Permanent magnetic atom chips

Barb, I.

Citation for published version (APA):
Planar micro structures have recently emerged as a very powerful and attractive tool for handling neutral ultracold atoms. These so-called 'atom chips' have been used to construct miniature atom optical elements including traps, waveguides, and beam splitters [1, 2, 3, 4, 5]. Atom chips are now in development to miniaturize atom optics and to make it more robust. They have great potential for application in quantum information processing and in atom interferometry. Large magnetic field gradients and thus large trapping forces can be achieved on-chip, removing the necessity of large, high power external coils. Miniature current carrying wires can produce tight magnetic trapping potentials that have successfully been used to create Bose-Einstein condensates of rubidium atoms [6, 7].

Currently atom chip based experiments are going on in many groups throughout the world. In the majority of cases, these atom chips are based on patterns of current carrying wires [5, 3, 4]. This thesis pursues a promising alternative approach using permanent magnetic micro structures. In the past, atom optical elements based on permanent magnets have been used to reflect atoms from periodically magnetized structures. The first of these atomic mirrors were based on audio-tape and floppy-disk [8, 9]. Subsequently video-tape and hard-disk materials were used as they allow for smaller periods and more homogeneous magnetic patterns. In this thesis we investigate a promising alternative based on patterned hard magnetic films to provide the microscopic magnetic potentials [10]. Waveguide designs using out-of-plane magnetized film have been reported before using CoCr films [11, 12], videotape [9] and magneto-optically patterned Co/Pt thin films [13]. This thesis gives a description over designs of self-biased Ioffe-Pritchard magnetic traps using in-plane magnetized FePt film as well as a description on how to handle this type of traps and the related experiments.

Patterned permanent magnetic materials provide greater design freedom, producing more complex magnetic potentials such as ring-shaped waveguides or large two-dimensional lattices of microtraps [14, 15]. The last geometry is particularly interesting for the realization of shift registers or quantum memory, explained
Chapter 1. Introduction

also in Chapter 3. The magnetic films used for making these atom chips can be as thin as \( \sim 100 \) nm, making it possible to create intricate trapping geometries. These magnetic films can have both magnetizations: in and out-of-plane, reaching magnetizations of 100 to 700 kA/m.

Patterned permanent magnetic materials can also provide intricate and stable trapping potentials for ultracold atoms with significant technical and scientific advantages. The advantages of permanent magnetic films are:

- No resistive power dissipation which for microfabricated wires operated at high current density causes excessive heating, broken circuits and current leakage.

- The absence of technical noise which minimizes in-trap heating and loss of atoms, ultimately extending the lifetime of trapped atoms.

- Possibility to reach large field gradients for tight confinement, allowing atom clouds to be compressed to one dimension and opening up possibilities for new physics.

- Thin and relatively high in specific resistance, two properties known to suppress thermally driven spin-flip transitions, a fundamental loss mechanism for atom chips.

- Unique magnetic field configurations, as compared with current-carrying wires, made possible because no lead wires are needed.

- Possibility to perform precise experiments involving atom-surface interactions near (magnetic) materials.

The thesis is organized in the following way. In Chapter 2 we compile some basic theoretical aspects relevant to the magnetic trapping. We begin with an introduction of the principle of magnetic trapping and a description of different Ioffe-Pritchard traps. We also introduce few types of different trap designs with a comparison between wire based and permanent magnetic traps.

In Chapter 3 various aspects of the experimental setup are described. Special attention is given to the construction of the apparatus as this was a new experimental set up (being now operational with a BEC). An overview of the vacuum system is followed by the outline of the laser setup. A section is dedicated to the magnetic field coils. Emphasis is put on the imaging of cold atomic clouds, including the selection of the optical elements and absorption detection with limitations of the method.

Chapter 4 gives a detailed description of the atom chip, the design and the building up. Here is also presented the fabrication of two different atom chips - the bulk atom chip and the thin film atom chip.
In Chapter 5 we present the experimental investigation of the magneto optical trap and all the steps toward the loading of the magnetic trapping. A simple characterization of different ways of trapping the atoms in a magneto-optical trap is as well presented. This is an important step for improving the atom number and the cloud temperature.

The final chapter studies the transfer of the permanent magnetic trap. A brief section deals with the calculated loading trajectory and the actual measurement results. Next we present the analyzing of the trap parameters like temperature, atom number and frequencies.