Charge modulation in a one-dimensional orbital chain in electron-doped cubic $SrMnO_3$

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Charge- and orbital-ordering phenomena observed in strongly correlated electron systems have long attracted significant interest, since they often govern the physical properties of the systems, such as transport, optical and dielectric responses. Typical examples are the hole-doped perovskite-type manganites $R_{1-x}A_xMnO_3$ (R and A being rare-earth and alkaline-earth ions, respectively). Around 50% hole doping, in particular, the charge ordering accompanied by the ordering of d_{3x2-r2}/d_{3y2-r2}-type e_g orbitals shows up, which has been intensively investigated so far in terms of the colossal magnetoresistance phenomena. With increasing the hole concentration, the pattern of the charge, orbital and spin ordering successively changes, and finally there appears the one-dimensional d_{3z2-r2}-type orbital ordering with the C-type (interchain) antiferromagnetism (inset to Fig. 1) for ~80% hole doping. In a further hole-doped regime (i.e. the electron-doped $A^{2+}Mn^{4+}O_3$ systems), however, the electronic phase diagram has been still unclear due to the difficulty in synthesizing single crystals.

We have recently developed a new synthesis technique combining the floating-zone and the high-pressure method, and succeeded in obtaining the single crystals of cubic $SrMnO_3$ and its electron-doped analogues. Figure 1 shows an electronic phase diagram for $Sr_{1-x}Ce_xMnO_3$ below 20% electron doping. Surprisingly, electrons with as low concentration as 4% make the ground state d_{3z2-r2}-orbital-ordered insulating phase, while the metallic phase is strongly suppressed (only below 2%). In this study, we have investigated in detail the electronic and lattice properties of such self-organized dilute polarons by performing the single-crystal x-ray diffraction at BL4C, KEK-PF.

Figures 2 show the diffraction patterns around the 115 reflection (in the pseudo cubic setting) for the x=0.05 compound. Below the orbital-ordering temperature (~190 K), the Bragg spot splits into two due to a minor twin domain in the tetragonal phase. With further decreasing the temperature, the diffuse scattering along (δ 0 δ) and (0 δ δ) gradually evolves and results in a broad peak structure with δ~0.08-0.09 at the lowest temperature. This suggests the (short-range) ordering of the carriers (~10%) doped in the d_{3z2-r2} orbital chains. The difference in temperature dependence of the order parameters between the charge and orbital sectors was clearly observed.

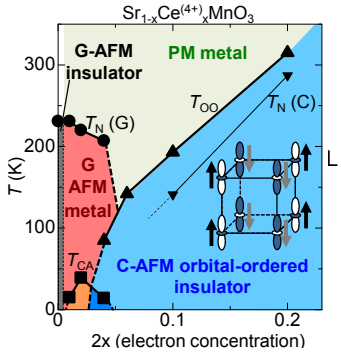

Fig. 1: Electronic phase diagram for $Sr_{1-x}Ce_xMnO_3$ as a function of electron concentration (2x).

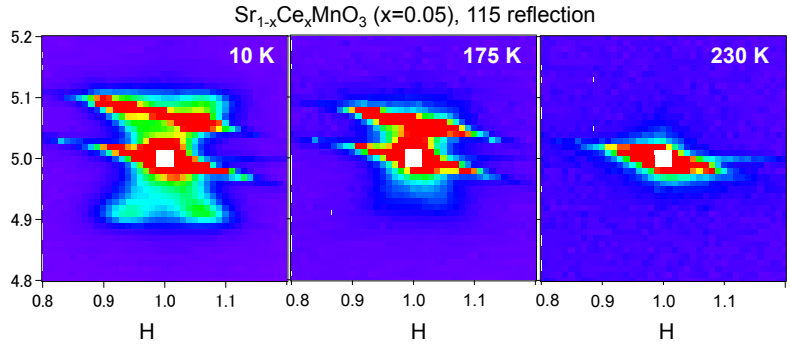

Fig. 2: Contour plots of the diffuse scattering around the (115) Bragg reflection on the (H 1 L) plane at 10, 175, and 230 K. The indices are based on the (pseudo) cubic setting.