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Novel Atomchip Technologies with Superconductors

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ABSTRACT

This thesis reports on the group's efforts and experimental advancements on combining two different fields in physics namely ultracold atomic physics and superconductivity. The main aim is to couple ultracold atoms to superconducting microwave resonators for quantum information applications. Apart from opening up possibilities for hybrid physics experiments, the constructed experimental setup allows for the probing of superconducting surfaces using ultracold atoms. Or the other way, superconducting properties can be utilized for novel atomchip traps. Along with this endeavor comes many technical hurdles between the different fields that need to be overcome. These are mainly in the technicalities of transporting ultracold 87Rb atoms to a cryogenic environment. A realization of a robust magnetic transport scheme to bring 3×108 ultracold 87Rb atoms into a 4K cryostat has been constructed. It begins with standard laser cooling and trapping of 87Rb atoms, then transportation of the atoms first horizontally, then vertically through radiation shields into a cryostat by a series of normal- and superconducting magnetic coils. After subsequent pre-cooling in a quadrupole-Ioffe trap, about 3×106 atoms at 30 μK are loaded on a superconducting atomchip. The superconducting atomchip can be fabricated from any superconducting material. Unlike its normal conducting counterparts, superconductivity brings in new features that can be useful to atomchip trapping especially the critical state behavior of Type-II superconductors. In this thesis, niobium and YBCO atomchips are designed, fabricated and studied. The various designs include features either for cQED applications with microwave resonators or novel superconducting traps for ultracold atoms using the remnant magnetization of the superconducting surface (vortex-like traps). Evidence of a current-induced remnant magnetization behavior of type-II superconductors has been measured with ultracold atoms. This hysteresis behavior is used to control the current distribution of the trapping wire either with a magnetic field or a current pulse. Control of the transport current distribution with a current pulse is studied in great detail. A major consequence of this is the ability to tune or tailor the effective width of the trapping wire, by controlling the current-pulse history experienced by the superconductor. Understanding how superconductivity affects atomchip trapping of ultracold atoms will be instrumental for the ultimate goal of coupling to a superconducting resonator or using superconducting vortices/periodic superconducting structures to create a lattice traps for ultracold atoms.