Optical control of matter-wave solitons in an atom-wave circuit

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A Bose-Einstein condensate (BEC) of a dilute atomic gas is one of macroscopic quantum degenerate systems, and is widely attracting great attention because of its optical controllability and accessibility. In this quantum condensed phase, the atomic gas behaves collectively as "matter-wave", namely, single coherent wave of matter. The object of our study is to explore novel quantum phenomena caused by its nonlinear propagation, which results from interactions between atoms in the condensate, and to develop its novel applications based on the nonlinearity. So far, several attractive nonlinear phenomena were reported in the BEC; for example, the self-trapping in the quantum tunneling and so on. Among them we especially focus on the matter-wave soliton because of its possibility as an indicator of the atomic phase. In the BEC the soliton can be stably formed as a dark soliton, that is, depletion in the atom number density distribution, and is characterized as a phase step in the matter-field. Therefore, by monitoring its propagation, the time-evolution of the atomic phase can be observed directly. However, its application has not yet been realized, because in the conventional trap the shape and inhomogeneity of its potential degrade the stability of the soliton propagation. To overcome such experimental difficulties, we started developing an "atom-wave circuit", namely, a BEC in a ring shape. So far, we constructed two frequency-stabilized laser systems and an ultra-high vacuum chamber for generating the BEC in ^{87}Rb. By operating a double magneto-optical trap with these systems, approximately 5×10^{8} Rb atoms in the $5s\,^2S_{1/2}$ $F=2$ state were prepared at about 100 μK after polarization gradient cooling. The cold atoms were further cooled by RF-induced evaporative cooling in a magnetic trap, and finally we obtained the BEC (about 1.8×10^{5} atoms) at the terminal RF frequency of about 1.355 MHz (Fig.1). We are now carrying forward the construction of the atom-wave circuit by transforming it into a ring shape with two laser beams.

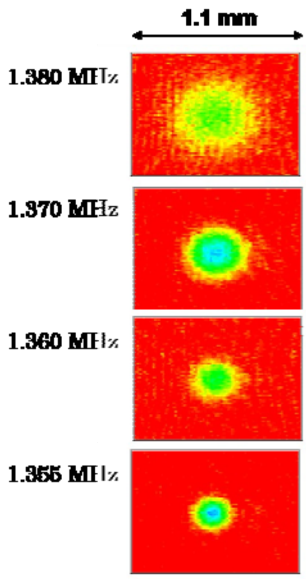

Fig.1: Absorption images of the ^{87}Rb atomic cloud showing the phase transition to the Bose -Einstein condensate. The cold atoms are confined in the Ioffe-Pritchard magnetic trap, whose axial and radial trap frequencies are, respectively, $2\pi\times18$ Hz and $2\pi\times110$ Hz, and are further cooled by the RF evaporative cooling. Each absorption image was obtained 20 ms after the release of the atomic cloud from the trap. The frequency indicated in the left column is the final RF frequency for each image.

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