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OBSERVATION OF MAGNETIC DOMAIN IN A FERROMAGNETIC SERIES $K_2Cu_1 - xCo_xF_4$ BY FARADAY EFFECT AT LOW TEMPERATURES

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Abstract. — Magnetic Domain observation on randomly mixed series $K_2Cu_{1-x}Co_xF_4$ is made by applying Faraday effect at low temperatures. A stripe shaped domain pattern is observed for the compounds with $x \approx 0.02$. A drastic decrease of domain width is found in the concentration range $x \approx 0.01$ and the origin is discussed.

Conventional methods of directly observing magnetic domain provide us an interesting way to examine the non-uniform ordered structure which may be realized in some two-dimensional (2D) isotropic or frustrated random magnets. Some trials have been reported e.g. for 2D XY-like ferromagnet $K_2CuF_4$ by Kleeman et al. [1] and for spin glass like mixed magnets $Eu_xSr_{1-x}S$ by Dillon et al. [2].

We have also investigated the ordered state of $K_2CuF_4$ and then a series of randomly mixed compounds with isomorphous Heisenberg (H) like antiferromagnet $K_2MnF_4$ [3], in order to examine the effect of random impurity on ordering of regular system and to see, if possible, how the modulated non-uniform ordered structure is induced and changes to a spin glass like phase with mixing concentration [4, 5]. A stripe shaped domain structure was observed in $K_2Cu_{1-x}Mn_xF_4$ for $x \approx 0.1$. Any distinguishable change of domain shape has not been noticed in the concentration range and the domain pattern disappeared perfectly in the compounds with $x \approx 0.001$ [3] as shown in figure 1. As a possible origin, an effective decrease of interplane interaction due to probably a local frustration effect was suspected. However, it was excluded experimentally because almost the same change of domain width was found also for a simple dilute series $K_2Cu_{1-x}Zn_xF_4$ [3]. In this work, we investigate a series of randomly mixed compounds with isomorphous Ising (I) like antiferromagnet $K_2CoF_4$, intending to examine the effect of anisotropy on the ordered structure and to get some information on the above mentioned rapid decrease of domain width with mixing, if possible.

The experimental apparatus by Faraday effect is constructed, especially for the use at very low temperatures [3]. A special cryostat of pyrex glass double dewer is used, which has a longitudinal path-way of light. The domain pattern is directly observed by a polarized microscope through optical windows at the bottom of the cryostat. Each specimen used in this experiment is cut out from transparent single crystals in the shape of thin orthorhombic plate of $a_1$ ($\approx 1$ mm) $\times a_p$ ($\approx 6$ mm) $\times c$ ($\approx 2$ mm) with the $ac$ plane on the $a_p \times c$ surface perpendicular to the incident light beam axis $z$ ($// a_1$). Two kinds of specimens are prepared. One is of the in-plane easy [110] direction along $z$ axis and the other is of the [100] direction.

A stripe shaped magnetic domain is observed for $K_2Cu_{1-x}Co_xF_4$ of $x \approx 0.02$. Figure 2 shows the ob-

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Fig. 1. — Concentration dependence of domain width $D$ (Ref. [3]).

Fig. 2. — The picture of stripe domain pattern observed for $K_2Cu_{1-x}Co_xF_4$ at 2 K. The domain line appears perpendicular to the $c$ axis. Scale in the picture is $100 \mu$m/div. and applicable also for $x = 0$. 

