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CRITICAL PHENOMENA OF ANISOTROPIC SPIN GLASS ZnMn

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Abstract. – Longitudinal (|| c) and transverse (⊥c) nonlinear susceptibilities have been measured on the Ising-type ZnMn spin glass. The critical exponents obtained from the scaling hypothesis depend on the anisotropy/exchange ratio, which can suggest a crossover effect from Heisenberg to Ising spin glasses in real RKKY systems.

Critical behaviors of the nonlinear susceptibility in spin glasses have been extensively studied by various experiments and numerical calculations. Recently, Yeshurun and Sompolinsky [1] have shown that the nonlinear susceptibility in CuMn is affected by the presence of random Dzyaloshinsky-Moriya (DM) anisotropy induced by Au impurity and suggested that there exists an anisotropy-induced crossover effect from Heisenberg to Ising behavior. More detailed investigations by Courtenay et al. [2] for CuMn and AgMn alloys have defined two sets of critical exponents: Ising type in the range of small field and temperature near $T_g$ and Heisenberg type in high field and temperature far from $T_g$. Numerical studies also have shown the importance of the anisotropy. It was suggested that the spin-glass transition does not occur at finite temperature for a three-dimensional (3D) Heisenberg model [3] but that weak anisotropic interactions induce a spin-glass transition at $T_g \neq 0$ [4]. Recently, we have studied the uniaxially anisotropic spin glass ZnMn [5] over a wide range of the Mn impurity concentration c. Since in ZnMn it is possible to control the ratio of the anisotropy to the variance of the random exchange interaction ($D/J$) by changing the Mn impurity concentration, systematic study for the effect of the uniaxial anisotropy $D$ on the spin-glass critical behavior could be done in this system.

Therefore, we have performed detailed measurements of the longitudinal (|| c) and transverse (⊥c) ac susceptibilities $\chi$ || and $\chi$ ⊥ of ZnMn single crystal at various fields parallel to the ac field. As we previously reported, ZnMn with 270, 390 and 600 ppm Mn show the two successive paramagnetic (P) – longitudinal (L) – mixed longitudinal and transverse (LT) spin glass transitions and the Ising like P-L transition only occurs for $c \leq 150$ ppm. The nonlinear part of the susceptibility is extracted from $\chi$ ||NL = $\chi$ || (0) – $\chi$ || $H$) || in the longitudinal direction and $\chi$ ⊥NL = $\chi$ ⊥ (0) $\chi$ ⊥ (H) ⊥ in the transverse direction as shown in figure 1 for ZnMn (270 ppm). Here, we assume from the maximum of $\chi$ || and $\chi$ ⊥ that the first P-L transition occurs at $T_g$ || = 0.53 K and the second L-LT transition occurs at $T_g$ ⊥ = 0.09 K. The obtained temperature and field dependence of the nonlinear susceptibility for the two directions is independently analysed in the framework of the scaling hypothesis: $\chi_{NL}/\tau^\beta = f (H^2/\tau^{\beta+\gamma})$, where $\tau$ is a reduced temperature ($T - T_g)/T_g$, $\beta$ and $\gamma$ are a critical exponent. Figure 2 is the double logarithmic scaling plot of $\chi_{NL}/\tau^\beta$ vs. $H^2/\tau^{\beta+\gamma}$ for ZnMn with 270 ppm Mn in the longitudinal and transverse directions respectively, by using the best fitted value of $\beta = 1.0 \pm 0.2$ and $\gamma = 3.0 \pm 0.3$ for $\chi$ ||NL and $\beta = 1.0 \pm 0.2$ and $\gamma = 2.7 \pm 0.3$ for $\chi$ ⊥NL. The scaling plot by using the mean-field value of $\beta = \gamma = 1$ is also shown in figure 2 for comparison. We have done the same scaling analysis for ZnMn with 150, 390 and 600 ppm Mn. We found that the best fitted value of $\beta$ is in the range of $\beta = 1.0 \pm 0.2$ for all the present samples in the longitudinal and transverse directions. The $\gamma$ value is dependent on the Mn concentration. The obtained critical exponent $\phi = \beta + \gamma$ is shown as a function of $D/J$ in figure 3. Here, we use the $D/J$ value estimated previously in reference [5].

From figure 3, it is found that the $\phi$ value for the longitudinal and transverse directions increases with increasing the relative anisotropy $D/J$ and that $\phi ||$ is slightly larger than $\phi \perp$ at any $D/J$ ratio where two successive transitions occur. We can roughly estimate the value of the “Heisenberg” limit from the extrapolation of $D/J \rightarrow 0$ as $\beta_H = 1.0 \pm 0.2$, $\gamma_H = 1.8 \pm 0.3$, and therefore $\phi_H = 2.8 \pm 0.4$ for both direc-
positions on the assumption of $\phi || = \phi_\perp$ in this limit as shown in figure 3. These “Heisenberg” values should be compared with the results of typical metallic spin glasses such as CuMn, AgMn and AuFe. The recent precise nonlinear magnetization measurements [2] for AgMn and CuMn show the critical exponents $\gamma = 2.2$ and $\beta = 1$ ($\phi = 3.2$) in the range of temperature near $T_s$ and small magnetic field. Similar values of $\beta$ and $\gamma$ are reported in recent nonlinear susceptibility measurements [6] on AuFe and AgMn in the same range of temperature and field. The present extrapolated values $\beta_H$ and $\gamma_H$ for ZnMn are obtained also in the similar range. It is possible that the present $\beta_H$ and $\gamma_H$ already include the effects of the DM or dipole anisotropy and that they are not pure Heisenberg exponents.

Thus, we can conclude that the critical behavior of ZnMn in the limit of $D / J \to 0$ (high Mn concentration limit) is the same as that of CuMn, AgMn and AuFe in the range of small field and temperature near $T_s$. Increasing the relative anisotropy $D / J$, we find that $\phi$ for the longitudinal direction increases and seems to approach $\phi || \sim 4.6$ for $D / J > \sim 1$, where the Ising behavior is well observed. The $\beta$ value remains nearly constant ($\sim 1.0$). We estimate the “Ising” limit values as $\beta_L = 0.9 \pm 0.2$, $\gamma_L = 3.7 \pm 0.5$, and therefore $\phi_L = 4.6 \pm 0.7$. It should be noted that these values are slightly larger than the exponents calculated in 3D short-range Ising spin glass, but seem consistent within the error bars [7]. The intermediate value of the exponents between the two limits arises from the crossover effect due to the uniaxial anisotropy. It is interesting to point out that $\phi$ for the transverse direction was also found to increase as a function of $D / J$, though $\phi_\perp$ is always smaller than $\phi ||$. However, since $T_s ||$ becomes

Jose to 0 K with the increase of $D / J$, we can not obtain definite conclusion for the critical exponents in the transverse direction.

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