Optical trapping and manipulation of atoms near surfaces
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Summary

This thesis describes our efforts to exploit the unique properties of evanescent waves in the field of cold atoms. We have demonstrated detection of cold atoms in close proximity of a dielectric surface. Other efforts were focused to obtain a sample of atoms with high phase-space density in a completely optical way, without using evaporative cooling.

In chapter 2 we described the theoretical background that is needed for the rest of the thesis. Light, and especially evanescent light, is described. We extend the concept of light intensity to an effective light intensity which is also applicable for evanescent waves. The interaction of atoms with light is described, both for near-resonant and far off-resonant radiation. This is applied to the case of $^{87}$Rb atoms. Some attention is paid to the Van der Waals interaction of atoms with a dielectric surface.

Chapter 3 discussed a slightly different subject. In the literature it is claimed that the success of Bose-Einstein condensation in dipole traps of a CO$_2$ laser is due to the sign of the polarizability of the excited state that is used in the laser cooling process. We have calculated the level shifts of the ground and excited state for radiation with wavelengths higher than 700 nm. Based on these calculations we found that the level shifts have the same sign as the DC value for wavelengths between 1366 nm and approximately 1400 nm and for wavelengths larger than 1529 nm. The magnitude of the light shift and the current day availability of high power and single spatial mode cw lasers lead to the conclusion that a laser with a wavelength of 2 μm is a promising alternative for a CO$_2$ laser.

The experimental setup that is used to perform the experiments is described in chapter 4. The laser beams that are used in the experiment are discussed. For beams that create evanescent waves, a very accurate method to determine the angle of incidence with respect to the critical angle is discussed. An accuracy below the diffraction limit was obtained. The components of the vacuum setup are discussed. In particular the quartz cell that provides the optical access for the experiments, the custom made prism that is used to create the various evanescent fields for the experiments and the dispenser that is used to get a low Rb vapor in the vacuum system are discussed in detail.

It is often necessary to quickly change a laser frequency during the experiment. This is convenient to, e.g. switch between a frequency needed for magneto-optic trapping to a frequency needed for polarization gradient cooling. In chapter 5 a method is discussed to perform this task very efficiently. Its effect is demonstrated using a diode laser system. The laser frequency is changed by changing the laser current, while this change is compensated by an AOM for the light that is used for spectroscopy. This way the laser will stay in lock even for very fast changes of the
frequency.

In chapter 6 we demonstrate a method to in situ detect atoms very close (\(~ \lambda \)) to a dielectric surface. We measure the absorption of a weak, resonant evanescent wave in order to detect atoms that are present in the volume of the evanescent wave. The method was tested by detecting the absorption of atoms falling onto the surface. In order to qualitatively understand the absorption of the evanescent wave for angles of incidence very close to the critical angle, the Gaussian character of the incident beam had to be taken into account. We also demonstrated loading of only a few potential minima of a standing-wave dipole trap by making use of the highly localized scattering of an evanescent-wave mirror. We used the evanescent probing technique to determine the number of trapped atoms. We determined that we have trapped more than \(1.5 \times 10^4\) atoms initially. We infer a density increase of two orders of magnitude.

Chapter 7 presents a numerical analysis of an evanescent-wave dark-state trap. Several trap geometries were discussed. For a geometry of two nearly co-propagating incident beams a more detailed analysis was performed. We optimized the experimental parameters within realistic limits for a large trapping fraction and a low scattering rate. We concluded that a trapping fraction of 10% could be realized, which leads to a density increase of a factor 130 and a phase-space density increase of a factor 75 with respect to the MOT values. Because scattering even a single photon is very likely to lead to loss from the trap, the life time of this trap is its weak point. The realization of this experiment was prevented by the inferior quality of the surface of the prism that was used to create the evanescent fields.

As an example of the unexpected possibilities of the combination of cold atoms and evanescent wave potentials may serve chapter 8. Atoms that reflect inelastically from an evanescent-wave mirror are transferred to a different internal state during the reflection from the potential. This transition can occur on the ingoing or the outgoing part of the trajectory. By numerically solving the Schrödinger equation we have shown that it is possible to observe interference between these two trajectories even though the transfer process is a spontaneous Raman transition, which is intuitively an incoherent process. This is possible if the initial velocity of the wave packet is well defined. The atoms then follow a trajectory that closely resembles a classical trajectory through phase space, but the wave packet is spread out along this trajectory such that both transfer points are covered simultaneously. This prevents knowledge of “which way” information by detecting the spontaneously emitted photon. The random direction of the recoil does not lead to a complete scrambling of the interference.