

Contents

1	Introduction and Theoretical Background	1
1.1	Elements of the Theory of Bose-Einstein Condensation in Atomic Gases	1
1.1.1	Condensation of the Ideal Bose Gas	2
1.1.2	The Weakly Interacting Bose Gas	4
1.1.3	Mean-Field Model: The Gross-Pitaevskii Equation	8
1.2	Bose-Einstein Condensate in a Double Well: Two-Mode Theory of the Bosonic Josephson Junction	18
1.2.1	Two-Mode Approximation	18
1.2.2	Two-Mode Bose-Hubbard Hamiltonian	20
1.2.3	Regimes of the Two-Mode Bose-Hubbard Model	30
1.2.4	Collective Spin Representation	37
1.2.5	Mean-Field Model in the Josephson Regime	49
1.3	Conclusion of the Theoretical Part	57
	References	59
2	Experimental Setup and Techniques	63
2.1	Experimental Setup	63
2.1.1	Vacuum Chamber and Rubidium Source	64
2.1.2	External Coils	65
2.1.3	Chip Mounting and Copper Structure	66
2.1.4	Atom Chip	68
2.1.5	Optics and Laser System	69
2.1.6	Radio-Frequency Evaporative Cooling	71
2.1.7	Computer Control and Acquisition	72
2.2	Trapping Atoms Magnetically with an Atom Chip	73
2.2.1	Magnetic Trapping with Static Fields	73
2.2.2	Double-Well Potentials Created by Radio-Frequency Dressing	78
2.2.3	Characterization of the Potential and Calibration of the Simulations	86

2.3	Imaging Systems	92
2.3.1	Absorption Imaging	94
2.3.2	Fluorescence Imaging System (Light Sheet)	98
2.4	Conclusion of the Experimental Part	100
	References	101
3	A Mach-Zehnder Interferometer for Trapped, Interacting Bose-Einstein Condensates	105
3.1	Introduction	105
3.1.1	A Prototypical Interferometer	105
3.1.2	Interferometry with Bose-Einstein Condensates	106
3.1.3	The Vienna BEC Mach-Zehnder Interferometer.	111
3.2	Number and Phase Estimation.	113
3.2.1	Relative Phase Measurement.	113
3.2.2	Number Difference Measurement.	123
3.2.3	Conclusion on Number and Phase Measurements	127
3.3	Matter Wave Source	128
3.4	Coherent Splitting and Generation of Atomic Squeezed States.	129
3.4.1	Coherent Splitting of a Condensate	130
3.4.2	Squeezing and Adiabatic Splitting	135
3.4.3	Results: State of the BEC After Splitting	137
3.4.4	A Simple Model to Describe Adiabatic Splitting	141
3.4.5	Discussion	144
3.5	Phase Evolution.	147
3.5.1	Phase Accumulation	147
3.5.2	Phase Diffusion.	151
3.5.3	Estimation of the Phase Diffusion Rate	163
3.5.4	Conclusion on the Phase Evolution	167
3.6	Two Phase-Sensitive Condensate Recombiners	169
3.6.1	Josephson Recombiner.	171
3.6.2	Non-Adiabatic Recombiner.	177
3.6.3	Comparison of the Two Recombiners	186
3.7	Interferometer Signal	190
3.7.1	Mach-Zehnder Fringes	190
3.7.2	Model for the Interferometric Signal	193
3.7.3	Discussion of the Interferometric Signal	198
	References	201
4	Outlook: Bosonic Josephson Junctions Beyond the Two-Mode Approximation	209
4.1	Observations Beyond the Two-Mode Picture.	210
4.2	Discussion	214
	References	217

**Appendix A: One-Dimensional Gross-Pitaevskii Simulations
in the Transverse Potential 219**

Appendix B: List of Symbols 223

Curriculum Vitae 227

<http://www.springer.com/978-3-319-27232-0>

Interferometry with Interacting Bose-Einstein
Condensates in a Double-Well Potential

Berrada, T.

2016, XIX, 229 p. 89 illus., 67 illus. in color., Hardcover

ISBN: 978-3-319-27232-0