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Ultracold atoms on superconducting atomchips

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Abstract:

Ultracold atoms on superconducting atomchips are a promising tool in atom opt ics, quantum information and quantum simulation. Combining the experimental techniques for ultracold atoms and superconductors is a very challenging task. This thesis describes the development of a complex experimental setup to transport ultracold atoms into a cryogenic environment where they are transfered to a superconducting atomchip. It also presents the properties of the superconducting atomchip trap and discusses approaches towards the creation of a hybrid quantum system.

The transport of ultracold atoms from a room temperature MOT chamber to a cryogenic science chamber is realized with a magnetic conveyor belt.
The cryogenic environment comes with technical advantages, like long atom lifetime because of the extremely low background pressure and rapid reconfigurability due to effective cryo-pumping, allowing to replace the atomchip in a matter of days rather than months. Magnetic microtraps realized by superconducting atomchips show some particularities as compared to their normal conducting counterparts. A detailed understanding of the current distribution in superconducting atomchips is necessary to make full use of their potential. I show how the current distribution in a type-II superconductor strongly depends on the history of applied fields and currents. It can therefore be tailored to a certain extent, allowing to reduce the effective wire width and to reach very small distances between the wire and the atom cloud. The magnetization of type-II superconductors also provides the possibility to create self-sufficient traps without any external connections, therefore being free from technical noise. This will allow future measurements of the reduced Johnson-Nyquist noise in the vicinity of superconducting surfaces. The primary goal of this project is however the creation of a hybrid quantum system with the long-lived hyperfine states of ultracold Rubidium 87 atoms and the excitations in a superconducting microwave cavity. I investigate the feasibility and present first steps towards the experimental realization of such a system using coplanar lambda-half and lumped element resonators. Finally, I discuss the prospect of superconducting vortex lattice traps for quantum simulation of Bose-Hubbard Hamiltonians.

Vortices penetrating type-II superconductors can be used to create almost arbitrary arrays of magnetic microtraps. The lattice constant of these trap arrays can be significantly smaller than that of optical lattices, thus allowing to study a parameter range not accessible to the latter.