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Magnetism and electrical transport in $Fe_{0.9}TM_{0.1}Si$, TM = Co, Rh, Ru

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Abstract

Our comparative study of magnetic and transport properties of $Fe_{0.9}Co_{0.1}Si$, $Fe_{0.9}Rh_{0.1}Si$, and $Fe_{0.9}Ru_{0.1}Si$ indicates that the ferromagnetism previously observed in $Fe_{0.9}Co_{0.1}Si$ is not due to localized magnetic moments residing on the Co atoms. It is rather the metallicity of the system which provides the formation of a ferromagnetic state.

Keywords: Doped FeSi; Kondo insulator; Magnetism; Transport

$Fe_xCo_{1-x}Si$ alloys with $0.2 \leqslant x \leqslant 0.95$, which form solid solutions crystallizing in the same cubic B20 structure as the strongly correlated semiconductor FeSi, exhibit a field induced transition from a helimagnetic to a ferromagnetic state [1]. The controversy about the localized or itinerant character of the ferromagnetic state has up to now not definitively been settled. We attempt to contribute to a better understanding of this point by investigating polycrystalline samples of the compounds $Fe_{0.9}TM_{0.1}Si$, with TM = Co, Rh, and Ru. While a localized moment may be expected to reside on the 3d Co sites, this is not anticipated for the 4d components Rh and Ru.

The results of our magnetic measurements of $Fe_{0.9}Co_{0.1}Si$ are in overall agreement with those previously published [1]. Isothermal magnetization curves between 2 and 35 K plotted as M^2 vs. H/M (Arrott plots) display, for $H \geqslant 40$ kOe, linear behaviour with an only slightly temperature dependent slope, in agreement with the Edwards–Wohlfarth model for weak itinerant ferromagnets [2]. Qualitatively similar behaviour is encountered also for $Fe_{0.9}Rh_{0.1}Si$ and $Fe_{0.9}Ru_{0.1}Si$. The extrapolated $H = 0$ moment is identified as the spontaneous magnetization M_s. A phenomenological description of the temperature dependence of M_s with $M_s = M_s(T=0)(1 - T/T_C)^n$ is possible over the entire range $0 < T < T_C$ with $M_s(T=0) = 0.94\mu_B$/Co, $0.54\mu_B$/Rh, and $0.06\mu_B$/Ru, with $n = 0.38$, 0.36, and 0.8, and with the Curie temperatures $T_C = 24$, 13, and 14 K, for $Fe_{0.9}Co_{0.1}Si$, $Fe_{0.9}Rh_{0.1}Si$, and $Fe_{0.9}Ru_{0.1}Si$, respectively. The normalized data $M_s/M_s(T=0)$ together with the best fits are plotted in Fig. 1 as a function of temperature T. The similar results for $Fe_{0.9}Co_{0.1}Si$ and $Fe_{0.9}Rh_{0.1}Si$ strongly disfavour the idea of magnetic moments being localized on the Co sites. The much smaller absolute values of M_s and the large value of n for the less conducting $Fe_{0.9}Ru_{0.1}Si$ point to the importance of metallicity for the formation of the ferromagnetic state.

The temperature dependence of the electrical resistivity ρ of $Fe_{0.9}Co_{0.1}Si$ and $Fe_{0.9}Rh_{0.1}Si$ in different magnetic fields is shown in Fig. 2. The magnetoresistance $MR = (\rho(H) - \rho(0))/\rho(0)$ is negligible at high temperatures but reaches approximately 18% at 1 K. The increase of MR sets in at a higher temperature for $Fe_{0.9}Co_{0.1}Si$ than for $Fe_{0.9}Rh_{0.1}Si$, in agreement with $T_C^{Co} > T_C^{Rh}$, pointing to a non-negligible interplay of magnetism and transport in these compounds. The temperature dependence of the electrical resistivity

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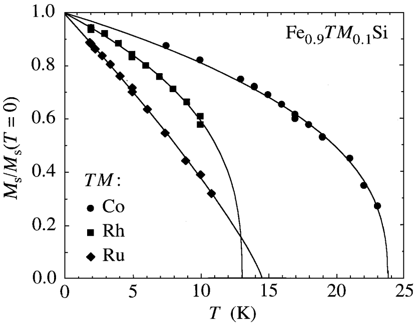

Fig. 1. Normalized spontaneous magnetization $M_s/M_s(T=0)$ vs. temperature T.

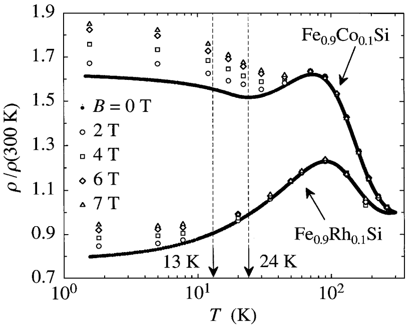

Fig. 2. Temperature dependence of the normalized electrical resistivity $\rho/\rho(300K)$ measured in different magnetic fields.

of $Fe_{0.9}Ru_{0.1}Si$ is similar to the one of pure FeSi [3], in agreement with Ru not acting as a dopant in FeSi. Most surprising is, however that at low temperatures pure FeSi and $Fe_{0.9}Ru_{0.1}Si$ saturate to approximately the same very low conductivity value, indicating that this well known saturation [3] is not defect or impurity controlled but a genuine property of FeSi.

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