

University of Groningen

High frequency spin dynamics in hybrid metallic devices

Costache, Marius Vasile

IMPORTANT NOTE: You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.

Document Version

Publisher's PDF, also known as Version of record

Publication date:

2007

[Link to publication in University of Groningen/UMCG research database](#)

Citation for published version (APA):

Costache, M. V. (2007). *High frequency spin dynamics in hybrid metallic devices*. s.n.

Copyright

Other than for strictly personal use, it is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license (like Creative Commons).

The publication may also be distributed here under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license. More information can be found on the University of Groningen website: <https://www.rug.nl/library/open-access/self-archiving-pure/taverne-amendment>.

Take-down policy

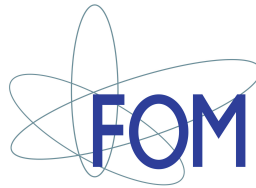
If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Downloaded from the University of Groningen/UMCG research database (Pure): <http://www.rug.nl/research/portal>. For technical reasons the number of authors shown on this cover page is limited to 10 maximum.

High Frequency Spin Dynamics in Hybrid Metallic Devices



University of Groningen
**Zernike Institute
for Advanced Materials**



Zernike Institute PhD thesis series 2007-08
ISSN 1570-1530
ISBN 978-90-367-3003-7
ISBN 978-90-367-3004-4

The work described in this thesis was performed in the research group Physics of Nanodevices (part of the Zernike Institute for Advanced Materials) at the University of Groningen, the Netherlands. The project was supported by the Dutch Foundation for Fundamental Research on Matter (FOM) with financial support from the Dutch Organization for the Advancement of Scientific Research (NWO).

Printed by: Print Partners Ipskamp, Eschede
Cover: Applied Physics Letters cover image of 06 Nov. 2006 issue.

RIJKSUNIVERSITEIT GRONINGEN

High Frequency Spin Dynamics in Hybrid Metallic Devices

Proefschrift

ter verkrijging van het doctoraat in de
Wiskunde en Natuurwetenschappen
aan de Rijksuniversiteit Groningen
op gezag van de
Rector Magnificus, dr. F. Zwarts,
in het openbaar te verdedigen op
vrijdag 25 mei 2007
om 14.45 uur

door

Marius Vasile Costache

geboren op 29 november 1977
te Onesti, Roemenië

Promotor: Prof. dr. ir. B.J. van Wees

Beoordelingscommissie: Prof. dr. Y. Otani
Prof. dr. R. Jansen
Prof. dr. ir. P.H.M. van Loosdrecht

Contents

1	Introduction	5
1.1	Spintronics	5
1.2	Motivation	7
1.3	Outline	8
2	Spin injection concepts	11
2.1	Spin injection due to charge current	11
2.1.1	Electrical properties of ferromagnetic metals	11
2.1.2	The basics of spin transport	12
2.1.3	The ferromagnet/normal-metal interface	14
2.1.4	Bloch equations	16
2.2	Spin injection due to magnetization precession	17
2.2.1	Spin transfer torque effect	17
2.2.2	Spin pumping effect	19
2.3	Magnetization dynamics	24
2.3.1	Ferromagnetic resonance of a ferromagnetic strip	24
3	Device fabrication and measurement techniques	31
3.1	Introduction	31
3.2	Device fabrication techniques	31
3.2.1	Creating an evaporation mask using electron beam lithography	31
3.2.2	Metal deposition and lift-off	33
3.3	Fabrication procedure for the individual samples	35
3.3.1	Device A	35
3.3.2	Device B	36
3.4	Measurement techniques	38
4	Spin accumulation probed in multiterminal lateral all-metallic devices	41
4.1	Introduction	41
4.2	Theoretical model	43
4.3	Spin valve measurements	44

4.3.1	Non-local spin valve configuration	45
4.3.2	Local spin valve configuration	49
4.4	Conclusions	50
5	On-chip detection of ferromagnetic resonance of a single sub-micron permalloy strip	53
5.1	Introduction	53
5.2	Results and discussion	55
5.3	Conclusions	59
6	Large cone angle magnetization precession of an individual nanopatterned ferromagnet with dc electrical detection	61
6.1	Introduction	61
6.2	Experimental results	64
6.2.1	Device layout	64
6.2.2	AMR measurements, no rf applied	65
6.2.3	AMR measurements, with rf applied	65
6.2.4	AMR rectification effect	68
6.3	Conclusions	71
6.4	Appendix	73
7	Electrical detection of spin pumping due to the precessing magnetization of a single ferromagnet	75
7.1	Introduction	75
7.2	Detection principle	76
7.3	Device fabrication and measurement technique	78
7.4	Detection of spin pumping	79
7.4.1	A. Transverse electrode device geometry	79
7.4.2	B. Longitudinal electrode device geometry	83
7.5	Analysis	87
7.5.1	Contribution from AMR rectification effects	87
7.5.2	Spin pumping model	88
7.6	Conclusions	89
7.7	Appendix	91
7.7.1	Magnetization precession cone angle	91
7.7.2	Contacts position and high power dependence	92
7.7.3	Results with cobalt	94
8	Microwave spectroscopy on magnetization reversal dynamics of nanomagnets with electronic detection	101
8.1	Introduction	101
8.2	Experimental realization	102
8.3	Results and discussion	103
8.4	Conclusions	107

Summary	109
Samenvatting	113
Publications	117
Acknowledgements	119

