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High temperature superconductor in the intermetallic compounds

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We have intensively investigated the superconducting properties of ternary silicide superconductor $Sc_5Ir_4Si_{10}$ polycrystalline sample and antiferromagnetic transitions in ternary rare-earth metal silicide $R_5Ir_4Si_{10}$ (R= Tb, Dy, Ho, Er) single crystals by performing the high-resolution measurement of the low-temperature specific heat. We consider the antagonism between superconductivity and magnetism and conclude that the two-dimensional material which is containing the light elements undergoes superconductivity.

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Keywords: Superconductor, Rare-earth metal silicide, $Sc_5Ir_4Si_{10}$

When we read the proceedings of International Conference on Ternary Superconductors held September 24-26, 1980 in Lake Geneva, Wisconsin, U.S.A. [1], we feel that the final goal of Professor B. T. Matthias is the high-temperature superconductor in the intermetallic compounds. Professor B. T. Matthias had the interest in the intermetallic compounds which is including the rare-earth metals (RE). Therefore, Matthias and co-workers had intensively investigated the effect of RE in the superconductor. The only known superconducting element among RE is La (lanthanum). In La, there are no f-electrons in 4f shell whereas 14 f-electrons have filled the 4f shell entirely in Lu (lutetium). However, Lu is not superconducting above 1.02 K because its metallic radius has become much smaller and at same time it is much heavier than La. Matthias et al. had noticed that the decreasing of the superconducting transition temperature T_c of La by doping 1at. % RE impurities are unambiguously determined by the spin quantum number of the 4f shell [2]. This discovery initiated a great deal of the theoretical activities, following the seminal paper by Abrikosov and Gor'kov [3]. In Ref. [2] it was found that among all the RE dopants, Ce^{3+} has a particularly strong effect in the reduction of T_c, this observation which could be subsequently ascribed to the action of the Kondo effect [4]. The Kondo effect is the problem of a localized spin in metals, which is a simple but essential problem. It is of fundamental importance in the history of the electron theory of solids. The high density Kondo Effect discovered in the RE intermetallic compounds, namely, the formation of the heavy-fermion (HF) systems at low temperatures have been intensively studying. Furthermore, superconductors that are containing a sufficiently low concentration of Kondo impurities, namely, Kondo superconductors, were first theoretically treated by Ludwig and Zuckermann [5] and Müler-Hartmann and Zittartz [6] because the pair-breaking action of magnetic impurities in the superconductors leads to a drastic depression of T_c with increasing magnetic impurity concentration. They predicted that the feature of the temperature dependence of the pair–breaking parameter in a Kondo superconductor might lead to the existence of two or even three successive transition temperatures (Tc1> Tc2 > Tc3). The experimental evidence for the three-T_c behavior in the Kondo superconductor $(La,Ce)_{0.8}Y_{0.2}$ was first observed in 1977 by Winzer [7].

As mentioned above, the efforts to explore the interaction between superconductivity and magnetic long-range order had been carried out by introducing low concentrations of magnetic impurity ions into superconducting elements and compounds. However, in these dilute impurity systems, the random spatial distribution of magnetic impurity ions resulted in clustered and/or glassy magnetic structures with ill-defined magnetic ordering temperatures and other physical properties which have proved difficult to interpret. However, in the ternary RE molybdenum chalcogenides, namely, $REMo_6S_8$ and the ternary RE compound $RERh_4B_4$, the RE ions are distributed periodically in the lattice, so that the ordering of RE magnetic moments should be of long-range rather than diffuse "spin-glass" type encountered in a dilute substitutional alloy. Thus these systems afford a unique opportunity to investigate the conditions under which superconductivity and magnetic long-range ordering can coexist.

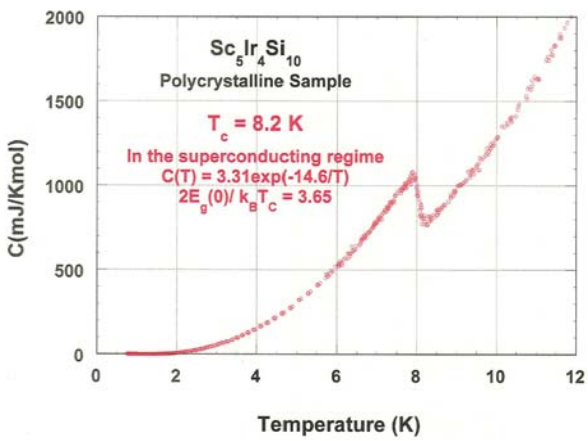

Fig. 1. Temperature dependence of the low-temperature specific heat of the ternary silicide superconductor $Sc_5Ir_4Si_{10}$ polycrystalline sample.

