Atom Chips

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Atom Chips

Edited by
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Library of Congress Card No.: applied for

British Library Cataloguing-in-Publication Data:
A catalogue record for this book is available from the British Library.

Bibliographic information published by the Deutsche Nationalbibliothek
The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available on the Internet at http://dnb.d-nb.de.

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Typesetting le-tex publishing services GmbH, Leipzig
Printing and Binding Fabulous Printers Pte Ltd, Singapore
Cover Design Adam Design, Weinheim

Printed in Singapore
Printed on acid-free paper

ISBN 978-3-527-40755-2
# Contents

<table>
<thead>
<tr>
<th>Part One</th>
<th>Fundamentals</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>From Magnetic Mirrors to Atom Chips</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Andrei Sidorov and Peter Hannaford</td>
<td></td>
</tr>
<tr>
<td>1.1</td>
<td>Introduction</td>
<td>3</td>
</tr>
<tr>
<td>1.2</td>
<td>Historical Background</td>
<td>4</td>
</tr>
<tr>
<td>1.3</td>
<td>Magnetic Mirrors for Cold Atoms</td>
<td>7</td>
</tr>
<tr>
<td>1.3.1</td>
<td>Basic Principles</td>
<td>7</td>
</tr>
<tr>
<td>1.3.2</td>
<td>Experimental Realization of Magnetic Mirrors</td>
<td>9</td>
</tr>
<tr>
<td>1.3.2.1</td>
<td>Macroscopic Array of Rare-Earth Magnets of Alternating Polarity</td>
<td>9</td>
</tr>
<tr>
<td>1.3.2.2</td>
<td>Micro-Fabricated Grooved Magnetic Mirrors</td>
<td>10</td>
</tr>
<tr>
<td>1.3.2.3</td>
<td>Micro-Fabricated Array of Current-Carrying Conductors</td>
<td>11</td>
</tr>
<tr>
<td>1.3.2.4</td>
<td>Magneto-Optical Recording of Magnetic Microstructures</td>
<td>12</td>
</tr>
<tr>
<td>1.4</td>
<td>The Magnetic Film Atom Chip</td>
<td>13</td>
</tr>
<tr>
<td>1.4.1</td>
<td>Background</td>
<td>13</td>
</tr>
<tr>
<td>1.4.2</td>
<td>BEC on a Magnetic Film Atom Chip</td>
<td>14</td>
</tr>
<tr>
<td>1.4.3</td>
<td>Spatially Resolved RF Spectroscopy to Probe Magnetic Film Topology</td>
<td>16</td>
</tr>
<tr>
<td>1.4.4</td>
<td>Adiabatic Splitting of a BEC for Asymmetric Potential Sensing</td>
<td>19</td>
</tr>
<tr>
<td>1.4.5</td>
<td>Spatially Inhomogeneous Phase Evolution of a Two-Component BEC</td>
<td>21</td>
</tr>
<tr>
<td>1.4.6</td>
<td>BEC on Other Permanent-Magnet Atom Chips</td>
<td>22</td>
</tr>
<tr>
<td>1.5</td>
<td>Permanent Magnetic Lattice on a Magnetic Film Atom Chip</td>
<td>23</td>
</tr>
<tr>
<td>1.5.1</td>
<td>Background</td>
<td>23</td>
</tr>
<tr>
<td>1.5.2</td>
<td>Basic Principles</td>
<td>24</td>
</tr>
<tr>
<td>1.5.2.1</td>
<td>One-Dimensional Magnetic Lattice</td>
<td>24</td>
</tr>
<tr>
<td>1.5.2.2</td>
<td>Two-Dimensional Magnetic Lattice</td>
<td>25</td>
</tr>
<tr>
<td>1.5.2.3</td>
<td>Permanent 1D Magnet Lattice for Ultra-Cold Atoms</td>
<td>26</td>
</tr>
<tr>
<td>1.5.2.4</td>
<td>Other Permanent Magnetic Lattices</td>
<td>28</td>
</tr>
</tbody>
</table>
2 Trapping and Manipulating Atoms on Chips

