Fluxoid distributions in superconductive honeycomb networks

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Abstract

We have studied fluxoid distributions and superconducting transition temperature of honeycomb superconductive networks with edges in the magnetic field making use of the de Gennes-Alexander equation. In honeycomb networks with edges, the suppression of superconducting transition temperature in the magnetic field is smaller than that of networks without edges. In the weak magnetic field, fluxoids emerge from center of the network. As the magnetic field increases, fluxoids are distributed parallel to edges.

Key words: superconducting network; Ginzburg-Landau equation

Multiply connected superconductors provide stages of macroscopic phase coherent effect such as the magnetic flux quatization. Although there are many ways of flux quatization around an arbitrary loop on a superconductive region, there exists a small number of thermally stable arrangements in a given external magnetic field. It is reported that the magnetic field dependence of critical temperature of superconducting network has a characteristic fine structure with a background of broad Little-Parks oscillation [1,2].

Recently, local super-currents in superconducting films with triangular micro-hole lattice is studied with use of the SQUID [3]. It is reported that near the critical temperature, the magnetic flux tends to form pararell lines.

In this paper, we theoretically investigate fluxoid configurations of honeycomb superconductive network that consists of strands with length a in the x-y plane immersed in applied magnetic field $\mathbf{H} = (0, 0, H_0)$ making use of the de Gennes-Alexander network equation [4].

For the honeycomb network, the network equation is expressed by

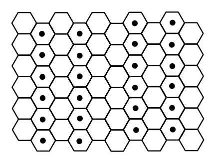

Fig. 1. A fluxons configuration in the periodic boundary condition at $\frac{\phi}{\phi_0} = \frac{2}{5}$.

$$\frac{1}{n_i} \sum_j \Delta_j \exp\left(i\gamma_{i,j}\right) = \Delta_i \cos \frac{a}{\xi(T)} \quad (1)$$

where summation of j is the sum over the nodes connecting by strands with node i, n_i is a number of strands connecting with node i, Δ_i denotes order parameter at node i. $\xi(T)$ is the Landau-Ginzburg coherence length. The temperature dependence of $\xi(T)$ near the T_c can be written as $\xi(T) = \xi_0/\sqrt{1 - T/T_0}$, where T_0 is the zero field transition temperature and ξ_0 is the coherence length at zero temperature.

The phase factor $\gamma_{i,j}$ is defined as,

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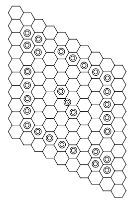

Fig. 2. A fluxons configuration in the network with edge composed of $10 \times 10 = 100$ hexagons at $\frac{\Phi}{\Phi_0} = \frac{1}{3}$.

$$\gamma_{i,j} = \frac{2\pi\Phi}{\Phi_0} \int_i^j \mathbf{Ads}, \tag{2}$$

where Φ_0 is the flux quantum. The integration performs along the strand. In the following discussion, we express the intensity of external magnetic field as $\frac{\Phi}{\Phi_0}$, where Φ is the external flux per a hexagon, $\Phi = (3\sqrt{3}/2)a^2 H_0$.

By solving eigenvalue equation of Eq.1, we can determine the superconductive transition temperature.

The transition temperature of network with periodic boundary condition shows dip structures at $\frac{\Phi}{\Phi_0} = \frac{1}{3}$, $\frac{2}{5}$, $\frac{3}{7}$, $\frac{1}{2}$, $\frac{3}{5}$, $\frac{4}{7}$, and $\frac{3}{5}$.

On the other hand, we cannot found these structures in networks with edges. It is also found that decrease of transition temperature due to the applied magnetic field is smaller than that of the network with the periodic boundary condition.

To find fluxons distribution, we solve Eq. 1 and trace the spatial variation of phase Δ along superconductive loops. One of fluxons arrangements of the network with the periodic boundary condition (edgeless network) for $\frac{\Phi}{\Phi_0} = \frac{2}{5}$ is shown in Fig.1. Fluxons are arranged in periodic parallel lines and the total flux pass through the network equals to external flux.

On the other hand, in the network with edge(without periodic boundary condition), fluxons tend to line up forming network edge's shape(Fig. 2). In the weak magnetic field ($\frac{\Phi}{\Phi_0} \sim \frac{1}{N}$, where N is the number of hexagons composing the network), fluxons are located near the center of the network. It is impossible in the weak field that fluxons are located near the edge, because arrangements of fluxons tend to form similar shapes of the network edge, if fluxons are located near the edge, it is necessary large number of fluxons.

The total flux pass through the network with edge is not the same as external flux. The difference between the total flux and the external flux $\Delta\Phi$ is shown in Fig.3. Multiply connected networks are able to create or annihilate the flux more than one flux quantum. In the single connected network, $\Delta\Phi$ should be in $-\frac{1}{2} < \frac{\Delta\Phi}{\Phi_0} < \frac{1}{2}$.

In conclusion, the existence of edges changes superconductive transition temperature and fluxons configurations from those of edgeless network with the periodic boundary condition.

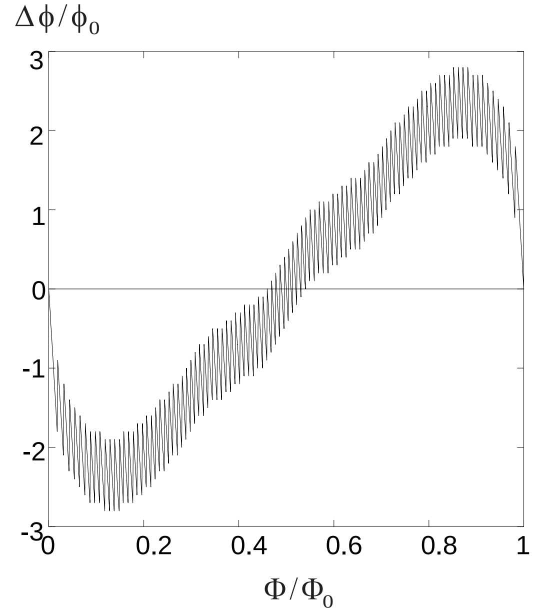

Fig. 3. The difference of the flux pass through the $10 \times 10 = 100$ hexagons network and external flux.

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