Non-equilibrium superconducting transition in correlated electron systems

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Whether superconductivity can occur in non-equilibrium situations is a long-standing, fundamental question. Here we theoretically address this problem from a viewpoint of non-equilibrium phase transitions. The study is motivated by two recent experimental developments: One is the fabrication of functional structures with oxide thin films, where injection of carriers to an epitaxial interface between two insulating oxides was realized in ref.[1]. The second is an observation of a non-equilibrium carrier distribution, i.e., double-step Fermi distribution, in a normal, mesoscopic wire[2].

Here we examine an open, two-dimensional Hubbard model coupled to electrodes as a starting point. In order to treat strongly-correlated electron systems out of equilibrium, we have combined the Keldysh Green's function approach with the fluctuation exchange approximation (FLEX). The obtained non-equilibrium phase diagram for the Hubbard model near half-filling in finite bias voltages between the electrodes is schematically shown in Fig. 1 (b) against the bias voltage V, doping δ from the half-filling, and temperature T. The effect of bias is incorporated as the chemical potentials, $\mu_1 = \mu + V/2$ and $\mu_2 = \mu - V/2$ respectively, for the two electrodes. We can see that both the antiferromagnetic and d-wave superconducting phases become suppressed with the bias voltage, so the effect of the smeared Fermi distribution seems to dominate in this situation. We shall also comment on the nonequilibrium phase diagram for organic superconductors where charge fluctuations can play an important role.

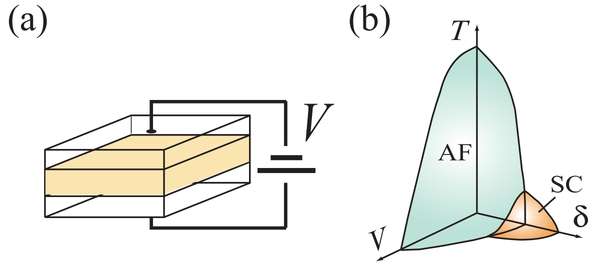

Figure 1: (a) Two dimensional correlated system (shaded) in a finite bias V.
(b) Obtained non-equilibrium phase diagram is schematically shown against the bias (V), the doping (δ), and the temperature (T) with antiferromagnetic (AF) and d-wave superconducting (SC) phases.

[1] A. Ohtomo and H. Y. Hwang, Nature **427**, 423 (2004).
[2] H. Potier *et al*. Phys. Rev. Lett. **79**, 3490 (1997).
[3] T. Oka and H. Aoki, in preparation.