

## **Atom Chips**

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# Atom Chips

*Edited by  
Jakob Reichel and Vladan Vuletić*



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## Contents

**Preface** XV

**List of Contributors** XVII

### Part One Fundamentals 1

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

1.6	Summary and Conclusions	28
	References	29
<b>2</b>	<b>Trapping and Manipulating Atoms on Chips</b>	<b>33</b>
	<i>Jakob Reichel</i>	
2.1	Introduction	33
2.2	Overview of Trapping Techniques	34
2.3	Magnetic Traps for Neutral Atoms	35
2.3.1	Magnetic Interaction	35
2.3.2	Stability against Spin-Flip Losses	36
2.3.3	Quadrupole Traps	37
2.3.4	Ioffe–Pritchard Traps	37
2.3.5	Some General Properties of Magnetic Traps	38
2.4	The Design of Wire Patterns for Magnetic Potentials	39
2.4.1	Conductor Elements and Multipoles	39
2.4.2	Wire Guide	40
2.4.3	Conductor Cross (“Dimple” Trap)	41
2.4.4	“H”, “Z”, and “U” Traps	43
2.4.5	Finite Wire Dimensions	44
2.4.6	Maximum Confinement	46
2.4.6.1	Field Gradient	46
2.4.6.2	Field Curvature and Trap Frequency	46
2.4.7	Combining Elements: Arrays, Conveyors and Others	47
2.5	Real Wires: Roughness and Maximum Current	48
2.5.1	Effect of Wire Roughness	48
2.5.2	Heat Transport and Maximum Current	49
2.5.2.1	Wire–Substrate Interface	49
2.5.2.2	Heat Evacuation through the Substrate	51
2.6	Loading Techniques	51
2.6.1	Mirror-MOT	51
2.6.2	Magnetic Elevator	52
2.6.3	“Mode Matching”	52
2.7	Vacuum Cells	53
2.7.1	Traditional Cell	53
2.7.2	Compact Cell with Atom Chip Wall	55
2.8	Conclusion and Outlook	57
	References	58
<b>3</b>	<b>Atom Chip Fabrication</b>	<b>61</b>
	<i>Ron Folman, Philipp Treutlein and Jörg Schmiedmayer</i>	
3.1	Introduction	61
3.2	Fabrication Challenges	62
3.3	The Substrate	63
3.4	Lithography	65
3.4.1	Optical Lithography	65

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–Pérots	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**

<b>4</b>	<b>Atoms at Micrometer Distances from a Macroscopic Body</b>	<b>121</b>
	<i>Stefan Scheel and E.A. Hinds</i>	
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
<b>5</b>	<b>Interaction of Atoms, Ions, and Molecules with Surfaces</b>	<b>147</b>
	<i>Carsten Henkel</i>	
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
<b>Part Three</b>	<b>Coherence on Atom Chips</b>	<b>171</b>
<b>6</b>	<b>Diffraction and Interference of a Bose–Einstein Condensate Scattered from an Atom Chip-Based Magnetic Lattice</b>	<b>173</b>
	<i>A. Günther, T.E. Judd, J. Fortágh and C. Zimmermann</i>	
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



6.7.3	Phase Modification by Inter-Atomic Interactions	204
6.7.4	Comparison of the Interacting Theory with Experiment	205
6.7.5	Locating the Low-Interaction Regime	206
6.8	Conclusion	207
	References	208
<b>7</b>	<b>Interferometry with Bose–Einstein Condensates on Atom Chips</b>	<b>211</b>
	<i>Thorsten Schumm, Stephanie Manz, Robert Bücker, David A. Smith and Jörg Schmiedmayer</i>	
7.1	Introduction	211
7.2	Atom Chip BEC Splitters Based on Static Fields	213
7.2.1	Transverse Splitting	213
7.2.1.1	The Two-Wire Splitter	214
7.2.1.2	The Five-Wire Splitter	216
7.2.1.3	The Y Splitter	218
7.2.2	Longitudinal Splitting	221
7.2.3	Electrostatic Splitter	222
7.3	Atom Chip BEC Splitters Based on Dressed Adiabatic Potentials	224
7.3.1	Dressed Adiabatic State Potentials	225
7.3.2	A BEC Splitter Based on Dressed Adiabatic State Potentials	228
7.3.3	Beyond the Rotating-Wave Approximation	230
7.3.4	Implementation on an Atom Chip	231
7.3.5	Advantages of RF-Induced Splitters over Static Splitters	232
7.4	Matter–Wave Interferometry with Bose–Einstein Condensates	234
7.4.1	Theoretical Aspects	234
7.4.2	Experimental Realizations	238
7.4.2.1	Coherent Splitting on Atom Chips	239
7.4.2.2	Interference of Independent Condensates	240
7.4.2.3	Phase Dynamics of Split Condensates	240
7.4.2.4	Merging of Split Condensates	245
7.5	Interferometry with 1D quasi condensates	246
7.5.1	Coherently Split 1D BECs: Coherence Dynamics	247
7.5.1.1	Decoherence of Uncoupled 1D Systems	249
7.5.1.2	Coherence Dynamics for Coupled 1D Condensates	251
7.5.2	Independent 1D BECs: Noise Statistics of Interference Amplitude	252
7.5.2.1	Average Interference Amplitude Square	253
7.5.2.2	Full Counting Statistics of Interference Amplitude	255
7.6	Summary and Outlook	257
	References	259
<b>8</b>	<b>Microchip-Based Trapped-Atom Clocks</b>	<b>265</b>
	<i>Vladan Vuletić, Ian D. Leroux and Monika H. Schleier-Smith</i>	
8.1	Basic Principles	265
8.2	Atomic-Fountain versus Trapped-Atom Clocks	265
8.3	Optical-Transition Clocks versus Microwave Clocks	267

8.4	Clocks with Magnetically Trapped Atoms: Fundamental Limits to Performance	267
8.5	Clocks with Magnetically Trapped Atoms: Experimental Demonstrations	271
8.6	Readout in Trapped-Atom Clocks	274
8.7	Spin Squeezing	277
	References	278
<b>9</b>	<b>Quantum Information Processing with Atom Chips</b>	<b>283</b>
	<i>Philipp Treutlein, Antonio Negretti and Tommaso Calarco</i>	
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
	References	305
<b>Part Four</b>	<b>New Directions</b>	<b>309</b>
<b>10</b>	<b>Cryogenic Atom Chips</b>	<b>311</b>
	<i>Gilles Nogues, Adrian Lupaşcu, Andreas Emmert, Michel Brune, Jean-Michel Raimond and Serge Haroche</i>	
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
<b>11</b>	<b>Atom Chips and One-Dimensional Bose Gases</b>	<b>331</b>
	<i>I. Bouchoule, N.J. van Druten and C.I. Westbrook</i>	
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
<b>12</b>	<b>Fermions on Atom Chips</b>	<b>365</b>
	<i>Marcus H.T. Extavour, Lindsay J. LeBlanc, Jason McKeever, Alma B. Bardon, Seth Aubin, Stefan Myrskog, Thorsten Schumm and Joseph H. Thywissen</i>	
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
<b>13</b>	<b>Micro-Fabricated Chip Traps for Ions</b>	<b>395</b>
	<i>J.M. Amini, J. Britton, D. Leibfried and D.J. Wineland</i>	
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

13.7	Trap Examples	411
13.8	Future	415
	References	417
	<b>Index</b>	<b>421</b>

## 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 benefitting 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

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.

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