Coexistence of the density wave and superfluid states in the optical lattice systems

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Ultracold fermionic systems have attracted considerable interest since the successful realization of the Bose-Einstein condensation in $^6Li_2$ molecules. Due to the high controllability of the system, remarkable phenomena have been observed such as the BCS-BEC crossover and the superfluid (SF) state in a spin-imbalanced system, where Cooper pairs are composed of ultracold atoms with distinct hyperfine states. Recently, fermionic mixtures with distinct ions, e.g., ^{6}Li and ^{40}K, have experimentally been realized [1,2], which stimulates further theoretical investigations on superfluid states in a mass-imbalanced system.

One of the interesting problems in such a mass imbalanced system is how the SF state is realized in the optical lattice. It is known that in the lattice model, a density wave (DW) state is stable since less mobile fermions tend to crystallize. This topic is closely related to an important issue in condensed matter physics, so called, the supersolid state [3] since the DW state can be regarded as a sort of the solid state. Therefore, it is necessary to clarify how the SF state coexists or competes with the DW state at low temperatures.

Here, we consider the infinite-dimensional attractive Hubbard model with different masses [4], as

$$H = \sum_{\langle i,j\rangle\sigma} t_\sigma (c^\dagger_{i\sigma} c_{j\sigma} + \text{h.c.}) - U \sum_i n_{i\uparrow} n_{i\downarrow}, \tag{1}$$

where $\langle i,j\rangle$ denotes nearest neighbor site, $c^\dagger_{i\sigma}(c_{i\sigma})$ is the creation (annihilation) operator of a fermion at the ith site with spin $\sigma(=\uparrow,\downarrow)$ and $n_{i\sigma} = c^\dagger_{i\sigma} c_{i\sigma}$. $U(>0)$ is the attractive interaction and t_σ is the hopping amplitude for the fermion with spin σ, where the effect of the mass imbalance is taken into account. We examine low temperature properties of this model, combining dynamical mean-field theory with the continuous-time quantum Monte Carlo simulations. By calculating the internal energy and the order parameter for both states, we clarify that the coexisting (supersolid) state, where the DW and SF states are degenerate, is realized in the intermediate coupling regime. We then determine the phase diagram at finite temperatures [5].

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