At last the destruction of the superconducting state by the onset of the magnetic long-range ordering state in the ternary rare-earth metal boride $ErRh_4B_4$ [8] and $Ho_{1.8}Mo_6S_8$ [9] were discovered. The following neutron scattering study on the powdered samples of $ErRh_4B_4$ demonstrated that the destruction of superconductivity occurs during the transition to a ferromagnetically long-range ordered state [10]. Samples of $ErRh_4B_4$ were synthesized from the high-purity elements by conventional arc melting and subsequent annealing processes.

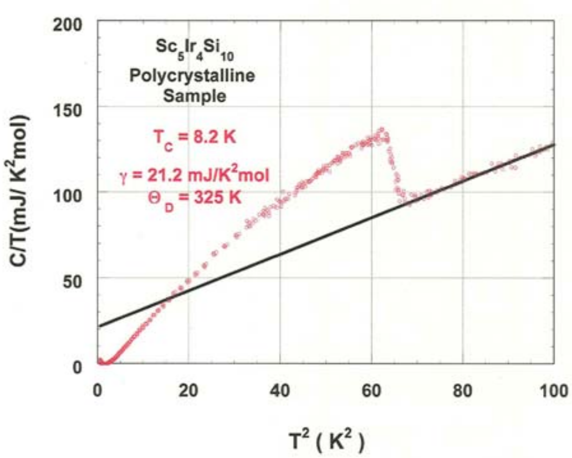

Fig. 2. Superconducting properties of ternary silicide superconductor $Sc_5Ir_4Si_{10}$ polycrystalline sample.

We have intensively investigated the superconducting properties of the ternary silicide superconductor $Sc_5Ir_4Si_{10}$ polycrystalline sample [12] and antiferromagnetic transitions in ternary rare-earth metal silicides $R_5Ir_4Si_{10}$ (R = Tb, Dy, Ho, Er) single crystals by performing the high resolution measurements of the low-temperature specific heat. The samples in the present study were prepared by a single-arc furnace for polycrystalline samples and a tetra-arc furnace for single crystalline samples by melting stoichiometric amounts of the constituent elements in a Ti-gettered high purity argon atmosphere. The thermal annealing process was not processed for the button prepared by a single arc-melting. However, for the single crystals we have always employed a solid state electro-transport method (SSE) in order to improve the quality of the single crystalline sample. We have already reported antiferromagnetic transitions of $R_5Ir_4Si_{10}$ (R= Tb, Dy, Ho, Er) compounds [12]. Following the above antiferromagnetic transitions, we describe the superconductivity of $Sc_5Ir_4Si_{10}$ polycrystalline sample. The onset transition temperature is 8.2 K, the electronic specific heat coefficient is 21.2mJ/K^2mol and the Debye temperature Θ_D is 325 K. In the superconducting regime the temperature dependence of the low-temperature specific heat C (T) is found to be fitted as follows.

$$C(T) = 3.31\exp(-14.6/T)$$

This result is precisely in accordance with a standard BCS exponential expression. Furthermore, we have got the results that $2E_g(0)/k_BT_c$ is 3.65 where $E_g(0)$ in the superconducting energy gap at T = 0 and k_B is Boltzmann constant. This value is a little larger than the BCS value of 3.52. This result means that the superconductivity of the ternary silicide superconductor $Sc_5Co_4Si_{10}$ is classified as one of the strong-coupling superconductors. These results are shown in Figs. 1 and 2.

Next, I must mention to superconductivity in high-pressurized metallic phases of silicon (Si) [13]. The highest superconducting transition temperature of the pressurized Si is 8.2 K at 15 Gpa in the simple hexagonal phase. This superconducting transition temperature, namely, T_C =8.2 K is the same as that of Sc5Ir4Si10 polycrystalline sample at ambient pressure. Therefore, we must discuss the striking similarities between a ternary silicide superconductor $Sc_5Ir_4Si_{10}$, the pressurized Si and a binary intermetallic high T_C superconductor MGB_2 [14]. The common feature of the compounds mentioned just above is the two-dimensionality. So that we must conclude that the two-dimentional material which is containing the light elements such a B and Si undergoes superconductivity.

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