Jakob Reichel

1.6 Summary and Conclusions

References

2 Trapping and Manipulating Atoms on Chips

Jakob Reichel

2.1 Introduction

2.2 Overview of Trapping Techniques

2.3 Magnetic Traps for Neutral Atoms

2.3.1 Magnetic Interaction

2.3.2 Stability against Spin-Flip Losses

2.3.3 Quadrupole Traps

2.3.4 Ioffe–Pritchard Traps

2.3.5 Some General Properties of Magnetic Traps

2.4 The Design of Wire Patterns for Magnetic Potentials

2.4.1 Conductor Elements and Multipoles

2.4.2 Wire Guide

2.4.3 Conductor Cross (“Dimple” Trap)

2.4.4 “H”, “Z”, and “U” Traps

2.4.5 Finite Wire Dimensions

2.4.6 Maximum Confinement

2.4.6.1 Field Gradient

2.4.6.2 Field Curvature and Trap Frequency

2.4.7 Combining Elements: Arrays, Conveyors and Others

2.5 Real Wires: Roughness and Maximum Current

2.5.1 Effect of Wire Roughness

2.5.2 Heat Transport and Maximum Current

2.5.2.1 Wire–Substrate Interface

2.5.2.2 Heat Evacuation through the Substrate

2.6 Loading Techniques

2.6.1 Mirror-MOT

2.6.2 Magnetic Elevator

2.6.3 “Mode Matching”

2.7 Vacuum Cells

2.7.1 Traditional Cell

2.7.2 Compact Cell with Atom Chip Wall

2.8 Conclusion and Outlook

References

3 Atom Chip Fabrication

Ron Folman, Philipp Treutlein and Jörg Schmiedmayer

3.1 Introduction

3.2 Fabrication Challenges

3.3 The Substrate

3.4 Lithography

3.4.1 Optical Lithography
3.4.2 Electron-Beam Lithography 67
3.5 Metallic Layers 68
3.5.1 Deposition and Etching 68
3.5.1.1 Electroplating 68
3.5.1.2 Evaporation and Lift-Off Metallization 70
3.5.1.3 Wet and Dry Etching 72
3.5.1.4 Designing Potentials by Postprocessing the Wires 73
3.5.2 Effects of Roughness and Homogeneity of the Fabricated Structures 74
3.5.3 Special Metals 76
3.5.3.1 Alloys 76
3.5.3.2 Superconductors 77
3.5.3.3 Semiconductors 79
3.5.4 Permanent Magnets 80
3.5.5 Metal Outlook 82
3.6 Additional Features 85
3.6.1 Planarization and Insulation 85
3.6.2 On-Chip Mirrors 87
3.6.3 Multi-Layer Chips 88
3.7 Current Densities and Tests 91
3.8 Photonics on Atom Chips 93
3.8.1 Fiber-Based Integrated Optics 93
3.8.1.1 SU8 – Holding Structures 93
3.8.1.2 Fiber-Based Fluorescence Detector 94
3.8.1.3 Fiber Cavities 95
3.8.2 Microlens and Cylindrical Lens 97
3.8.3 Microdisks and Microtoroids 98
3.8.4 Mounted and Fully Integrated Fabry–Pérot 99
3.8.5 Planar Optics 101
3.8.6 Photonics Outlook 102
3.9 Chip Dicing, Mounting, and Bonding 104
3.10 Further Integration and Portability 106
3.11 Conclusion and Outlook 109
References 110

Part Two Ultracold Atoms near a Surface 119
4 Atoms at Micrometer Distances from a Macroscopic Body 121
   Stefan Scheel and E.A. Hinds
4.1 Introduction 121
4.2 Principles of QED in Dielectrics 123
4.3 Relaxation Rates near a Surface 126
4.3.1 Spin Flips near a Dielectric or Metallic Surface 126
4.3.2 Spin Flips near a Superconductor 130
4.3.3 Transverse Spin Relaxation 132
4.3.4 Heating 133
4.3.5 Electric Dipole Coupling of Molecules to a Surface 134
4.4 Casimir–Polder Forces 138
4.5 Closing Remarks 144
References 145

5 Interaction of Atoms, Ions, and Molecules with Surfaces 147
Carsten Henkel
5.1 Qualitative Overview 147
5.1.1 Electromagnetic Dipole Moments 148
5.1.2 Electromagnetic Field Strengths 149
5.1.3 Digression: Surface Green Functions 151
5.2 Interaction Potentials 153
5.2.1 Charges and Permanent Dipoles 153
5.2.2 Van der Waals Potential 154
5.2.3 Casimir–Polder Potential 155
5.2.4 Recent Developments 156
5.3 Surface-Induced Atomic Transitions 157
5.3.1 Visible Frequencies: Spontaneous Emission 158
5.3.2 Thermal Frequencies: Spin-Flips 159
5.3.3 Trap Heating 161
5.3.4 Atom Chips and Decoherence 162
5.4 Perspectives 165
References 166

