# Magnetodynamics of pseudo-spin-valves investigated using coplanar wave guide and spin-torque ferromagnetic resonance techniques

Coupled and uncoupled trilayers, coincidence point resonance, and the high Q-factor peak at the resonance of coupled layers

**Masoumeh Fazlali**
Institutionen för fysik
Naturvetenskapliga fakulteten

**Opponent:** Prof. Sergei Demokritov
Institut für Angewandte Physik
University of Münster
**Huvudhandledare:** Prof. Johan Åkerman
Institutionen för fysik
Göteborgs Universitet
**Ordförande:** Prof. Dag Hanstorp
Institutionen för fysik
Göteborgs Universitet

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Göteborgs universitet
412 96 Göteborg
Telefon +46 31 786 9146

## Abstract

Nanocontact spin-torque nano-oscillators (NC-STNOs), based on magnetic multilayers, can generate a wide range of highly nonlinear localized and propagating spin wave modes for use in magnonics. In this thesis, we study some aspects of these structures from the fundamental physics point of view using the spin torque ferromagnetic resonance technique (ST-FMR) and conventional broadband FMR technique. The structure under focus is Co/Cu/Py pseudo-spin-valves (pSV). The thesis is thematically divided into two parts.

**First,** the ST-FMR technique is utilized to excite and detect spin-wave resonance (SWR) spectra in tangentially magnetized NCs:

**i)** The origin of the magnetodynamics of the detected spectra is explored. It is found that the NC diameter sets the mean wavevector of the exchange-dominated spin wave, in good agreement with the dispersion relation. The micromagnetic simulations suggest that the rf Oersted field in the vicinity of the NC plays the dominant role in generating the spectra observed.

**ii)** The exchange-dominated spin wave is tuned using lateral current spread. To this end, different thicknesses of the Cu bottom layer are used to control the lateral current spread.

**Second,** the coupling between two ferromagnetic layers is explored through different thickness of Cu interlayers.

**i)** The nature of coupling in tangentially magnetized blanket trilayer Co/Cu(t)/Py is studied with different thickness of Cu of 0–40 Å by using conventional broadband FMR. In particular, RKKY type of interaction between layers is shown. Regarding samples with $t_{\mathrm{Cu}}$ belong to the collective regime, it is found a critical field below which just one acoustic mode exists. This mode below the critical field shows very low linewidth, compared to single-layer or alloy-like regime samples. These results demonstrate that, by using the strength of the IEC, it is possible to engineer a cut-off frequency in magnetic trilayers, below which the spin pumping is turned off.

**ii)** Knowing the fact that Co and Py have very different f-H dependency (field spectra), I focus on the collective dynamics of the FM/N/FM system, when the FMR frequencies of the separate layers form a cross-point (CP) at a particular value and angle of the applied magnetic field and are substantially different otherwise. Here I observe substantially three different types of field spectra as a function of Cu thickness: alloy-like regime, the collective regime, and very weak coupled regime. In the case of the collective regime, a broad bandgap ($>$ 1 GHz) is formed at the field spectra CP. The numerical fit helps in explaining the experimental data.

**iii)** The NC-STNOs with two different $t_{\mathrm{Cu}}$ (one, very weakly coupled and another one almost uncoupled as the reference sample) at the same field configuration in the previous work is studied for the effect of rf current in the vicinity of CP in coupled pSV. Surprisingly, it is observed that a sharp mode (minimum linewidth of 0.8 mT) appears in the vicinity of the CP in the weakly coupled sample spectra. It seems that the coupling of FM layers near the CP point tends to suppress all the spectra, except over a very narrow range of f–H, which leads to these sharp peaks. One possible explanation for this phenomenon is the Slonczewski mode nucleated by the spin pumping from Co to Py layer.

**Keywords:** Spintronics, Nanocontact pseudo spin valve, Spin waves, Spin transfer torque, Oersted field, Interlayer exchange coupling, Spin pumping, Collective mode, Acoustic and optical mode, Slonczewski mode