

University of Groningen

Magnetic anisotropy induced novel phenomena in itinerant ferromagnet SrRuO₃ thin films

Zhang, Ping

DOI:
[10.33612/diss.260675656](https://doi.org/10.33612/diss.260675656)

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:
2023

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

Citation for published version (APA):

Zhang, P. (2023). *Magnetic anisotropy induced novel phenomena in itinerant ferromagnet SrRuO₃ thin films*. [Thesis fully internal (DIV), University of Groningen]. University of Groningen.
<https://doi.org/10.33612/diss.260675656>

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).

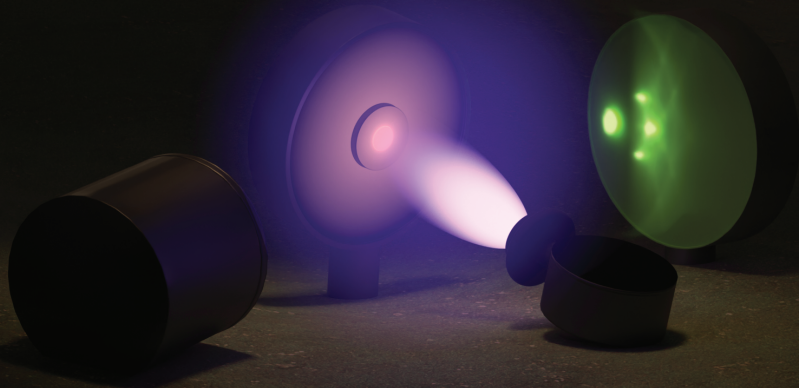
The publication may also be distributed here under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license. More information can be found on the University of Groningen website: <https://www.rug.nl/library/open-access/self-archiving-pure/taverne-amendment>.

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.

Magnetic anisotropy induced novel phenomena in itinerant ferromagnet SrRuO_3 thin films



Ping Zhang

Magnetic anisotropy induced novel phenomena in itinerant
ferromagnet SrRuO₃ thin films

Ping Zhang



**university of
 groningen**

faculty of mathematics and
 natural sciences

zernike institute for
 advanced materials

Zernike Institute PhD thesis series 2023-01
ISSN:1570-1530

The work described in this thesis was performed in the research group Spintronics of Functional Materials of the Zernike Institute for Advanced Materials at the University of Groningen, the Netherlands. This work was supported by China Scholarship Council (CSC, No. 201608500070), NanoLab NL and the Zernike Institute for Advanced Materials.

Cover design: Paper Lantern Studio

Printed by: Gildeprint, Enschede

© Ping Zhang 2023. All rights reserved.



rijksuniversiteit
 groningen

Magnetic anisotropy induced novel phenomena in itinerant ferromagnet SrRuO_3 thin films

PhD thesis

to obtain the degree of PhD at the
 University of Groningen
 on the authority of the
 Rector Magnificus Prof. C. Wijmenga
 and in accordance with
 the decision by the College of Deans.

This thesis will be defended in public on

Tuesday 10 January 2023 at 11:00 hours

by

Ping Zhang

born on 14 June 1989
 in Chongqing, China

Supervisors

Prof. T. Banerjee

Prof. B. Noheda

Assessment Committee

Prof. B. J. Kooi

Prof. T. T. M. Palstra

Prof. P. K. Johnny Wong

to Gang and Zhilan

Contents

1	Introduction	1
1.1	Complex Oxides and Spintronics	1
1.2	Resilience and Adaptability: New pathways with Skyrmion bubbles	1
1.3	SrRuO ₃ for spintronic and topological phenomena	2
1.4	Motivation and thesis outline	3
	Bibliography	5
2	Theoretical concepts and Materials	7
2.1	Perovskite ABO ₃	8
2.2	Magnetic oxides	9
2.2.1	Spin-orbit coupling	9
2.2.2	Magnetic interaction	10
2.2.3	Itinerant ferromagnetism	12
2.2.4	Magnetic anisotropy	13
2.3	Magneto-transport effect	15
2.3.1	Anomalous Hall effect	15
2.3.2	Magnetoresistance	17
2.4	Itinerant ferromagnet SrRuO ₃	17
2.4.1	Structure	17
2.4.2	Non-Fermi Liquid behavior	19
2.4.3	Magnetism	19
2.4.4	SrRuO ₃ thin film growth	20
2.4.5	Magnetic Anisotropy in SrRuO ₃	20
2.4.6	Anomalous Hall effect in SrRuO ₃	22
2.5	Substrate	22
	Bibliography	24

3	Experimental Techniques	29
3.1	Thin film growth	30
3.1.1	Substrate preparation	30
3.1.2	Pulsed laser deposition	32
3.2	Characterization methods for thin films	34
3.2.1	Atomic force microscopy	34
3.2.2	X-ray diffraction	36
3.2.3	Magnetic properties characterization	37
3.3	Device fabrication and measurement set-up	39
3.3.1	Hall bar fabrication	39
3.3.2	Measurement set-up	40
	Bibliography	42
4	Growth, characterization and magnetic properties study in SrRuO₃ thin films	43
4.1	Introduction of non-bulk-like properties in the thin film of SrRuO ₃	44
4.2	Growth of SrRuO ₃ thin film on SrTiO ₃ (001) substrate	46
4.3	Structural characterization of SrRuO ₃ thin films	48
4.4	Electrical transport of SrRuO ₃ thin films	48
4.5	Thickness dependence of magnetic properties in SrRuO ₃ thin films	51
4.6	SrRuO ₃ thin film on LaAlO ₃ substrate	53
4.7	Comparison of magnetic properties	54
4.8	Conclusion	56
	Bibliography	57
5	Robust skyrmion-bubble textures in single SrRuO₃ thin films	61
5.1	Introduction	62
5.2	Experimental results	63
5.2.1	Structural and morphological characterization	63
5.2.2	Magnetic property and transport studies	64
5.3	Discussion	68
5.4	Conclusions	71
5.5	Outlook	72
	Bibliography	75
6	Investigation of the magnetic and transport properties in SrMnO₃/SrRuO₃ bilayers	79
6.1	Introduction	80
6.2	Experimental details	81
6.3	Film properties characterization	81
6.4	Magneto-transport studies	84

Contents

6.4.1	Field-dependent transport studies	84
6.4.2	Ip-plane angular-dependent transport studies	86
6.5	Discussion	91
6.6	Additional information	92
	Bibliography	94
	Summary	97
	Samenvatting	101
	Acknowledgements	105
	Publications	112
	Curriculum Vitae	114