Part Three Coherence on Atom Chips 171
6 Diffraction and Interference of a Bose–Einstein Condensate Scattered from an Atom Chip-Based Magnetic Lattice 173
A. Günther, T.E. Judd, J. Fortágh and C. Zimmermann
6.1 Introduction 173
6.2 Experimental Setup 174
6.2.1 The BEC Apparatus 174
6.2.2 The Magnetic Lattice Chip 177
6.3 The Magnetic Lattice Potential 178
6.3.1 Infinite Lattice 178
6.3.2 Finite Size Effects 181
6.3.3 The Double Meander Potential 182
6.4 Diffraction and Interference 184
6.4.1 Diffraction Scheme 184
6.4.2 Theoretical Model for the Interaction 185
6.4.3 Diffraction in the Raman–Nath Regime 189
6.4.4 Evolution of the Wave Function after the Lattice Interaction 190
6.5 Ballistic Expansion and Phase Imprinting 194
6.6 Experimental Results 195
6.7 Effect of Atomic Interactions 202
6.7.1 Modeling BEC Surface Diffraction 202
6.7.2 Density Profile Dynamics 203
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.4</td>
<td>Clocks with Magnetically Trapped Atoms: Fundamental Limits to Performance</td>
<td>267</td>
</tr>
<tr>
<td>8.5</td>
<td>Clocks with Magnetically Trapped Atoms: Experimental Demonstrations</td>
<td>271</td>
</tr>
<tr>
<td>8.6</td>
<td>Readout in Trapped-Atom Clocks</td>
<td>274</td>
</tr>
<tr>
<td>8.7</td>
<td>Spin Squeezing</td>
<td>277</td>
</tr>
<tr>
<td>9</td>
<td>Quantum Information Processing with Atom Chips</td>
<td>283</td>
</tr>
<tr>
<td>10</td>
<td>Cryogenic Atom Chips</td>
<td>311</td>
</tr>
</tbody>
</table>

9.1 Introduction | 283 |
9.2 Ingredients for QIP with Atom Chips | 284 |
9.3 Qubit States with Long Coherence Lifetime | 285 |
9.4 Qubit Rotations (Single-Qubit Gates) | 288 |
9.5 Single-Qubit Readout (Single-Atom Detection) | 290 |
9.6 Single-Qubit Preparation (Single-Atom Preparation) | 291 |
9.7 Conditional Dynamics (Two-Qubit Gates) | 291 |
9.7.1 Internal-State Qubits and Collisional Interactions | 292 |
9.7.2 Motional-State Qubits and Collisional Interactions | 298 |
9.7.3 Alternative Chip-Specific Approaches to Entanglement Generation | 300 |
9.7.4 Cavity-QED-Based Schemes | 300 |
9.7.5 Quantum Gate Schemes that Can Be Adapted from Other Contexts | 301 |
9.8 Hybrid Approaches to QIP on a Chip | 303 |
9.8.1 Hybrid Approaches to Entanglement Generation | 303 |
9.8.2 Interfacing Atoms (Storage/Processing Qubits) with Photons (Flying Qubits) | 304 |
9.8.3 Quantum Information Technology for Precision Measurement and Other Applications | 304 |
9.9 Conclusion and Outlook | 305 |

Part Four New Directions | 309 |

10.1 Introduction | 311 |
10.2 Superconducting Atom Chip Setup: Similarities and Differences with Conventional Atom Chips | 312 |
10.2.1 Experimental Considerations | 312 |
10.2.1.1 Chip Fabrication and Wiring | 312 |
10.2.1.2 The Cryogenic Cell | 314 |
10.2.2 Trapping and Cooling: First Results | 316 |
10.2.2.1 Magnetic Trap | 316 |
10.2.2.2 Forced Evaporation and Quantum Degeneracy | 317 |
10.3 Perspectives for Cryogenic Atom Chips:  
A New Realm of Investigations  319
10.3.1 Probing the Superconducting Film Current Distribution  319
10.3.2 Integration of Atom Chips with Superconducting Circuit Elements  321
10.3.2.1 Coupling with a Superconducting Qubit  321
10.3.2.2 Coupling with a Superconducting Resonator: On-Chip CQED  322
10.3.3 Atom Chips for Circular Rydberg States  325
10.4 Conclusion  328
References  329

