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Andreev Reflection Spectroscopy Study of Spin Polarization in $Co_2Cr(Fe)Al$ Heusler Alloys

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The present paper is dealing with the experimental study of the influence of Fe substitution on the Curie temperature and spin polarization in Co_2CrAl Heusler alloys. A recently successfully introduced new rapid quenching method has been used for the preparation of Co_2CrAl and $Co_2Cr_{0.6}Fe_{0.4}Al$ ribbon samples. The Curie temperatures have been determined from magnetization measurements being 378 K for Co_2CrAl and much above 400 K for $Co_2Cr_{0.6}Fe_{0.4}Al$. The spin polarization parameter P_0 of the studied samples has been estimated from point-contact Andreev reflexion spectroscopy measurements. In pure Co_2CrAl $P_0 = 0.5{-}0.9$, and in the case of $Co_2Cr_{0.6}Fe_{0.4}Al$ $P_0 = 0.4{-}0.9$. Hence, it is shown that Fe substitution of Cr in $Co_2Cr_{1-x}Fe_xAl$ Heusler alloys at a concentration of $x = 0.4$ significantly increase the Curie temperature without marked influence on the spin polarization.

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1. Introduction

The emergence of spintronics gained particular significance in the research of new materials with controlled magnetic properties and spin polarization. The Heusler compounds contain a lot of systems with perspective application potential in the field of spintronics. The typical example of such a Heusler metal is Co_2CrAl [1]. It reveals almost 100% spin polarization with a Curie temperature $T_c = 380$ K. However, real room temperature applications require much higher Curie temperatures. It is well known that the increased Fe substitution in $Co_2Cr_{1-x}Fe_xAl$ leads to the increase of the Curie temperature up to $T_c = 1170$ K at $x = 1$ [2]. Unfortunately, this effect is followed by a rapid suppression of the spin polarization down to 30% [2]. The recent paper is dealing with the influence of Fe substitution on the Curie temperature and spin polarization in $Co_2Cr_{1-x}Fe_xAl$ ($x = 0$ and 0.4) systems produced by melt-spinning method. This method offers two desirable advantages: avoiding of thermal annealing to reach a homogeneous single-phase alloy and production of an alloy with well-defined anisotropy, which is important property for promising spintronics applications [3, 4].

2. Experiment

Half metallic ribbons of the Heusler alloys of Co_2CrAl and $Co_2Cr_{0.6}Fe_{0.4}Al$ have been prepared using melt-spinning method. First, we investigated the magnetic properties of the ribbons. The Curie temperatures of the samples have been determined from magnetization measurements (see Fig. 1), performed on MPMS system of Quantum Design in the temperature range from $T = 10$ K to 400 K in an applied field of 1 T. The $T_c = 378$ K of the Co_2CrAl ribbon (open symbols) has been estimated from the minimum of the dM/dT curve. In the case of $Co_2Cr_{0.6}Fe_{0.4}Al$ (solid symbols) T_c is much higher, far above our experimental possibilities.

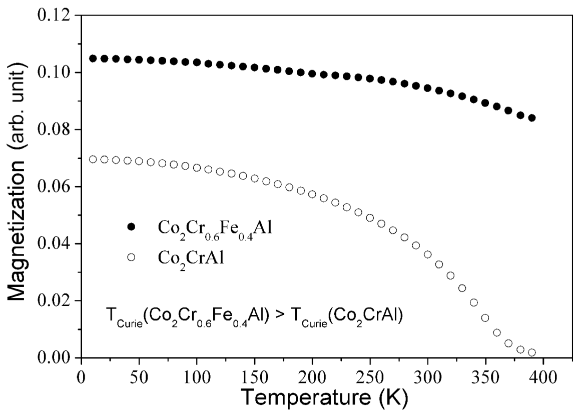

Fig. 1. Temperature dependence of the magnetization curves.

Point-contact Andreev reflection spectroscopy (PCAR) measurements have been used for the study of spin polarization. The experiments have been performed in a special point-contact approaching system, which allows measurements from $T = 1.3$ K up to room temperatures. The ballistic point-contacts (PC) were prepared *in situ* at low temperatures by pressing a superconducting Nb tip on the freshly polished surface of the sample. The PC spectra i.e. the differential conductance as a function of the applied voltage on PC's have been measured applying a standard lock-in method. The charge transfer through a PC between

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a superconductor and a spin polarized metal is realized in two independent channels of the normal current and spin polarized current. The Andreev reflection process is suppressed proportionally with the level of spin polarization. The spin polarization parameter P_0 can be determined from fitting to the BTK model, modified for spin polarized transport (MBTK), where the spin polarization parameter P_0, the superconducting energy gap Δ, the energy smearing Γ and the barrier strength Z are the fitting parameters [5, 6].

