Towards understanding of the superconductivity in quasicrystals: superconductivity in quasiperiodic system

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A superconductivity in quasicrystals have attracted considerable interests since the superconductivity in the system without translational symmetry is highly nontrivial. Recently, first observation of bulk superconductivity in Al-Mg-Zn quasicrystal [1] were reported. These observations necessitate theoretical investigation of emergent superconductivity in such system.

We address the above issues in the Hubbard model on two-dimensional Penrose tiling. The model Hamiltonian is given as

$$H = \sum_{\langle i,j\rangle,\sigma} t\left(c_{i\sigma}^{\dagger}c_{j\sigma} + h.c.\right) - U\sum_{i} n_{i\uparrow}n_{i\downarrow}$$

where $\langle i,j\rangle$ denotes nearest neighbor site, $c_{i\sigma}^{\dagger}(c_{i\sigma})$ is the creation (annihilation) operator of a fermion at the *i*th site with spin $\sigma = (\uparrow,\downarrow)$ and $n_{i\sigma} = c_{i\sigma}^{\dagger}c_{i\sigma}$. t denotes the hopping integral, and U the attractive interaction.

First, we studied a possible superconductivity emerging in quasiperiodic system by means of real-space dynamical mean field theory(RDMFT) [2], namely, the attractive Hubbard model on the Penrose lattice. On the periodic lattices, this model is known to show the superconductivity at any finite value of the attraction $|U|>0$ while the character of the superconductivity changes from BCS to BEC type. Our findings suggest that the emerging superconducting phase is categorized into three different regions (Fig. 1), which cross over each other, in the phase diagram of average electron density and attractive interaction [3]. Especially, unconventional spatially extended Cooper pairs have been found in the weak-coupling region, which possibly consistent with the bulk superconductivity observed in Al-Mg-Zn quasicrystal.

Moreover, we extend the dual fermion approach [4] to real-space description [5] for investigating intersite electron correlations in inhomogeneous lattices since intersite electron correlation effects e.g. antiferromagnetic fluctuations in this system, cannot be dealt by means of cluster extensions of DMFT such as cellular DMFT (CDMFT) [6], and dynamical cluster approximation (DCA) [7]. The main difficulty underlying here is; periodic boundary condition should not be applied to the system due to the absence of translational symmetry. On the other hand, diagrammatic extensions of DMFT are candidates of treating intersite electron correlation effects in such system [8,9]. We study short-range correlations on the half-filled two-dimensional repulsive Hubbard model and show real-space dual fermion approach gives reasonable local quantities by comparing that obtained by DMFT and dual fermion approach. Moreover, we study the half-filled repulsive Hubbard model on the Penrose lattice as an example of strongly correlated electron system on an inhomogeneous lattice and show the short-range correlation effect affects local quantities at the strong coupling region. Our study offers new powerful method for investigating anisotropic superconductivity on inhomogeneous lattices.

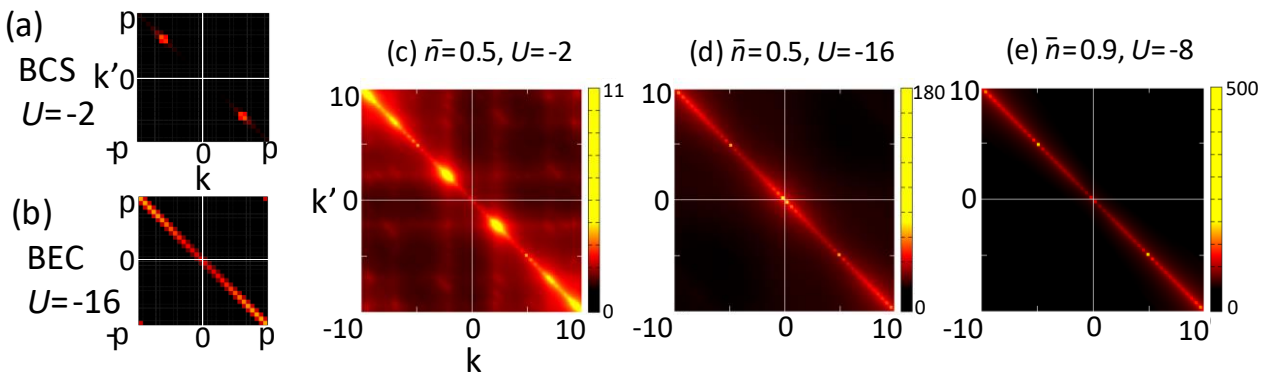

Figure 1. (a) and (b) Intensity map of Fourier-transformed off-site pair amplitude calculated for a square lattice at quarter filling for U = −2 and −16, respectively. (c)–(e) The same quantity for the three character: extended (c), short-ranged (d) and localized (e).

1. K. Kamiya, T. Takeuchi, N. Kabeya, N. Wada, T. Ishimasa, A. Ochiai, K. Deguchi, K. Imura, and N. K. Sato, Nature Communications **9**, (2018) 154.
2. A. Georges et al., Rev. Mod. Phys. 68, (1996) 13.
3. S. Sakai, N. Takemori, A. Koga, and R. Arita, Phys. Rev. B **95** (2017) 024509.
4. A. N. Rubtsov et al., Phys. Rev. B **77**, (2008) 033101.
5. N. Takemori, A. Koga and H. Hafermann, arXiv:1801.02441
6. G. Kotliar, S. Y. Savrasov, G. P´alsson, and G. Biroli, Phys. Rev. Lett. **87**, (2001) 186401.
7. M. H. Hettler, A. N. Tahvildar-Zadeh, M. Jarrell, T. Pruschke, and H. R. Krishnamurthy, Phys. Rev. B **58**, (1998) R7475.
8. G. Rohringer, H. Hafermann, A. Toschi, A. A. Katanin, A. E. Antipov, M. I. Katsnelson, A. I. Lichtenstein, A. N. Rubtsov, and K. Held, arXiv:1705.00024 [cond-mat.str-el].
9. H. Kusunose, J. Phys. Soc. Jpn. **75**, (2006) 054713.

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