11 Atom Chips and One-Dimensional Bose Gases  331
I. Bouchoule, N.J. van Druten and C.I. Westbrook
11.1 Introduction  331
11.2 Regimes of One-Dimensional Gases  332
11.2.1 Strongly versus Weakly Interacting Regimes  334
11.2.2 Nearly Ideal Gas Regime  335
11.2.3 Quasi-Condensate Regime  338
11.2.3.1 Density Fluctuations  340
11.2.3.2 Phase Fluctuations  341
11.2.4 Exact Thermodynamics  342
11.3 1D Gases in the Real World  345
11.3.1 Transverse Trapping and Nearly 1D Bose Gases  345
11.3.2 Applying 1D Thermodynamics to a 3D Trapped Gas  347
11.3.3 Longitudinal Trapping  347
11.3.3.1 Local Density Approximation  348
11.3.3.2 Validity of the Local Density Approximation  349
11.3.4 3D Physics versus 1D Physics  349
11.4 Experiments  351
11.4.1 Failure of the Hartree–Fock Model  352
11.4.2 Yang–Yang Analysis  353
11.4.3 Measurements of Density Fluctuations  355
11.4.3.1 A Local Density Analysis  355
11.4.3.2 Ideal Gas Regime: Observation of Bunching  356
11.4.3.3 Quasi-Condensate Regime: Saturation of Atom Number Fluctuations  358
11.5 Conclusion  359
References  360

12 Fermions on Atom Chips  365
Marcius H.T. Extavour, Lindsay J. LeBlanc, Jason McKeever, Alma B. Bardon, Seth Aubin, Stefan Myrskog, Thorsten Schumm and Joseph H. Thywissen
12.1 Introduction  365
12.2 Theory of Ideal Fermi Gases  366
12.2.1 Thermodynamics  366
12.2.2 Density Distribution  368
12.2.3 Crossover to Fermi Degeneracy 370
12.3 The Atom Chip 371
12.3.1 Chip Construction and Wire Pattern 372
12.3.2 Electrical and Mechanical Connections 372
12.3.3 The Z-Wire Magnetic Trap 373
12.4 Loading the Microtrap 373
12.4.1 Laser Cooling and Magnetic Transport to the Chip 374
12.4.2 Loading Bosons and Fermions onto the Atom Chip 374
12.4.3 Effective Trap Volume 375
12.4.4 A Full Tank of Atoms: Maximum Trapped Atom Number 376
12.4.5 Effect of Geometry on Loaded Atom Number 377
12.5 Rapid Sympathetic Cooling of a K-Rb Mixture 377
12.5.1 Forced Sympathetic RF Evaporation 378
12.5.2 K-Rb Cross-Thermalization 379
12.5.3 Density-Dependent Loss 380
12.5.4 Required Temperature 380
12.5.5 Experimental Signatures of Fermi Degeneracy 381
12.6 Species-Selective RF Manipulation 382
12.6.1 Sympathetic RF Evaporation 383
12.6.2 Species-Selective Double Wells 385
12.7 Fermions in an Optical Dipole Trap near an Atom Chip 387
12.7.1 Optical Trap Setup 388
12.7.2 Loading the Optical Trap 388
12.7.3 Microwave and RF Manipulation 389
12.8 Discussion and Future Outlook 390

References 391

13 Micro-Fabricated Chip Traps for Ions 395
J.M. Amini, J. Britton, D. Leibfried and D.J. Wineland

13.1 Introduction 395
13.2 Radio-Frequency Ion Traps 396
13.2.1 Motion of Ions in a Spatially Inhomogeneous RF Field 396
13.2.2 Electrode Geometries for Linear Quadrupole Traps 398
13.3 Design Considerations for Paul Traps 399
13.3.1 Doppler Cooling 399
13.3.2 Micromotion 401
13.3.3 Exposed Dielectric 402
13.3.4 Loading Ions 403
13.3.5 Electrical Connections 404
13.3.6 Motional Heating 405
13.4 Measuring Heating Rates 406
13.5 Multiple Trapping Zones 407
13.6 Trap Modeling 408
13.6.1 Modeling 3D Geometries 408
13.6.2 Analytic Solutions for Surface-Electrode Traps 409
Preface

This book intends to give both an introduction and an in-depth review of the beautiful physics being done with atom chips. Topics range from the manipulation of single atoms to the quantum entanglement between many atoms, and from interferometry with atomic matter waves to studies of fundamental atom–surface interactions.

