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ABSTRACTS

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pound with anftiferromagnetic intra plane and ferromagnetic inter-plane couplings[3]. For $J_\perp$=0, the double-layered spin system reduces to layers of non-interacting square planar lattices. Block of completely coupled 5 spins in square planar geometry is the building block of 2D square lattice of J_1-J_2-J_3 model[4]. It is widely accepetd in the literature that in absence of $J_\perp$ and J_3(the third neighbor), the J_1-J_2 spins in a plane exist in (π,π) phase for J_2/J_1 < 0.4 and in $(0,\pi)$ phase for J_2/J_1 > 0.6. For intervening coupling regime 0.4<J_2/J_1<0.6, the system exist in paramagnetic phase[4 and references therein]. Our model calculation on 5+5 spin systems with Hilbert Space dimensionality of 1024, indeed shows (π,π) phase for J_2/J_1<0.25 and $(0,\pi)$ phase for J_2/J_1>1. In the intervening coupling regime the system exists in co-existing phases. This variation in our exact diagonalization results is possibly due to the small size of 5-spin square planar lattice. Calculation on two-layered 18 spin system with 9 spins in each layer, is in progress and will be reported soon. As we introduce $J_\perp$, the co-existing phases vanish and long range order is established in the system in agreement with Mermin-Wagner theorem.

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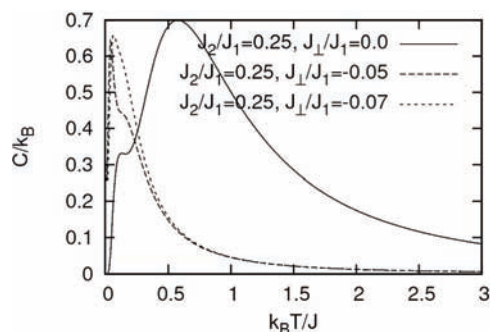
Specific Heat for 5+5 layered system from exact diagonalization using low-lying 16 eigenstates. Solid line: Plot of a single 5-spin square planar system. Dashed line: Plot of a two layered system for ferromagnetic inter-layer coupling in agreement with experimental result in[2]. Dotted line: With further increase in inter-layer coupling, kink in specific heat curve at low-temperature disappears.

EX-13. Effect of Y-doping on the spin entropy in Ca3-xYxCo4O9+δ.D. Zhang[1,2], Z. Wang[1,3], G. Tang[4], L. Qiu[1], D. Zhang[5] and Y. Du[1,2]*1. National Laboratory of Solid State Microstructures, Nanjing University, Nanjing, China; 2. Jiangsu Provincial Laboratory for NanoTechnology, Nanjing, China; 3. Center for Superconducting Physics and Materials, Department of Physics, Nanjing University, Nanjing 210093, Nanjing, China; 4. Department of Materials Science and Engineering, Nanjing University of Science and Technology, Nanjing, China; 5. Department of Informatics, Linyi University, Linyi, China*

Among the layered cobalt oxides, misfit-layered Ca3-xYxCo4O9+δ, which displays an extraordinary large thermopower, has been considered to be a good candidate for the thermoelectric materials [1]. Up to now, the source of its large thermopower has drawn much attention [2-6]. Many theoretical and experimental studies disclose that the spin entropy is the main source of the large thermopower in these materials [2-5]. In cobalt oxides, the spin entropy contribution to the thermopower depends on not only the spin state of Co ions but also the concentration of Co4+ ion based on the generalized Heikes formula [2]. The substitution of trivalent rare-earth ion R3+ for Ca2+ may adjust the Co4+ concentration. Therefore, the R3+ doping may be a powerful way to improve the spin entropy contribution to the thermopower. In this paper we will report the effects of Y-doping on the spin entropy in Ca3xYxCo4O9+δ based on the magnetothermopower and magnetization

measurements. A strong magnetic-field suppression of the thermopower indicates the emergence of large spin-entropy effect. The magnetothermopower increases with increasing Y doping level, suggesting that Y doping improves the spin entropy of Ca3-xYxCo4O9+δ. The magnetic results confirm that the concentration of Co4+ reduces with increasing Y doping, which results in the enhanced spin entropy. A suitable theoretical model can explain well the enhancement of the spin entropy induced by Y doping.

