On the Possible new High Temperature Superconductors

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Abstract: It shows that the hybrid graphene may be the high temperature superconductor based on a simple superconductivity theory. However the pure graphene cannot be the high temperature superconductor. The efforts to make the graphene to be superconductors are to use the Graphene-Boron Nitride or other graphene-ceramics sandwich structure. Calculations show that this sandwich structure can satisfy the demanding of high temperature superconductivity.

Key words: Superconductivity; HTC; Graphene; Boron Nitride

1 Introduction

How to find high temperature superconductive materials is always the leading subject in the essential theory of physics. BCS theory can explain conventional superconductor. However it cannot explain the high temperature superconductors. Cheng[1] provided a simple superconductivity theory that can obtain the similar results as the BCS theory. It has more operability to predict new types of superconductors for the reason of simple calculations of the superconductive mechanisms.

For the graphene materials, researchers had obtained lots results. Some authors had discussed the important superconductive characteristics of graphene in room temperature environment [2]. Other authors had discussed how to make the superconductive materials based on graphene [3]. Many other researches show that the decorated graphene has superconductivity.

2 Three characteristics of superconductive material

A superconductive material must have three important characteristics according to Cheng's theory [1].

1. The atoms that consist of the crystal must be light. The light atom needs more energy to jump from lower energy level to higher energy level. If the electron's energy is not larger enough, it cannot emitter virtual photons to oscillate the crystal atoms. The electrons will not lost energy in this condition. So it can transfer through the crystal without any resistance.

2. The coefficient of elasticity of the crystal lattice shall be larger enough based on harmonic oscillation model. It can make the same effect of the light atoms. The atoms will be more firmly bound in the hard crystal. It can increase the coefficient of elasticity. This may be the reason why almost all of the high temperature superconductors are consisted of hard ceramic materials.

3. The material's effective fermi energy should be lower. The lower fermi energy means that

the electrons in the crystal need more extra energy to reach to the lowest phonon's energy created by the atoms in crystal. If the electron's energy is lower than the ground state energy of the crystal (based on harmonic oscillation model), the electron will not be able to emitter virtual photons to the atoms in crystal according to Cheng's theory.

However, the material's fermi energy is calculated based on the free electron gas model. It means that all of the electrons in a block of material will obey the same fermi statistical distribution. It may not be true in reality since the interaction between electrons is limited in a localized area. So the effective fermi energy is more important than the fermi energy of a material.

The effective fermi energy means that only a part of electrons have the ability to participate in the same fermi statistician distribution, since this part of electrons has close relationships. The parameter that used to describe the close relationships is correlation length [1]. If the correlation length of the electrons in the crystal is longer, the effective fermi energy will be higher. Otherwise, the effective fermi energy will be low.

To form the lower effective fermi energy, the number of electrons in the crystal must be relatively small and the distances among electrons must be longer enough. The correlation length is proportional to material's electric conductivity in generally.

3 The superconductivity of Graphene

In room temperature and pressure, the materials that can meet these three characteristics are not many.

The lightest atom in nature is hydrogen atom. There are many compounds that consisted of hydrogen atom and other atoms had been found in the past. However, these compounds cannot meet the second and third characteristics in atmospheric pressure. Therefore, many hydride compounds have the abilities of superconductivity only under high pressure. The high pressure can change the structure of these hydride compounds, and to enlarge the crystal lattice's coefficient of elasticity. Currently, researchers found that the sulfide is the high temperature superconductor under 150GPa pressure. The critical temperature of sulfide in high pressure can reach to 203K.

The large lattice coefficient of elasticity materials under room temperature and atmosphere pressure are diamonds and ceramics. However, since the diamonds and many ceramics are insulators, there are no more current carriers in them. The ordinary diamond and many ceramics are not suitable to make superconductors. Graphene may also have large lattice coefficient of elasticity for the reason of special hexagon crystal lattice structure. Since it has enough carriers, the graphene materials may be the suitable high temperature superconductors.

The graphene can meet these three superconductivity characteristics.

1. The atomic weight of C is very light. Even on the basis of BCS theory, the superconductors that consisted of graphene can reach higher critical temperature then copper oxides.

2. The crystal lattice coefficient of elasticity is larger for pure graphene.

3. There are suitable amount of carriers in graphene. On the other hand, the graphene's fermi energy is lower than many materials. Some studies show that the graphene's fermi energy is 0.3eV [4].

We can simply estimate the difference between graphene's effective fermi energy and lattice oscillation energy (phonon energy) below.

The crystal lattice oscillation energy can be express as below by using the harmonic oscillation model.

$$E_k = n\hbar\sqrt{\frac{k}{M}} = n\hbar\omega \quad \cdots\cdots (1)$$

It corresponds to phonon's energy. The single atom's oscillation energy (single phonon) in graphene crystal lattice is about [5,6]:

$$E_{kc} = \hbar\omega = 200\times 10^{-3} eV \quad \cdots\cdots (2)$$

How to calculate the graphene's effective fermi energy should consider the fermi energy that calculated from free electron gas model and the electrons' correlation length based on paper [1]. The electrons' correlation length can be obtained from graphite's electric conductivity. The reason why we use the electric conductivity of graphite instead of graphene's is because we believe the graphene may be the room temperature superconductor. We will explain it in this paper's part 4 and part 5.。

The graphite's electric conductivity is about 0.003×$10^8 Sm^{-1}$. It is smaller than metals. This is advantage for us to obtain the shorter electrons correlation length. The formula that used to calculate the electrons correlation length is shown below according to paper [1]:

$$E_c \approx c^2\sigma^2 E_F \quad \cdots\cdots (3)$$

Here c is a constant, while E_F is the fermi energy based on free electrons gas model. So we can calculate the highest electrons energy in graphene lattice.

