

Cover Page



Universiteit Leiden



The handle <http://hdl.handle.net/1887/61001> holds various files of this Leiden University dissertation.

Author: Voogd, J.M. de

Title: Magnetic Resonance Force Microscopy and the spin bath : towards single-spin massive-resonator entanglement and the spoiling influence of the spin bath

Issue Date: 2018-02-20

Magnetic Resonance Force Microscopy and the Spin Bath

TOWARDS SINGLE-SPIN MASSIVE-RESONATOR ENTANGLEMENT
AND
THE SPOILING INFLUENCE OF THE SPIN BATH

PROEFSCHRIFT

TER VERKRIJGING VAN
DE GRAAD VAN DOCTOR AAN DE UNIVERSITEIT LEIDEN,
OP GEZAG VAN RECTOR MAGNIFICUS PROF. MR. C. J. J. M. STOLKER,
VOLGENS BESLUIT VAN HET COLLEGE VOOR PROMOTIES
TE VERDEDIGEN OP DINSDAG 20 FEBRUARI 2018
KLOKKE 13.45 UUR

DOOR

Jacobus Marinus de Voogd

GEBOREN TE VLISSINGEN
IN 1989

Promotor: Prof. dr. ir. T. H. Oosterkamp

Promotiecommissie: Dr. A. C. Bleszynski Jayich (University of California,
Santa Barbara, USA)

Prof. dr. R. Hanson (Technische Universiteit Delft)

Dr. J. van Wezel (Universiteit van Amsterdam)

Prof. dr. J. Aarts

Prof. dr. E. R. Eliel

Casimir PhD series, Delft-Leiden 2018-01

ISBN 978-90-8593-333-5

An electronic version of this thesis can be found at openaccess.leidenuniv.nl

The work described in this thesis was performed at the Huygens - Kamerlingh Onnes Laboratory, Universiteit Leiden, Niels Bohrweg 2, 2333 CA, Leiden.

This work is part of the research programme of the Foundation for Fundamental Research on Matter (FOM), which is part of the Netherlands Organisation for Scientific Research (NWO).

Cover design by Studio Zint - The cover shows a symbolic impression of the ultimate experiment as proposed in this thesis.

Copyright © 2018 Marc de Voogd

Printed by: Gildeprint - Enschede

PUBLISHED BY CASIMIR RESEARCH SCHOOL

Dedicated to

Yintel

&

Alix

Contents

1	Introduction	9
1.1	Spin mechanics	10
1.2	Mechanical resonators	12
1.3	Thermal noise	15
1.4	Heating	16
1.5	Contents	18
2	Spin - resonator equilibrium dynamics	21
2.1	Basic principles	23
2.2	Susceptibility	26
2.3	Spin bath - resonator coupling	28
2.4	Spin - electromagnetic resonator	31
2.5	Resonator coupling to other systems	33
2.6	Discussion and conclusions	35
2.7	Resonator - semiclassical spin Lagrangian	37
2.8	Equilibrium magnetic moment	37
2.9	Zeroth order solution	38
2.10	First order solution	39
2.11	Spin bath integral	41

3	Spin-mediated dissipation and frequency shifts of a cantilever at milliKelvin temperatures	43
3.1	Theory	45
3.2	Experimental details	46
3.3	Results and discussion	50
3.4	Conclusions	53
4	MRFM on diamond	55
4.1	Defects in diamond	56
4.2	Methods	61
4.3	Equilibrium dynamics	64
4.4	Spin resonance I: saturation	67
4.5	Spin resonance II: spin coherence	69
4.6	Conclusions and outlook	76
5	Gravitational decoherence of NV-resonator systems	79
5.1	Gravitational collapse	80
5.2	Probing the instability of a quantum superposition of time dilations	84
5.3	Mode heating due to spontaneous wave function collapse	88
5.4	Quantum description of spin - resonator system	90
5.5	The experiment blueprint	95
5.6	Roadmap and outlook	99
6	Techniques and instrumentation	103
6.1	Sample	104
6.2	Cantilever	107
6.3	SQUID	108
6.4	Anneal-o-tron	110
6.5	Nanopositioning	111

6.6	Cryostat wiring	117
6.7	From cryostat to electronics	118
6.8	Electronic infrastructure	119
7	Fast and reliable pre-approach for scanning probe microscopes based on tip-sample capacitance	123
7.1	Introduction	124
7.2	Subfemtofarad capacitance measurement principles	127
7.3	Results	131
7.4	Finite element analysis	136
7.5	Analytical models	141
7.6	Conclusion	144
	Bibliography	147
	List of publications	159
	Summary in dutch	163
	Experiment	164
	Techniek	166
	Wetenschappelijke bevindingen	167
	Acknowledgements	169
	Curriculum Vitae	171

