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Studies of the incommensurate structures of B20 alloys

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Abstract

The B20 structure is capable of supporting a long-range antiferromagnetic static spin density wave, and for transition metal silicides and germanides it has previously been found that the Néel temperatures, high field magnetizations and magnetic propagation vectors q all suggest a dependence on an electron concentration parameter. This relationship has yet to be confirmed.The present measurements from mixed alloys in the series CrSi/FeSi, CrSi/MnSi, CrSi/CoSi. MnSi/CoSi and CrGe/FeGe have extended the electron concentration range previously covered and the results support the suggested dependence. The q values are practically independent of temperature and the CrGe/FeGe display high Néel temperatures comparable with that of FeGe. © 1998 Elsevier Science B.V. All rights reserved.

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Metallic alloys with the B20 ($P2_13$) crystal structure which lacks inversion symmetry have been found to support an antiferromagnetic static spin density wave at low temperatures probably through the operation of a Dzyaloshinskii–Moriya-type interaction [1]. The periods of the magnetic structures observed are generally long and small-angle neutron scattering is an ideal technique for studying such systems. The variations with composition of the Néel temperatures, high-field magnetisations and propagation vectors q have previously been studied for a few such alloys and the similar form of all these has suggested a dependence on d-electron band filling [1, 2]. Such a relationship has not yet been finally established and we have therefore fabricated a wide range of polycrystalline intermetallic silicides and germanides which span the electron concentration ranges of interest. We report the results of magnetization and SANS measurements carried out at Salford and RISØ, respectively.

Alloys have been prepared by argon arc melting from the mixed series CrSi/FeSi, CrSi/MnSi, CrSi/CoSi, MnSi/CoSi and CrGe/FeGe. The alloys were remelted four or five times to ensure homogenisation, crushed into powder form and heat-treated in sealed ampoules. The silicides were heat treated at 825°C for 24 h, quenched into water, and subsequent X-ray analysis indicated the B20 crystal structure, The germanides showed a two-phase structure after such treatment and it was necessary to heat these at 500°C for 1 week before quenching to produce single-phase alloys. Magnetization measurements in fields up to 12 T were carried out on the Manchester/Salford VSM over the range 4–300 K. The SANS measurements were performed in the neighbourhood of the Néel temperatures over the low q range up to 0.10 $Å^{-1}$.

Typical results for the magnetization measurements as a function of field for the alloy $Mn_{0.95}Cr_{0.05}Si$ exhibiting long-range antiferromagnetism are shown in Fig. 1. In the antiferromagnetic regime the magnetization increases linearly with field before levelling off above a critical field ~ 0.5 T. The variation with temperature of the intercept obtained from extrapolation of the high-field part of the Arrott plots to zero field enabled the Néel temperature of 16.2 K to be determined. For the silicides the Néel temperatures were all below ~ 40 K, whereas for the germanides they were ~ 230 K, comparable to that observed for FeGe; see Table 1.

The SANS data were corrected by the subtraction of a high-temperature spectrum and the satellite occurring

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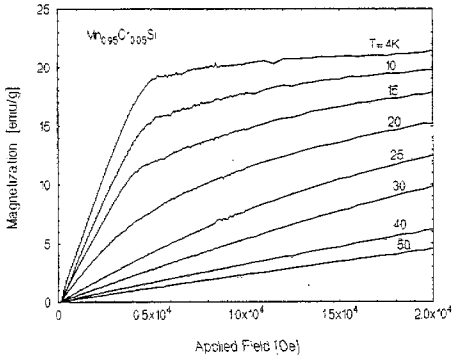

Fig. 1. Magnetization versus field for $Mn_{0.95}Cr_{0.05}Si$ in the vicinity of its Néel temperature.

Table 1
Néel temperatures of the alloys examined

Alloy composition	3d-electrons/f.u.	Néel temperature (K)
$Mn_{0.95}Cr_{0.05}Si$	4.95	16.2
$Mn_{0.9075}Cr_{0.0925}Si$	4.9075	6.2
$Mn_{0.85}Cr_{0.15}Si$	4.85	Below 4.2
$Mn_{0.95}Fe_{0.05}Si$	5.05	16.4
$Mn_{0.90}Fe_{0.10}Si$	5.10	10.7
$Mn_{0.86}Fe_{0.14}Si$	5.14	Below 4.2
$Mn_{0.95}Co_{0.05}Si$	5.10	10.8
$Mn_{0.90}Co_{0.10}Si$	5.20	~ 4.5135
$Fe_{0.85}Cr_{0.15}Ge$	5.70	~ 230
$Fe_{0.75}Cr_{0.25}Ge$	5.50	

at low q was found to be prominent and well defined. The radial average of the magnetic intensity was fitted to a Lorentzian. For comparison a powdered MnSi sample was examined and the corresponding q-value agreed with that previously published [3]. The results for a MnCr/CrSi sample shown in Fig. 2 indicate that $|q|$ is practically independent of temperature and of the same order of magnitude as that observed for MnSi with $|q| \sim 0.035$ Å^{-1} (corresponding to a period of ~ 180 Å). For the FeGe/CrGe samples we found high Néel temperatures and modulation vectors of magnitude about 0.01 Å^{-1} corresponding to a period of 630 Å, comparable with that seen for pure FeGe [4]. The FeSi/MnSi series produced results which parallel those seen for FeSi/CoSi [2, 5].

An overall view of the results for the variation of $|q|$ with 3d-electron concentration is shown in Fig. 3 (assuming for MnSi a value of 5). Beille et al. [5] have interpreted the sinusoidal variation in FeMnSi alloys in terms of the electron concentration dependence of the DM interaction as the d-band is filled [6]. Our results so far are consistent with such a dependence but the completion of this diagram requires the examination of alloys covering the range shown by the dotted line in Fig. 3 and this work is currently in progress.

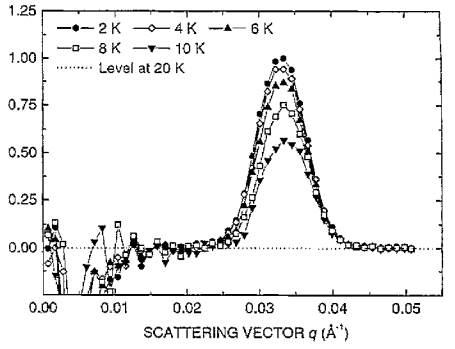

Fig. 2. SANS radially averaged intensity versus momentum transfer q for $Mn_{0.95}Cr_{0.05}Si$. The structure at very low q is most probably due to an inadequate background correction for the sample holder at different temperatures.

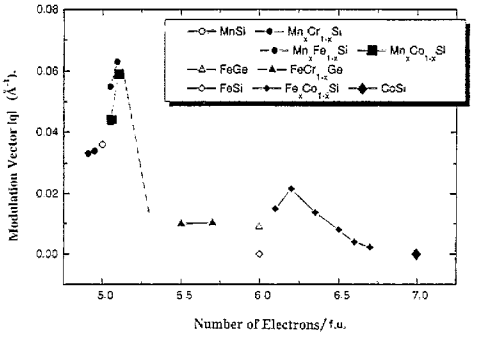

Fig. 3. Modulation vector q versus number of 3d electrons per formula unit for the B20 alloys: (●) MnSi/CrSi (present work) and MnSi/FeSi (present work); (▲) FeGe/CrGe (present work); (■) MnSi/CoSi, [2]; (○) MnSi [3]; (◆) FeSi/CoSi [2, 5], FeSi [7], FeGe [3].

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