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On Possibility of Superconductivity in Thin Films

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Abstract: Behavior of electrons inside a thin coating layer is studied. It is based on Cheng-Born theory of broken symmetry and TFDC(Thomas-Fermi-Dirac-Cheng) electron theory. For a specimen (TiO_2, say) coated on a conducting metal plate (e.g. platinum), according to the TFDC model, a small group of electrons (or holes) will transfer from one side of boundary to the other. Based on Cheng-Born theory, in case where only few electrons exist in zone, only a few corners are occupied, broken symmetry in momentum space will occur and lead to advent of superconductivity. Following the general formulation of thermodynamics, an estimate on the transition temperature in two-dimensional space is made. The result shows that the superconductors in two-dimensions are in general inherent to HTS, T_c of superconductor in two-dimensions would be at least by one order larger than T_c of normal superconductor in three-dimensions. In this text an experiment is designed to look for superconductivity of thin film.

Key words: superconductivity; thin film; broken symmetry; TFDC

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1 General Review of Important Phenomena

The mechanism of superconductivity remains unsolved to date. There are however several important facts which are obviously correlated with the advent of superconductivity. They can be laid down as follows:(1) Almost all single-valence elements are not superconductive[1]; (2) Normal states of superconductors are in general poor conductive or even insulator; (3) Transition temperature of superconductivity is generally altered by addition or diminishing of electrons from the specimen by many different possible means, e.g. by doping or substitution of different elements, by coating a suitable layer at boundary, and even by simple compression; (4) Non-isotropic superconductors usually possess higher transition temperatures. HT_C is characterized by two dimensional crystal structure. It is highly dependent on symmetry in the electronic distribution; (5) No insulator is superconductive, which indicates that mere mutual interaction could not be the cause except by the aid of defects and holes which are in short of electrons(or holes) in a full band or valence band.

2 Behavior of Electrons Inside a Thin Coating Layer

Consider a specimen (TiO_2, say) coated on a conducting metal plate (e.g. platinum), as showing in Fig.2. According to the revised TFD model, a small group of electrons (or holes) will transfer from one side to the other. It creates a small shell of electron distribution of the tens nm thickness. They have electron density from maximum about 20th power decreasing down to zero at the other end. This is the typical model in two dimensional distribution[2].

The density of electrons can be controlled by applying potential difference V between the terminals of the dipole film.

In this way one could artificially create an environment of a HT_C (or rather a superconductor with a high transition temperature). It is of two dimensions and is capable of carrying variable density of electrons as demanded. Pressure inside the coated shell can be controlled by adjusting metallic base, which will create controllable pressure inside the coating layer[3,4].

In this way we are able to create two dimensional superconductors. The parameters to be selected will be: (1) the average density of the transferred electron n, (2) the thickness of the coating layer d, (3) the suitably chosen coating metal base and the coated specimen, (4) the value of potential bias for the controlling the electron density.

Although we are aware that there were already experiments done in this field and had shown the predictions here, yet there are not systematic and were not correlated in a systematic way with a the definite

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theory. In the following section we shall engage some calculation based on the Cheng-Born theory of superconductivity. The theory stresses difference in the exchange energies among electrons in a same zone and between electrons from different corners of the same zone(note the difference between the momenta from two corners and inside the same corner in a large Brilluoin). We shall show that the above four conditions to produce superconductivity are self-consistent.

3 Compatibility of a Superconductor by Broken Symmetry

Here first write down the energy of formulations for electrons in two dimensional momentum space. In this space we assume a distributions of equivalent corners in a Brillouin zone according to Cheng-Born theory of broken symmetry, in case only few electrons exist in this zone, or only a few corners are occupied that leads to broken symmetry in momentum leading to the advent of superconductivity.

First consider the case where all corners are all occupied. Then find the condition of broken symmetry, when the total energy do not suffice to fill all full corners, leaving some vacant.

1) According to Fermi statistics, the total energy of electrons inside a disc of corners in a two-dimensional space:

$$\varepsilon_0=\sum_{s=0}^{\infty}\int_0^{\infty}\frac{2\pi}{h^2}p\mathrm{d}p\left(\frac{p^2}{2m}+\frac{(2s+1)}{2md^2}h^2\right)+E_{\mathrm{ex}}+n\mu \tag{1}$$

where *s* is the quantum number designating the quantum state in the vertical dimension which *d* is the width of the narrow film, μ is the change of chemical potential including the external applied potential eV. Here consider only one spin direction, since two cases are the same. And we presume that s=0, because the narrow thickness of the layer would contribute large kinetic energy when $s\neq 0$. Thus the term containing *s* is a constant and will be included in the chemical potential:

$$\mu_1=\mu+\frac{h^2}{2md^2}+\mathrm{eV} \tag{2}$$

E_{ex} is the exchange energy in two dimensional space:

$$E_{\mathrm{ex}}=-\int\frac{e^2}{|r_1-r_2|}\exp\left[2\pi(p_1-p_2)(r_1-r_2)/h\right]\mathrm{d}p_1\mathrm{d}p_2\mathrm{d}r_1\mathrm{d}r_2/d^2 \tag{3}$$

where the bold character represents a vector in the two dimensional space. *d* is the thickness of the volume of which the area is taken to be unity.

2) In a superconductor, the number of electrons in a definite zone is small that they could only fill a small part of different zone corners and in most cases (see Fig.1), $|p_1'-p_2|>>|p_1-p_2|$, therefore the exchange energy inside a same zone corner will be larger than that between two different zone corners.

