$ constant will yield an absorption spectrum corresponding to the FMR response at that particular frequency.

Left: Transmission coefficient $S_{21}$ of a CPW in the presence of a magnetic sample, when HDC is swept while holding the frequency of $h_{rf}$ constant. The absorption spectrum corresponds to the FMR response of the sample. Right: Lock-in output signal.

Furthermore, if we refer to the Kittel formula for thin films with an in-plane magnetization and negligible anisotropy,

$$f_{FMR} = \frac{\gamma}{2\pi} \sqrt{4\pi M_S + H_D}$$

we can see that for this geometry it is possible to extract the saturation magnetization $M_S$ or the gyromagnetic ratio $\gamma$. Finally, the linewidth of the peak can be used to extract parameters of the dynamic behavior of the spin excitation, such as the intrinsic damping $\alpha$ and the inhomogeneous line broadening $\Delta H_0$. Comes ready with all microwave and detection hardware, as well as measurement and analysis software.
PhaseFMR-40

- Revolutionary turn-key FMR spectrometer
- Extracts the $M_S$, damping, inhomogeneous broadening and gyromagnetic ratio
- Extended frequency range 2 – 40 GHz
- Easy to use LabView interface

System specifications

<table>
<thead>
<tr>
<th>Component</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnet control</td>
<td>Range: -10 V to +10 V 16 bit digital to analog converter with a resolution (one least significant bit, 1 LSB) of $20/2^{16} = 0.3$ mV</td>
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<tr>
<td>RF source</td>
<td>Range: 2 to 17 GHz RF output accurate to ±0.05 GHz</td>
</tr>
<tr>
<td>Readout</td>
<td>Range: -10 V to +10 V 16 bit analog to digital converter with a resolution (one least significant bit, 1 LSB) of $20/2^{16} = 0.3$ mV. Max sampling rate 100 kS/s.</td>
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<tr>
<td>AC field modulation</td>
<td>A modulation setting of 0.45 with the standard 120 mm diameter 35 turns Helmholtz coils mounted at 100 mm distance corresponds to an AC field of 1 Oe peak-to-peak.</td>
</tr>
<tr>
<td>Minimum computer requirements</td>
<td>Processor: Pentium III/Celeron 866 MHz or equivalent RAM: 256 MB OS: Windows 7/Vista, Windows XP SP3 Disk space: 353 MB</td>
</tr>
</tbody>
</table>

PhaseFMR includes

- RF Frequency source (2-17 GHz) along with Lock-in detection module
- SMA cables 2-17 GHz length 36”
- standard CPW waveguide with SMA end launches
- Helmholtz modulation coils, diameter 120 mm
- Hall sensor assembly
- power supply unit, 110/220 V
- LabView executable software

Not included

- PC
- Electromagnet
- Electromagnet power supply
- Holder for the waveguide suitable for the selected magnet

PhaseFMR-40 includes

- RF Frequency source (2-40 GHz) along with Lock-in detection module
- 2.92 mm cables 2–40 GHz length 36”
- standard CPW waveguide with 2.92 mm end launches
- Helmholtz modulation coils, diameter 120 mm
- Hall sensor assembly
- power supply unit, 110/220 V
- LabView executable software

Not included

- PC
- Electromagnet
- Electromagnet power supply
- Holder for the waveguide suitable for the selected magnet

$M_S$ and damping extracted with PhaseFMR-40
CryoFMR has a built-in lock-in amplifier to recover FMR response signals that may be obscured by noise orders of magnitude larger than the signal itself. We use a pair of Helmholtz coils connected to an internal AC source (490 Hz) in order to generate a small modulation field $h_m$ parallel to $H_{DC}$, as illustrated in the schematic. This added component modulates the FMR response, and the output of the lock-in will be a derivative trace instead of an absorption peak.

- Variable temperature turn-key FMR spectrometer
- Extracts the temperature dependent $M_s$, damping, inhomogeneous broadening and gyromagnetic ratio
- Frequency 2 – 17 GHz
- Temperatures from 4 K to 400 K
- Easy to use LabView interface

For integration with the PPMS family, a dedicated modified multifunction probe with Helmholtz coils is required. NanOsc Instrument provides two CPWs for analysis of thin films with in-plane and out-of-plane magnetic fields.

**CryoFMR for PPMS includes**
- RF Frequency source (2–17 GHz) along with lock-in detection module
- SMA cables 2–17 GHz, length 36
- dedicated MFP probe with Helmholtz coils
- CPWs for analysis of thin films in-plane and out-of-plane respectively
- 110/220 V to ±15 V power supply adapter
- LabView executable software

**Not included**
- PC
- Quantum Design PPMS
CryoFMR for Cryostation from Montana Instruments

- Variable temperature turn-key FMR spectrometer
- Extracts the temperature dependent $M_s$, damping, inhomogeneous broadening and gyromagnetic ratio
- Frequency 2 – 17 GHz
- Temperatures from 5 K to 400 K
- Easy to use LabView interface

CryoFMR for Cryostation includes

- RF Frequency source (2 – 17 GHz) along with lock-in detection module
- SMA cables 2 – 17 GHz, length 36
- CPW with SMP connectors
- Coldfinger for in-plane and out-of-plane
- Helmholtz modulation coils, diameter 20 mm
- Hall sensor assembly
- 110/220 V to ±15 V power supply unit
- LabView executable software

Not included
- PC

Cryostation with magneto-optical option