Atom Chips

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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

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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 *Jakob Reichel and Vladan Vuletić*

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