3) Let p_0 be maximum momentum of a corner in the zone and be sufficiently large that $\frac{p_0^2}{2m}$ is comparable to the exchange energy. In this case the above suppositions for existence of a broken symmetry of distribution of electrons would be appear.

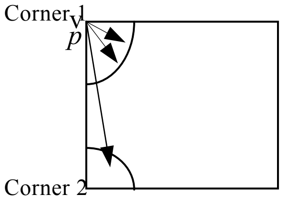

Fig.1 The different zone corners in a momentum space

Consider the limit case where all corners are occupied for a specific chemical potential 0. Then the total energy and electron density *n* together are given as follows:

$$\varepsilon_{\mathrm{T}}=\frac{\pi}{4mh^2}p_0^4+E_{\mathrm{ex}} \tag{4}$$

$$n=\int\frac{1}{h^3}2\pi p\,\mathrm{d}p\cdot\frac{h}{d} \tag{5}$$

Now prosecute the calculation of all related quantities of the two dimensional superconductivity: (1) The number of electrons occupied in a zone, which is in a form of a disc with radius p_0 and thickness *d*, p_0 is the maximum value of *p* of the electrons:

$$N=\int\mathrm{d}n=\int\frac{h}{d}\cdot\frac{2\pi p_0}{h^3}\mathrm{d}p=\frac{\pi p_0^2}{dh^2} \tag{6}$$

(2) The kinetic energy density is as follows:

$$\varepsilon_{\mathrm{k}}=\sum\frac{1}{2m}p^2=\frac{\pi}{4mh^2d}p_0^4 \tag{7}$$

(3) The exchange energy density:

$$\varepsilon_{\mathrm{ex}}=\frac{-2\pi e^2p_0}{h} \tag{8}$$

The total energy density ε_{T} is then as follows:

$$\varepsilon_{\mathrm{T}}=\frac{\pi}{4mh^2}p_0^4-\frac{2\pi e^2}{d^2h}p \tag{9}$$

Let $\frac{\partial\varepsilon_{\mathrm{T}}}{\partial p_0}=0$ as optimum, then $p_0\approx\left(\frac{2e^2mh}{d^2}\right)^{1/3}$ So

$$\frac{p_0}{m}=\left(\frac{2e^2h}{d^2m^2}\right)^{1/3}=5.31\times10^6 \tag{10}$$

here *d* is taken approximately as 5×10^{-6}. Hence, the optimum kinetic energy of an average superconductivity electron is as $\frac{1}{2m}p_0^2 = 7.9\times10^{-3}\text{eV} \approx 90^0\ \text{K}$, being of order of transition temperature.

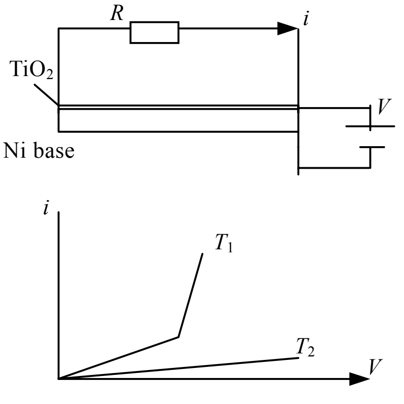

Fig.2　An experiment to detect the two dimensional superconductor

In conclusion one is inclined to believe that in two-dimensional space superconductors are in general inherent to HTS, in contrast to three-dimensional specimen wherein transition temperatures are in general lower. The reason owes probably to the relative strength of energy densities between kinetic energy and the density of strengthened exchange energy that is sensitive to the optimum condition of superconductivity. The author therefore humbly recommends the present suggestions and expects that it might be critical to bring light to the discrimination to theory of superconductivity, the transition temperature in two-dimension is at least large by one order of magnitude.

Here, the author proposes an experiment to detect the existence of the two dimensional superconductor. Let an insulator thin film(TiO$_2$, say) be coated on a platinum base. The thickness is round 50 nm(see Fig.2). Let a potential bias *V* be laid between the layer and base. This is to change the chemical potential of TiO$_2$ in such a TiO$_2$ way that free electron density inside the layer *V* may be altered and controlled.

A circuit connecting two ends of the layer with a resistance *R* is formed. Then measure the current *i* passing through at different temperature from ~10 to 200 K. Plot (*i*, *V*) for different temperature T_1, T_2…., to look for a kink of a curve for a temperature *T*. The advent of a kink is a sign indicating a superconductive state might be in the way. Then in the region, use normal technique to measure the characteristics of a superconductor and determine the transition temperature against the applied voltage bias.

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论薄膜的超导电性

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摘　要：应用 Cheng-Born 能带对称破缺理论和 TFDC(Thomas-Fermi-Dirac-Cheng) 电子理论研究了薄膜层内电子的特性。对金属铂上的 TiO$_2$ 膜层来说，TFDC 理论指出电子(或空穴)将由金属与膜的间界面一侧迁移到另一侧。根据 Cheng-Born 对称破缺理论，当能带中只有很少的电子时，则只有极少的角区中存在电子，动量空间即产生对称破缺，从而导致超导电性，并由热力学估算出薄膜超导体的转变温度。结果显示薄膜超导体的转变温度至少比块材超导体的转变温度高一个量级。作者还设计了一个研究薄膜超导电性的实验。

关键词：超导电性；薄膜；对称破缺；TFDC

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