学 位 論 文 内 容 の 要 旨

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学 位 論 文 題 名

Induced charge density wave and superconductivity in Cu-doped $TaSe_3$
(Cuドープした $TaSe_3$における誘起された電荷密度波と超伝導)

The relationship between superconductivity (SC) and charge density wave (CDW) has been a major research topic in condensed matter physics and has been investigated in many materials. However, previous studies were actually limited to two cases: the first is where SC and a CDW intrinsically exist; the second is where SC is induced in a CDW material. To understand the whole picture of the relationship between SC and CDW, we investigated the relationship in a third case where a CDW is induced in a superconducting material.

Transition metal trichalcogenides, MX_3 (M: Nb, Ta; X: S, Se), has a structure consisting of chains made of transition metals and chalcogens, and the chains are weakly bonded by van der Waals forces. Owing to this structure, MX_3 is a quasi-one-dimensional conductor in which an electric current travels well in the direction of the chain axis. In most materials belonging to MX_3 ($NbSe_3$, TaS_3, and NbS_3), the Fermi surface of is close to a plane. Therefore, the nesting condition is good and a CDW develops below the transition temperature in these materials. On the other hand, $TaSe_3$ which is one of MX_3 exhibits no CDW transition but the filamentary superconductivity transition at about 2 K because $TaSe_3$ is more three-dimensional than the other MX_3 compounds.

If Cu atoms are doped in $TaSe_3$, the Cu atoms are considered to be difficult to substitute for Ta atoms because the common valence that Cu takes (+1 or +2) is different from that of Ta (+5). On the other hand, the Cu atoms are expected to enter in the Van der Waals gap and to increase the distance between chains of $TaSe_3$. Therefore, it is presumed that Cu doping decreases in dimensionality and improves the nesting condition in $TaSe_3$.

In this thesis, we tried to induce a CDW in $TaSe_3$ with a superconducting material by Cu doping, and investigated the relationship between the induced CDW and SC.

We have synthesized single crystals of Cu-doped $TaSe_3$, and measured precisely the temperature dependence of the resistance from 4.2 to 280 K. We discover an anomalous sharp dip in the temperature derivative of the resistance (dR/dT) at about 91 K in Cu-doped $TaSe_3$, which is never observed in pure $TaSe_3$. The dip suggests that there is a sudden change in state with a relative increase in resistance. In addition, the dip is "γ" shaped. We reveal that the same "γ"-shaped dip in dR/dT is commonly observed at the CDW transition temperature in many CDW conductors, which is a universal consequence resulting from the opening and growth of a CDW gap on a Fermi surface. Furthermore, the result of the single-crystal X-ray diffraction (XRD) analysis implies that the lattice parameters perpendicular the chain axis increase and that parallel to the chain axis decreases by Cu-doping, leading to an improvement in the nesting condition. The "γ"-shaped dip and the result of the single-crystal XRD analysis show that a CDW emerges by Cu doping in $TaSe_3$.

We investigated the effect of Cu doping on SC in Cu-doped $TaSe_3$ by measuring the temperature dependence of the resistance from 0.6 to 2 K. We observed an emergence of a region where the SC transition temperature decreased in samples with higher Cu concentrations, and found that the region tended to expand with increasing Cu concentration. These results and the fact that the SC of $TaSe_3$ is filamentary show that SC is suppressed locally by Cu doping in Cu-doped $TaSe_3$.

From the above discussions, it was revealed that a CDW is induced while SC is suppressed in Cu-doped $TaSe_3$. Hence, the induced CDW and SC would be in a competitive relationship.

The locality of SC suppression suggests that the induced CDW is local. The resistance anomaly due to the induced CDW was extremely small. Moreover, the size of the anomaly was enhanced with increasing Cu concentration but the temperature at which the anomaly appeared hardly changed. These results of the anomaly can be interpreted consistently from the short-range order of the induced CDW in the vicinity of a Cu atom.

From all the discussions above, we conclude that the induced short-range order CDW and SC are in a competitive relationship in Cu-doped $TaSe_3$. The competitive relationship between short-range order CDW and SC obtained in the present work is different from the non-competitive relationship previously reported in Cu_xTiSe_2 where SC is induced in a CDW material. By comparing the detailed experimental results of these two materials, we will clarify the physics that defines the relationship between short-range order CDW and SC.