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Towards Rydberg Excitations in Magnetic Lattices on Atom Chips
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Summary

Quantum information science is a rapidly growing field. One of the ways, by which physicists can contribute to this field, is to realize platforms for quantum computation and quantum simulation.

Quantum computation uses quantum bits (qubits). Qubits, like classical bits, have two possible states, but in contrast to their classical counterparts they display quantum behavior: quantum superposition and entanglement. This increases the amount of stored information exponentially with the number of qubits, and thus makes quantum computers superior to classical ones for some specific tasks, for example factorization problems or data base search.

For quantum simulation one would prepare a system of interacting quantum particles with some specific interaction, resembling another, less controllable or accessible system. By measuring this model system, one can learn something about the complex one. Quantum simulators can be useful for different areas of physics and chemistry. An important difference with quantum computers is that more modest numbers of qubits are already enough for interesting scientific applications.

This thesis contributes to the quantum platform based on an atom chip. In our atom chip, atoms are trapped by means of a magnetic field. This magnetic field is created by a very thin ($100-200\,\mathrm{nm}$) layer of a permanently magnetized material, which is etched to create a periodic structure. Together with an applied homogeneous bias field this structure creates a periodic lattice of magnetic field minima. Cold atoms are trapped in these minima (so called microtraps). In our experiment we want to induce interaction between atoms in different lattice sites by exciting them into so-called Rydberg states: atomic states with a very large principal quantum number n. These states have some extreme properties: very strong van der Waals interaction (scaling as $\propto n^{11}$), polarizability ($\propto n^7$), and long lifetimes ($\propto n^3$). This makes Rydberg atoms promising candidates to build a quantum platform. In this thesis we investigate different challenges that one encounters on the way to a quantum platform based on an atom chip with Rydberg atoms.

In chapter 2 we present our work on a spatial light modulator (SLM). The idea of using an SLM in our experiment is that the atomic states in the microtraps can

be manipulated by spatially addressing laser beams to only some specific microtraps on-demand. We calculate the phase patterns needed to apply to the SLM, to be able to operate both lasers for the two-photon Rydberg excitation at the same time: a 780 nm ("red") laser beam and a 480 nm ("blue") laser beam. This ensures that simultaneously a red and a blue laser spot are directed to selected lattice sites. We also use our liquid crystal SLM device to measure and compensate for the aberrations in our test optical setup. The aberrations measurement is done by a so-called Shack-Hartmann procedure, where a local tilt of the wavefront is measured. Later we use two different approaches to reconstruct the wavefront from the measured map of local tilts: zonal and modal approaches. The zonal method is essentially a direct integration, whereas in the modal method a number of polynomials is used to approximate the wavefront and reconstruct it from the measured data. We compare these two methods and find that the result depends on the wavelength: the modal method works better for the 780 nm beam, whereas the zonal method shows better results for the 480 nm beam. Finally, we also modify existing software to enable the generation of spot patterns of arbitrary geometries.

In chapter 3 we present our experimental results on measuring and controlling stray electric fields on our atom chip. The enormous polarizability makes Rydberg atoms very sensitive to stray electric fields. We use the Rydberg sensitivity to measure the z component of the stray fields at different distances from the chip. Moreover, we find that by illuminating the chip with our blue laser, we can adjust the field strength and even change its direction. We find a regime of the blue laser exposure, where the z component is compensated with a precision of 0.2 V/cm. It is known that the stray field is created by adsorbed atoms on the chip surface. We model ad-atoms distributions, which explain the measured fields.

Even though the dipole distributions, causing the fields discussed in chapter 3 are known, the precise adsorption and desorption mechanisms are to be revealed. In chapter 4 we construct a comprehensive model, describing such mechanisms in order to describe the measured fields as well as its dynamical change. We see that our model can qualitatively describe the results. However there are too many unknown physical parameters in our model, which makes direct fitting impossible. We conclude that more studies are needed in order to find those parameters.

In chapter 5 we present a setup for our new Magchips Nano experiment. In this experiment we have a new chip with different lattice geometries (triangular, rectangular, tapered) and periods (from 200 nm to 20 μm).

Finally, in chapter 6 we present our first steps, taken to bring the new Magchips Nano machine to life. We characterize the following steps: a magneto-optical trap (MOT), a u-wire based magneto-optical trap (uMOT), and a z-wire based magnetic trap. We report that evaporative cooling was not possible because of insufficient density. This was likely caused by magnetic field oscillations during the switch from the uMOT to the magnetic z-wire trap, limiting the loading efficiency of the magnetic z-wire trap. We find the reason of the oscillations to be a spurious (but difficult to avoid) LC circuit between the coils inductance and a capacitor in the power supply.

The current oscillations could be overcome by installing new coils with lower self-inductance and using different power supplies. Then it will be possible to try Rydberg physics and lattice physics with ground state atoms on the chip. The construction of our vacuum chamber will allow relatively easy exchange of the chip and thus probe different chips with new lattice geometries and surfaces.