University of Groningen

Spin transport and spin dynamics in antiferromagnets

Hoogeboom, Geert

DOI:
[10.33612/diss.157444391](https://doi.org/10.33612/diss.157444391)

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:
2021

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

Citation for published version (APA):
Hoogeboom, G. (2021). *Spin transport and spin dynamics in antiferromagnets*. [Thesis fully internal (DIV), University of Groningen]. University of Groningen. <https://doi.org/10.33612/diss.157444391>

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.

Spin transport and spin dynamics in antiferromagnets

Geert Roelof Hoozeboom

university of
 groningen

faculty of mathematics and
 natural sciences

zernike institute for
 advanced materials

Zernike Institute PhD thesis series 2021-02

DOI:

The work described in this thesis was performed in the research group Physics of Nanodevices of the Zernike Institute for Advanced Materials at the University of Groningen, the Netherlands. This work is part of the research program Magnon Spintronics (MSP) No. 159 funded by the Nederlandse Organisatie voor Wetenschappelijk Onderzoek (NWO). Further, the Spinoza Prize awarded in 2016 to B. J. van Wees by NWO is gratefully acknowledged.

Cover: The front and back cover pages consist of data presented in Fig. 5.5 a) and Fig. 5.5 b) and is modified in color and data point size. The arrows, from Fig. 5.5 a), represent the antiparallel magnetic moment directions in an antiferromagnet. The figure on the invitation are the fits in Fig. 5.4, modified in color. Printed by: Ipskamp Printing, Enschede

rijksuniversiteit
 groningen

Spin transport and spin dynamics in antiferromagnets

Proefschrift

ter verkrijging van de graad van doctor aan de
Rijksuniversiteit Groningen
op gezag van de
rector magnificus prof. C. Wijmenga,
en volgens besluit van het College voor Promoties.

De openbare verdediging zal plaatsvinden op

vrijdag 26 februari 2021 om 14:30 uur

door

Geert Roelof Hoogeboom

geboren op 13 maart 1989
te Amsterdam

Promotor

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

Co-promotor

dr. T. Kuschel

Beoordelingscommissie

Prof. dr. R. A. Duine

Prof. dr. E. Chicca

Prof. dr. B. Noheda Pinuaga

Contents

1	Introduction	1
1.1	Motivation and outline	3
	Bibliography	6
2	Theoretical background	9
2.1	Abstract	9
2.2	Exchange interactions and magnetic order	10
2.2.1	Direct exchange interaction	10
2.2.2	Indirect exchange interaction: superexchange	12
2.2.3	Magnetic order	13
2.3	Equilibrium antiferromagnetic response to a magnetic field	14
2.3.1	Equilibrium sublattice magnetization state model	15
2.3.2	Spin reorientations in an easy-axis antiferromagnet	15
2.3.3	Spin reorientations in an easy-plane antiferromagnet	17
2.3.4	Néel vector	18
2.3.5	First- and second-order transitions	19
2.4	Spin Hall magnetoresistance	22
2.4.1	Spin Hall magnetoresistance in ferromagnets	25
2.4.2	Spin Hall magnetoresistance in antiferromagnets	25
2.4.3	Easy-axis and easy-plane magnetic anisotropy models	27
2.4.4	Frustrated antiferromagnets outlook	28
2.5	Excited states	29
2.5.1	Antiferromagnetic magnons	31
2.5.2	Magnon populations	35
2.5.3	Magnon-magnon interactions	38
2.6	Spin currents	40

2.6.1	Introduction	40
2.6.2	Spin Seebeck effect in ferromagnets	42
2.6.3	Spin Seebeck effect in antiferromagnets	43
2.6.4	Magnon transport	45
2.6.5	Electrical injection of magnons	47
	Bibliography	51
3	Experimental methods	57
3.1	Abstract	57
3.2	Sample fabrication	58
3.3	Measurement setup	62
	Bibliography	64
4	Negative spin Hall magnetoresistance of Pt on the bulk easy-plane antiferromagnet NiO	65
4.1	Abstract	65
4.2	Introduction	66
4.3	NiO	67
4.4	Spin Hall magnetoresistance in antiferromagnets	67
4.5	Experimental method	71
4.6	Results and discussion	72
4.7	conclusion	77
4.8	Outlook	77
	Bibliography	79
5	Magnetic order of Dy³⁺ and Fe³⁺ moments in antiferromagnetic DyFeO₃ probed by spin Hall magnetoresistance and spin Seebeck effect	83
5.1	Abstract	83
5.2	Introduction	84
5.3	Magnetic and multiferroic properties of DyFeO ₃	85
5.4	Probing methods	86
5.4.1	Spin Hall magnetoresistance	86
5.4.2	Spin Seebeck effect	87
5.5	Methods	88
5.5.1	Fabrication, characterization and measurements	88
5.5.2	Modelling the spin Hall magnetoresistance of Pt DyFeO ₃	89
5.6	Results	93
5.7	Conclusion	101
5.A	Appendix A: Longitudinal and 2 K spin Hall magnetoresistance	102
5.B	Appendix B: Exchange interaction	104

5.C	Appendix C: Nonlocal spin transport in DyFeO_3	104
	Bibliography	109
6	Nonlocal spin Seebeck effect in the bulk easy-plane antiferromagnet NiO	115
6.1	Abstract	115
6.2	Introduction	116
6.3	Theory	117
6.3.1	Magnon modes	117
6.3.2	Spin Seebeck effect	119
6.3.3	Spin Hall magnetoresistance	120
6.4	Properties of NiO	120
6.5	Methods	121
6.6	Results	121
6.7	Conclusion	127
6.8	Outlook	127
	Bibliography	128
7	Role of NiO in the non-local spin transport through thin NiO films on $\text{Y}_3\text{Fe}_5\text{O}_{12}$	131
7.1	Abstract	131
7.2	Introduction	132
7.3	Method	133
7.4	Theory	135
7.5	Results and Discussion	137
7.6	Conclusion	145
	Bibliography	146
	Summary	151
	Samenvatting	154
	Acknowledgements	159