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EX-14. Spin ordering between sub-lattices in nasicon Li3Fe2(PO4)3 measured by Mössbauer spectroscopy.H. Kim[1], W. Kwon[1] and C. Kim[1]*1. Department of Physics, Kookmin University, Seoul, Republic of Korea*

The nasicon structured α-$Li_3Fe_2(PO_4)_3$ is interesting for its chemical stability and conductivity, which can be suitable as for a cathode material. In this study, we have investigated the hyperfine interaction between two different magnetic sub-lattices in $Li_3Fe_2(PO_4)_3$. $Li_3Fe_2(PO_4)_3$ was prepared by solid-state reaction method and studied by x-ray diffraction (XRD), vibrating sample magnetometer (VSM), and Mö ssbauer spectrometer. The XRD pattern of $Li_3Fe_2(PO_4)_3$ was analyzed by Rietveld refinement method and confirmed the monoclinic structure with space group of $P2_1/n$. The lattice constants of $Li_3Fe_2(PO_4)_3$ were determined to be a_0 = 8.570 Å, b_0 = 12.014 Å, c_0 = 8.616 Å, and γ = 90.511°. In the temperature-dependent zero-field-cooled (ZFC) and field-cooled (FC) magnetization curves from 4.2 to 40 K, $Li_3Fe_2(PO_4)_3$ showed antiferromagnetic behavior below the Né el temperature (T_N = 29.5 K). In the ZFC curve, the magnetization was constant while the temperature increased up to the splitting temperature of two sub-lattices (T_S = 11 K). However, above T_S, the magnetization increased with increasing temperature as shown Fig. 1. In order to investigate the hyperfine interaction through Fe nucleus, Mö ssbauer spectra of the $Li_3Fe_2(PO_4)_3$ was measured at various temperatures from 4.2 to 295 K. The Mö ssbauer spectra below T_S were analyzed by 1-set of six line Lorentzian patterns with the resulting values of H_{hf} = 558 kOe, ΔE_Q = -0.24 mm/s, and δ = 0.45 mm/s at 4.2 K. At temperatures above T_S = 11 K, the spectra consist of two sextets with δ_A = 0.44 mm/s and δ_B = 0.46 mm/s, showing two Fe^{3+} states due to the difference in thermal agitation present at each Fe^{3+} sub-lattice. Moreover, in temperature-dependent magnetic hyperfine curve up to T_N, the decreasing magnetic hyperfine field showed abrupt change in slope at T_S = 11 K. These results suggest that the change of spin ordering in $Li_3Fe_2(PO_4)_3$ is originated from the difference in hyperfine interactions of the localized magnetic Fe^{3+} ions at each of two sub-lattices.

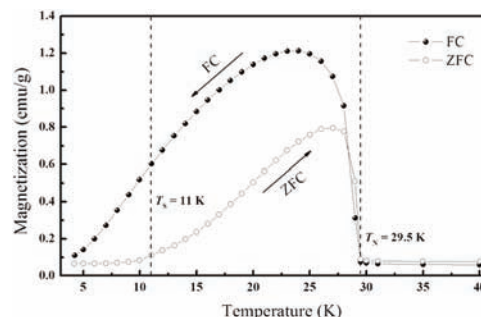[1] L. Vijayan, R. Cheruku, and G. Govindaraj, J. Appl. Phys. 111, 064905, (2012).

Fig. 1. Temperature dependence of magnetization curves under 100 Oe between 4.2 and 40 K.
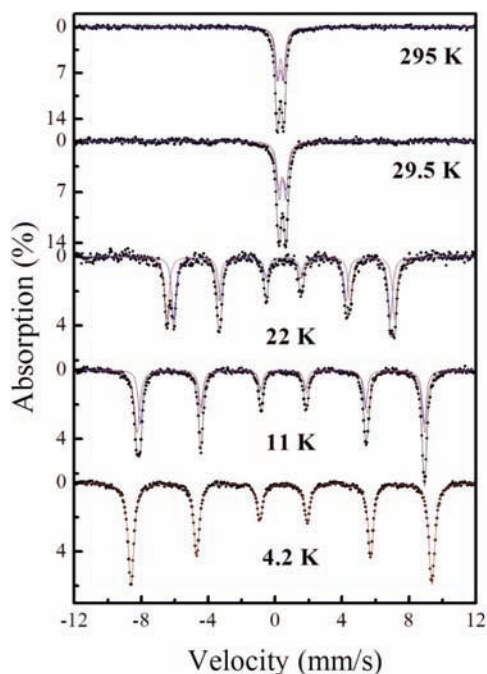
Fig. 2. Mössbauer spectra of $Li_3Fe_2(PO_4)_3$ at various temperatures.