3. Results and discussion

The PCAR spectroscopy measurements have been realized on different Co_2CrAl and $Co_2Cr_{0.6}Fe_{0.4}Al$ samples with a superconducting Nb tip. The energy gap of the Nb tip $\Delta(0) = 1.53$ meV has been determined from PCAR spectra, measured on PC between Nb and a pure metal (Cu) at $T = 1.5$ K via fitting to the standard BTK model [6]. This $\Delta(0)$ of pure Nb has been used in the fitting procedure to the determination of the spin polarization parameter P_0 of our samples. The PCAR spectra measured on Co_2CrAl and $Co_2Cr_{0.6}Fe_{0.4}Al$ samples revealed different contact resistances in dependence on the pressing force of the Nb tip. The best spectral resolution have been obtained in junctions with $R = 10-30\ \Omega$ contact resistances. The majority of these contacts revealed high transparencies with low values of the barrier strengths (Z below 0.4). Typical PCAR spectra, measured at PC resistances $R = 12\ \Omega$ (Nb-$Co_2Cr_{0.6}Fe_{0.4}Al$ at temperature $T = 1.5$ K) and 25 Ω (Nb-Co_2CrAl at temperature $T = 1.23$ K) are shown in Fig. 2 with the solid lines. All spectra have been normalized to their value at the bias voltage $U = 15$ mV, far above the value of the superconducting energy gap and fitted to the MBTK model. At the fitting the known value of the Nb gap $\Delta(0) = 1.53$ meV has been fixed and the values of Γ, Z and P_0 have been varied as the fitting parameters.

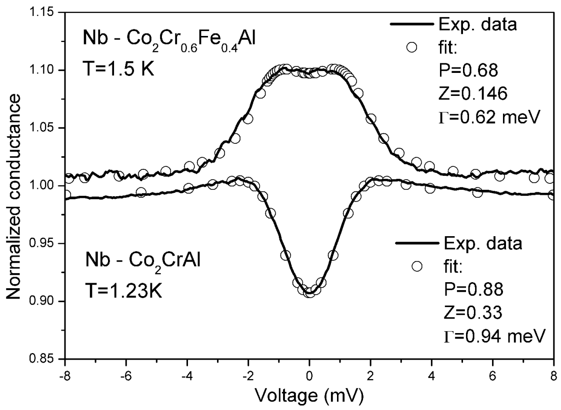

Fig. 2. Normalized PCAR conductance curves (solid lines): Nb-$Co_2Cr_{0.6}Fe_{0.4}Al$ point-contact spectrum at a temperature $T = 1.5$ K — upper curve, Nb-Co_2CrAl at 1.23 K — lower curve. The open symbols plot the fitting curves to the MBTK model. The lower curve is vertically shifted for the clarity.

The model fits our curves in a good agreement with the parameters $P_0 = 0.68$, $Z = 0.146$ and $\Gamma = 0.62$ meV for Nb-$Co_2Cr_{0.6}Fe_{0.4}Al$ and $P_0 = 0.88$, $Z = 0.33$ and $\Gamma = 0.94$ meV for Nb-Co_2CrAl. The fitting curves are shown in Fig. 2 with open symbols. PCAR spectra measured on both sets of the studied samples revealed high range of the spin polarization parameter. In pure Co_2CrAl $P_0 = 0.5-0.9$, and in the case of $x = 0.4$ Fe doped samples $P_0 = 0.4-0.9$. The obtained high dispersion of the P_0 values can be connected with local chemical and structural instabilities in both systems. Our samples have been prepared by melt-spinning method, where due to rapid cooling a local disorder of the Heusler lattice can be expected. Also, the local interchange of Co atoms with Al or Cr is feasible. Both these effects can strongly influence the spin polarization of quasiparticles.

4. Conclusions

The influence of Fe substitution on the Curie temperature and the spin polarization parameter have been studied in Co_2CrAl Heusler alloys. The Curie temperatures of $Co_2Cr_{1-x}Fe_xAl$ melt-spun ribbon have been determined to be 378 K for $x = 0$ and well above 400 K for $x = 0.4$. The spin polarization parameters have been estimated from low temperature PCAR measurements. In pure Co_2CrAl $P_0 = 0.5-0.9$, and in the case of $x = 0.4$ Fe doped samples $P_0 = 0.4-0.9$. Our results show that Fe substitution of Cr in Co_2CrAl Heusler alloys at a concentration of $x = 0.4$ significantly increase the Curie temperature without expressive influence on the spin polarization.

Acknowledgments

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