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served domain patterns in the long range ordered state below $T_c$ of the specimens with [110] along $z$ axis. The domain width decreases with increasing $x$. The apparent concentration limit $x \sim 0.02$, which is much smaller than $x \sim 0.1$ for $K_2Cu_{1-x}Mn_xF_4$ or $K_2Cu_{1-x}Zn_xF_4$, has not any essential meaning in this case but is only due to the rapid shift of $T_c$ to a lower temperature with increasing $x$. We have also observed the domain structure of the specimen with [100] along $z$ axis. No essential change is observed for the specimen from that with [110] along $z$ axis, except that the domain width for the former is a little larger than for the latter as shown in figure 3 where the concentration dependences of domain width for both the specimens are summarized. A remarkable here is that a drastic decrease of domain width is found also for the present series $K_2Cu_{1-x}Co_xF_4$ in the same concentration range $x \leq 0.01$ as for $K_2Cu_{1-x}Mn_xF_4$ or $K_2Cu_{1-x}Zn_xF_4$, which is not easily understood.

For qualitative or semiquantitative discussion, the domain width $D$ may be estimated, based on a probable model for the present stripe shaped domain structure with reduced domains on the $ac$ plane, as

$$D = \left( \frac{K_1}{K_0} \right)^{1/2} \times \alpha(\tau) \times a_1$$

(1)

where $K_1$ and $K_0$ are the in-plane and the out-of-plane anisotropy energy, $\alpha(\tau)$ is a factor determined by the ratio $\tau$ of $180^\circ$ wall energy $\sigma_{180}$ to the wall energy between the main and the reduced domain $\sigma$, and $a_1$ is the sample thickness. The factor $\alpha$ is a monotonic increasing function of $\tau$ and changes from zero to one with increasing $\tau$. For $K_2CuF_4$, the obtained width $D \approx 16 \mu m$ can be reasonably estimated by using the already estimated values of $K_1$ and $K_0$ [6] and assuming tentatively $\tau \sim 1$ or $\sigma_{180} \sim \sigma'$. For $K_2Cu_{1-x}Co_xF_4$, the effective in-plane anisotropy field $H_A$, which is about 0.1 Oe for $x = 0$, increases rapidly with increasing $x$ (several hundred Oe for $x = 0.01$), while the out-of-plane anisotropy field is almost unchanged with $x$ in this concentration range [7]. Therefore, we may simply expect an increase of domain width with $x$ based on equation (1), which is quite contrary with the observed rapid decrease. So, if the equation (1) is applicable, the origin of the decrease of $D$ with $x$ should be attributed to some drastic decrease of $\tau$ or relative increase of $\sigma'$ to $\sigma_{180}$. Such an increase of $\sigma'$ may suggest a remarkable change of magnetostrictive nature, since $\sigma'$ is essentially concerned with the strain energy in the reduced domain.

Meanwhile, the concentration dependence of $D$ near the dilute limit $x \leq 0.01$ for $K_2Cu_{1-x}Co_xF_4$ is not so much different from that for $K_2Cu_{1-x}Mn_xF_4$ in which the change of anisotropy with $x$ is much smaller than that for the former. Now, the concentration dependence of $D$ looks quite independent of the kind of impurity, which may imply that a quite different mechanism is responsible for the present domain structure formation.

Fig. 3. – Concentration dependence of domain width $D$. Data for $K_2Cu_{1-x}Mn_xF_4$ is also plotted for a reference.

For qualitative or semiquantitative discussion, the domain width $D$ may be estimated, based on a probable model for the present stripe shaped domain structure with reduced domains on the $ac$ plane, as

$$D = \left( \frac{K_1}{K_0} \right)^{1/2} \times \alpha(\tau) \times a_1$$

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where $K_1$ and $K_0$ are the in-plane and the out-of-plane anisotropy energy, $\alpha(\tau)$ is a factor determined by the ratio $\tau$ of $180^\circ$ wall energy $\sigma_{180}$ to the wall energy between the main and the reduced domain $\sigma$, and $a_1$ is the sample thickness. The factor $\alpha$ is a monotonic increasing function of $\tau$ and changes from zero to one with increasing $\tau$. For $K_2CuF_4$, the obtained width $D \approx 16 \mu m$ can be reasonably estimated by using the already estimated values of $K_1$ and $K_0$ [6] and assuming tentatively $\tau \sim 1$ or $\sigma_{180} \sim \sigma'$.

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