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Author(s)	J.J.P. van Es
Faculty	FNWI: Van der Waals-Zeeman Institute (WZI)
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Summary

This thesis reports on experiments that are aimed at investigating the properties of dilute atomic gases at temperatures near absolute zero ($\leq 1\ \mu$K). At such low temperatures the atoms show behavior different from what we are used to at room temperature. Most notably a phase transition occurs when the de Broglie wavelength of the atoms becomes of the order of the inter-particle spacing and the atoms form a Bose-Einstein condensate (BEC), revealing the quantum nature of matter.

The goal of our experiment is to provide fundamental physical knowledge, like the understanding of the one-dimensional dynamics and the coherence properties of cold bosonic gases. Furthermore it is expected that the technology and the techniques developed to this end will result in new products such as extremely precise sensors and clocks. Some even speculate that these developments may one day culminate in the realization of a quantum computer, which is predicted to be immeasurably more powerful for some specific tasks than current-day computers.

In the experiment we cool clouds containing several million ^{87}Rb atoms down from room temperature to typically $\leq 1\ \mu$K using the techniques of laser cooling and evaporative cooling. The cold gas is suspended in a magnetic field in a vacuum to prevent heating and loss through contact to the surroundings. The magnetic field is produced by an atom chip: a device consisting of a planar substrate and a micro-fabricated wire pattern through which we send current. We trap the atoms either in a static field, made with stationary currents or in a field which is the combination of static and radio-frequency (rf, ~ 2 MHz). The potential originating from the latter is named rf-dressed potential to distinguish it from the static potential.

Chapter 1 of this thesis outlines the historical developments that preceded modern cold atom experiments. It touches upon the initial development of quantum mechanics and the discovery of Bose-Einstein condensation in the beginning of the 20th century. Equally important for practical experiments were technical developments in the second half of the century like the invention of the laser and the computer. The new insights and technology came together in the development of laser cooling of neutral atoms in the 1980s and the successful use of atom chips for BEC in the new millennium.

Chapter 2 is devoted to calculation of the trapping potential in which we produce and capture our cold gas clouds. In the first part of the chapter we provide several approximations with different levels of accuracy for the potential of our static magnetic trap formed by a Z-shaped wire on the atom chip. In the second part we give expressions for the rf-dressed potential. The rf-dressed potential offers exciting new possibilities to manipulate the precise shape of the trapping potential through the amplitude, polarization and frequency of the rf-field. Most notably a single potential minimum can be transformed into a double-well potential in a smooth and

continuous way, allowing a BEC to be split in two parts.

Chapter 3 describes the atom chip with which we produce our magnetic fields. First we describe the micro-fabrication process that includes optical lithography and gold vapor deposition to produce gold wires of ~ 2 μm thickness and ≥ 5 μm width. Careful fabrication is essential to create smooth, defect-free potentials. In the second part of the chapter we characterize the chip. We routinely send 2.25 A of current through a 125 μm wide wire which corresponds to a current density of 10^6 A/cm^2. The maximum current density of $\geq 10^7$ A/cm^2 is achieved in more narrow wires. The chip wire current is limited by the thermal resistance between the wires and the surroundings which is 9.9 K/W. Initial characterization indicates the roughness of the magnetic potential is $\Delta B/B \sim 5 \times 10^{-5}$ at 77 μm distance from the chip surface.

Chapter 4 describes the experimental setup apart from the atom chip. It includes the ultra-high vacuum system, laser system, magnetic coils and control computer hard- and software. Special attention is given to the rf generators that we use to produce the rf magnetic fields. These sources were developed in-house. Their advantage with respect to commercially available function generators is that they can be reprogrammed much faster (within 10 μs) allowing much more flexibility in the design of experiments.

In chapter 5 we present several experiments in which we use BECs to characterize the rf-dressed potential. We use both rf spectroscopy and measurements of the oscillation frequency to show that potential variations due to small longitudinal magnetic field variations can be suppressed by at least a factor of 10 compared to the bare magnetic potential. This effect can be of use when making smoother waveguides on atom chips. We perform vertical splitting of a BEC by transforming the single potential minimum into a double-well potential. We show that it is possible to compensate the effect of gravity by tuning the static and rf field gradient and have equal distribution of the atoms over the two wells. In chapter 5 we also describe a spatial beamsplitter.

Finally, chapter 6 provides some initial results of atom-chip-based matter-wave interference experiments. We obtain matter-wave interference by vertically splitting a BEC and releasing it from the double-well potential. The overlapping atom clouds interfere. From analysis of the interference pattern we determine several properties, like the imbalance of the double-well potential and the phase coherence length. The release of the atoms from the double-well rf-dressed potential is non-adiabatic and transfers the atoms into a distribution of Zeeman states. We show the Zeeman state distribution can be manipulated through the exact switch-off procedure of the trapping potential.