EX-15. Coexistence of incommensurate and commensurate spiral orders and pressure effect on polycrystalline CoCr2O4. *X. Chen*[1], *Z. Yang*[1], *Y. Zhou*[1], *Z. Huang*[2], *L. Ling*[2], *S. Zhang*[2], *Y. Sun*[1,2] and *Y. Zhang*[2,3] *1. Key Laboratory of Materials Physics, Institute of Solid State Physics, Chinese Academy of Sciences, Hefei, Anhui, China; 2. High Magnetic Field Laboratory, Chinese Academy of Sciences, Hefei, Anhui, China; 3. University of Science and Technology of China, Hefei, Anhui, China*

In this paper, we have studied X-ray diffraction (XRD), magnetization under different magnetic fields and pressures, specific heat and Infrared (IR) spectrum of polycrystalline CoCr2O4. At a field of 100 Oe, three sharp transitions can be seen clearly in M-T curve at TC = 94 K, TS = 25 K and TL = 14 K, respectively, in agreement with the coercivity investigations. TC indicates the long-range ferrimagnetic order and TS the long-range incommensurate spiral one as big peaks shown in specific heat. TL denotes an incommensurate-commensurate spiral transition. With increasing magnetic field, TC increases while field up to 4.5 T has no evident influence on the spiral magnetic transitions except for an increasing of the magnitude of magnetization. A thermal hysteresis behavior below TL appears and it is invariant under high field. We tentatively assign this unusual behavior to a martensitic-like transformation resulted from the coexistence and competition of incommensurate and commensurate spiral orders. This can also explain why there is no sign in specific heat linked to the TL transition. Pressure can induce an enhancement of the three critical temperatures at a rate of 0.2 K/kbar. The sensitivity of TC, TS and TL to pressure implies that weak geometrical frustration survives even with a magnetic Co2+ in the tetrahedron. All of the four IR-activated modes show clear shifts below TC, indicative of a spiral-spin-driven structural instability.

EX-16. Size Dependent Ferromagnetic Resonance and Anisotropic Field of Hexagonal Barium Ferrite Powders. L. Chao[1] and *M. Afsar*[1] *1. Electrical and Computer Engineering, Tufts University, Medford, MA*

Several hexagonal barium ferrite (BaFe12O19) powders with different particle sizes were characterized to show the shift of ferromagnetic resonance. The characterization explores the potential relation of resonant frequencies, particle sizes and anisotropic magnetic fields inside the hexagonal ferrite powders. The particle sizes of the barium ferrite powders are located in several different size ranges. Four commercially available barium ferrite powders were purchased from Advanced Ferrite Technology GmbH, Sigma-Aldrich Inc and BGRIMM MAGMAT with particle size 40 nanometer to 100 nanometer, 0.8 micrometer to 1 micrometer, 1 micrometer to 3 micrometer, 3 micrometer to 6 micrometer. A free-space quasi-optical transmittance millimeter wave spectrometer system powered by high-vacuum, high-power backward wave oscillators (BWO) was used to record the transmittance spectra continuously from 30 to 120 GHz. All four barium ferrites exhibits strong absorption in the millimeter wave transmittance spectra due to the natural ferromagnetic resonance. However, the resonant frequencies of the two powders with particle sizes smaller than 1 micrometer shift to lower frequencies obviously. The smaller particle size will lead to lower resonant frequency which shows the magnetic anisotropy reduction. Figure 1 shows the transmittance spectra of the four different size barium ferrite powders. Table 1 shows the ferromagnetic resonant frequency and strength of anisotropic field. To explain the shift of the ferromagnetic resonant frequency, we focus on investigating on the domain size and the thermal flips of magnetic spins. As the barium ferrite particle size becomes smaller than 1 micrometer, the anisotropic field will lose partial alignment because of the weaker constraints to the random magnetic spin flips. Thus, a better explanation of size dependent anisotropic field can be presented by varying the temperature to control the thermal condition inside the particles.
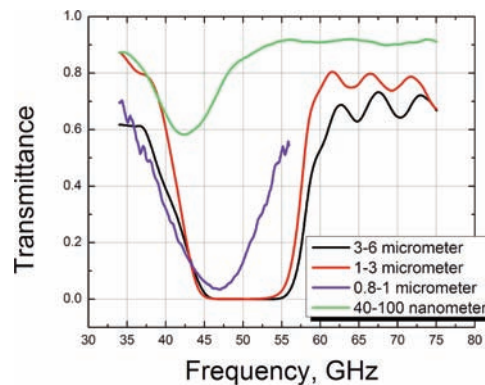
Transmittance spectra of four different particle size barium ferrite powders.

TABLE I
FERROMAGNETIC RESONANT FREQUENCY AND ANISOTROPIC FIELD

Particle size	Resonant frequency f,(GHz)	Anisotropic field H_a (kOe)
3-6 micrometer	49.2	17.6
1-3 micrometer	49.0	17.5
0.8-1 micrometer	46.3	16.5
40-100 nanometer	42.5	15.2