However, we cannot calculate the constant c directly. Here we can use Pb's parameters to estimate its value. Consider the phonon energy of Pb crystal is about [7]:

$$E_{kpb} = 8 \times 10^{-3}(eV)$$

The electric conductivity of Pb metal is 0.0481×$10^8 Sm^{-1}$,

When Pb superconductor reaches the critical temperature, it has:

$$E_{cpb} = E_{kpb}$$

So we can have:

$$c^2 = \frac{E_{kpb}}{\sigma^2 E_{Fpb}} = \frac{8\times 10^{-3}}{4.81^2\times 10^{12}\times 6.9} = 5\times 10^{-17}(\Omega m)^2 \quad \cdots\cdots (4)$$

Then we can obtain the electrons' effective fermi energy of graphene by using the graphite's data from formula (3).

$$E_{cc} = c^2\sigma^2 E_{Fc} = 5\times 10^{-17}\times 9\times 10^{10}\times 0.3 = 1.35\times 10^{-6}(eV) \quad \cdots\cdots (5)$$

It is obviously that the graphene's effective fermi energy is smaller than its phonon energy from above calculation. It means that the electrons need much more energies to reach the lattice oscillation energy level. According to paper [1], it also means that the electrons in graphene lattice cannot exchange virtual photons with lattice. No exchanging of virtual photons means that there is no energy loss for electrons when they produce current.

So if the graphene is the superconductivity material, then we can estimate the critical temperature of graphene by comparing its effective fermi energy and its phonon energy produced by graphene crystal lattice. Consider the critical temperature of Pb metal is nearly 7.19K. Since the Pb metal's effective fermi energy is 1000 times the graphene's effective fermi energy, we can estimate the graphene's critical temperature is very high. The ordinary graphene has the ability to be the room temperature superconductivity material.

4 Why ordinary graphene have no room temperature superconductivity ability?

Although we estimate that the ordinary graphene has the ability to be the room temperature superconductor, we have not observed the room temperature superconductivity of graphene directly until now.

The reason may be that ordinary graphene has the two dimensional structure. Two dimensional structures will have two interfaces with other materials. When the electrons move through the graphene, they will also have interactions with other atoms outside the 2D graphene. This process will cause the electrons energy losing, since the energy level of outside atoms is very low.

5 Possible new superconductors based on graphene

To solve the problems of interaction with other atoms outside graphene, we can consider inserting a single layer graphene into the hard and insulation materials. So we can keep graphene's two dimensional structure, and we can also prevent the electrons insider graphene to have interaction with other low energy level atoms outsider graphene in the same time. The reason to choose insulation material is to guarantee there are only graphene's electrons in the hybrid material. So the electron correlation length will be shorter in this material.

Currently, some researches show that there is sandwich structure that constructed by inserting single layer graphene into the c-BN crystal, which can change the graphene's resistance effectively [8]. It also reflects that the graphene's resistance is produced by outside atoms.

Of cause we can also use h-BN or other insulation ceramic materials to construct this sandwich lattice structure besides c-BN.

In summary, we consider those possible high temperature superconductivity graphene materials below.

1. The single layer graphene growing in hard ceramic materials (such as c-BN, SiO_2 and etc.). We can place these materials in the vacuum environment so that there are no other low energy

level atoms outside can interact with the electrons in graphene.

However, there are some problems existed in these materials. The asymmetry structure may have negative affect on its superconductivity. But we believe that these materials can have superconductivity in some lower temperature since the electric coefficient of substrate material's crystal lattice is very large.

2. The sandwich structure of graphene and c-BN. When insert a single layer graphene into tow block c-BN crystal, and keep them close contact without any other atoms doping in it, this structure will have highly symmetry. The other great advantages of this structure are to keep the two dimensional structure of graphene and most of the carriers can only move in graphene. Even if some carriers enter the c-BN lattice, the higher phonon energy of c-BN lattice can also guarantee this sandwich structure material to have higher enough critical temperature.

3. The sandwich structure of graphene and h-BN. There is much paper study on this hybrid material currently. The advantage of this structure is that h-BN has the same hexagon structure as graphene. So if we place single layer graphene between two single layers of h-CN, it will not destroy the graphene and h-BN's structures both. Since there are few free electrons in h-CN, it will not decrease the material's performance just like multilayer graphene. If this sandwich structure can have superconductivity ability, it will be applied into integrated circuit technology. This will greatly reducing energy consumption of the circuits.

4. Other graphene-ceramic sandwich structure. There are many advantages to use Boron Nitride, including the Boron and Nitride's atom weight is lighter than most other atoms. So Boron and Nitride elements are suitable for making superconductors. However, if Boron-Nitride is proved that it does not suitable for making superconductors in the end, we can also choose other harder and insulation ceramic or diamond materials with graphene together to make this sandwich structure. We can also doping some rare earth elements to improve those ceramics material's performance.

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