

University of Groningen

Magnetotransport of Ising superconductors

Zheliuk, Oleksandr

DOI:
[10.33612/diss.113195218](https://doi.org/10.33612/diss.113195218)

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:
2020

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

Citation for published version (APA):
Zheliuk, O. (2020). *Magnetotransport of Ising superconductors*. University of Groningen.
<https://doi.org/10.33612/diss.113195218>

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).

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.

Magnetotransport of Ising superconductors

Oleksandr Zheliuk

Magnetotransport of Ising superconductors

Oleksandr Zheliuk
PhD thesis
University of Groningen

Zernike Institute PhD thesis series 2020-04
ISSN: 1570-1530
ISBN: 978-94-034-2345-6 (printed version)
ISBN: 978-94-034-2344-9 (electronic version)

The work described in this thesis was performed in the research group “Device physics of Complex Materials” of the Zernike Institute for Advanced Materials at the University of Groningen, the Netherlands.

Cover and Layout design: Oleksandr Zheliuk
Printing: Gildeprint



university of
 groningen

faculty of science
 and engineering

zernike institute for
 advanced materials



university of
 groningen

Magnetotransport of Ising superconductors

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

Friday 7 February 2020 at 14:30 hours

by

Oleksandr Zheliuk

born on 20 July 1991
 in Rivne, Ukraine

Supervisor

Prof. J. T. Ye

Co-supervisor

Prof. M. V. Mostovoy

Assessment committee

Prof. B. J. van Wees

Prof. Y. Iwasa

Prof. A. Brinkman

Contents

1.	Introduction to Ising superconductors.....	1
1.1.	Two-dimensional (2D) Van der Waals materials.....	2
1.2.	Spin-orbit coupling.....	7
1.3.	Ising superconductors.....	10
1.4.	Motivation and outline of this thesis.....	13
	References.....	14
2.	Evidence for two-dimensional Ising superconductivity in gated MoS_2 . ($\beta_{SO} + \alpha_{Ra}$)	19
2.1.	Superconducting dome of gated MoS_2	20
2.2.	Two-dimensional transport.....	23
2.3.	In-plane upper critical field.....	24
2.4.	The interplay between Rashba and Zeeman type SOC.....	28
2.5.	Mean-field theory including Rashba and Zeeman type SOC.....	30
2.6.	Device fabrication and transport measurements.....	33
	References.....	34
3.	Superconducting dome of strong Ising protection in WS_2 monolayers. ($\beta_{SO} \gg \Delta$).....	37
3.1.	Full electronic spectrum of monolayer WS_2	38
3.2.	Superconducting phase diagram.....	40
3.3.	Strong Ising protection over the entire dome.....	42
3.4.	Re-entrant insulating phase at strong gating.....	44
3.5.	Material and Device.....	47

3.6. Gating protocol.....	49
3.7. Electrostatic nature of ionic gating in WS ₂ monolayers...	51
3.8. Linking transfer curves and determining effective gate voltage.....	54
References.....	59
4. Screening and proximity in few-layer WS ₂ . ($\beta_{S0} \gg t$).....	63
4.1. Superconducting dome of bi-, tri- and quad-layer system.....	64
4.2. Superconducting dome splitting in dual-gate configuration.....	67
References.....	72
5. Josephson coupled Ising superconducting state in suspended MoS ₂ bilayers. ($\beta_{S0} \sim t$).....	73
5.1. Superconducting dome of suspended MoS ₂ bilayers	74
5.2. In-plane upper critical field.....	79
5.3. Single band K/K' pairing.....	84
5.4. Josephson coupling in layered superconductors.....	85
5.5. Device fabrication and measurement.....	87
5.6. The Klemm-Luther-Beasley model of upper critical field	89
5.7. The $V-I$ measurement and lateral SS' junction.....	92
5.8. Appendix.....	96
References.....	98
Summary.....	101
Samenvatting.....	105
Acknowledgement.....	110
List of publications.....	114
Curriculum Vitae.....	115