For about three decades researchers have used magnetic and electric fields from DC to optical frequencies to confine neutral atoms for a variety of experiments and applications. The term atom chip has come to designate setups where microscopic or micro-fabricated structures, typically confined to a surface, generate three-dimensional trapping fields in the vicinity of the surface.

At its inception, the atom chip was regarded primarily as a tool to conveniently generate electromagnetic fields varying on a small length scale, and as such is related to early prototypes of magnetic mirrors. In fact, the attainment of Bose–Einstein condensation on a chip in 2001 in Tübingen and Munich was the first landmark that brought atom chips to the attention of the physics community at large. Since then, a growing number of research groups has adopted microchips as a convenient and fast method for the creation of Bose–Einstein condensates (BECs), and now also degenerate Fermi gases.

The strongly confining, complex, multi-parameter potentials that can be realized with atom chips have enabled experimentalists to explore new situations. For example, studies of one-dimensional quantum gases are benefiting from extremely elongated single traps that can be generated on atom chips, and BECs have been diffracted from specifically designed magnetic lattices realized on the chip surface.

However, atom chips are not merely devices to form atom traps by a combination of conductors and insulators on a surface. Atom chips promise rich functionality and integrability, and possibly nano-scale miniaturization, as advertised early on by a number of researchers in the field. The small length scale well matched to the condensate size and proximity of a solid surface have opened up and driven further research possibilities. The first and perhaps most immediate example is the investigation of fundamental surface-induced forces, such as the van der Waals and Casimir–Polder forces. This field has progressed and expanded considerably due to the close and stimulating interaction between atom chip experimentalists and theorists. Furthermore, the repertoire of fields and interactions used on atom chips

Atom Chips. Edited by Jakob Reichel and Vladan Vuletić
Copyright © 2011 WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim
ISBN: 978-3-527-40755-2
Preface

has grown to include radiofrequency and microwave potentials, resonant and far-detuned optical fields in miniature optical devices, as well as surface interactions with micro-mechanical structures. In each case, the small-scale, near-field situation of the atom chip has been exploited in ingenious ways to create new and rich physical situations that go beyond the possibilities of macroscopic experiments. Examples include coupling of a BEC to an oscillating mechanical cantilever, cavity quantum electrodynamics experiments with BECs, and some of the most beautiful condensate interferometry experiments performed so far.

The combination of these features makes atom chips an interesting platform for quantum information and quantum simulation experiments. This has also motivated the development of the newest family of atom chips, surface-electrode-based ion traps, which present both similarities and interesting differences compared to their neutral-atom counterparts.

A third area has emerged where atom chips are used as a means to construct the most compact and robust ultra-cold atom devices. The very recent demonstration of BEC in microgravity was enabled by an atom chip. Trapped-atom clocks on atom chips are being explored as promising secondary frequency standards. The idea of “integrated atom optics” on atom chips as a means to build atom interferometers emerged with the first atom chip experiments, but is certainly still in its infancy today. Last but not least, experiments with BECs in cryogenic environments also benefit from the small size and robustness of atom chips.

This book represents a collective effort by the community of atom chip researchers to outline the state of their knowledge as of 2009/2010. Each chapter starts with a thorough introduction before exposing the state of the art on a specific topic. Additionally, there are introductory chapters describing the particularities of designing magnetic potentials and producing BECs on atom chips, as well as on atom chip fabrication. The latter is discussed in a tutorial style and sufficient detail to enable a researcher with minimal micro-fabrication knowledge to start fabricating atom chips. In this way, we hope that the book will be valuable for students and researchers who are entering the field of atom chips or are active in one of the neighboring fields, but also for anyone desiring to get an overview of this beautiful and active area of contemporary quantum physics.

Paris and Cambridge, June 2010

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