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In-situ angle-resolved photoemission study of epitaxial thin films of Mn oxides

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Introduction

Hole-doped perovskite manganese oxides $R_{1-x}A_xMnO_3$, where R is a rare-earth (R = La, Nd, Pr) and A is an alkaline-earth atom (A = Sr, Ba, Ca), have attracted much attention because of their remarkable physical properties such as colossal magnetoresistance and the ordering of spin, charge, and orbitals [1]. In order to understand these interesting properties, it is inevitable to experimentally determine their band dispersions by angle-resolved photoemission spectroscopy (ARPES). In this study we have performed *in-situ* ARPES measurements of epitaxial thin films of $Nd_{0.6}Sr_{0.4}MnO_3$ grown on $SrTiO_3$ (001) substrates and $Pr_{0.6}Ca_{0.4}MnO_3$ grown on $LaAlO_3$ (001) substrates by laser molecular beam epitaxy (laser MBE).

Experimental

The $Nd_{0.6}Sr_{0.4}MnO_3$ and $Pr_{0.6}Ca_{0.4}MnO_3$ thin films were fabricated in a laser MBE chamber connected to a synchrotron radiation photoemission system at BL-2C of the Photon Factory [3]. $Nd_{0.6}Sr_{0.4}MnO_3$ thin films were deposited on $SrTiO_3$ (001) substrates at 1050 ^oC, and $Pr_{0.6}Ca_{0.4}MnO_3$ thin films were deposited on $LaAlO_3$ (001) substrates at 400 ^oC, both at an oxygen pressure of 1×10^{-4} Torr. The fabricated thin films were transferred into the photoemission chamber under vacuum of 10^{-10} Torr. The ARPES spectra were taken at 20 K with the total energy resolution of about 150 meV.

Results and Discussion

Figure 1 shows the second derivatives of ARPES spectra of $Nd_{0.6}Sr_{0.4}MnO_3$ (a) and $Pr_{0.6}Ca_{0.4}MnO_3$ (b) epitaxial thin films, where dark parts correspond to energy bands. In (a), the overall band dispersions are very similar to those of $La_{0.6}Sr_{0.4}MnO_3$ epitaxial thin films [4]. The $e_{g\uparrow}$ bands are located between the Fermi level and -1 eV and show clear dispersions. The $t_{2g\uparrow}$ bands are located between -1 and -2 eV and show weaker dispersions. The O 2p bands are between -3 and -7 eV. In (b), the band dispersions of the O 2p bands are similar to those of $Nd_{0.6}Sr_{0.4}MnO_3$, but those of the Mn 3d bands are very different. The $e_{g\uparrow}$ and $t_{2g\uparrow}$ bands are located between -2 and -3 eV and show a very weak dispersion.

These differences of the band dispersions can be interpreted by considering the magnetic states of these thin films. The present $Nd_{0.6}Sr_{0.4}MnO_3$ thin films on the $SrTiO_3$ (001) substrates are relaxed from the substrates, and show ferromagnetism, which explains that the band dispersions of $Nd_{0.6}Sr_{0.4}MnO_3$ thin films are very similar to those of ferromagnetic $La_{0.6}Sr_{0.4}MnO_3$ thin films. The present $Pr_{0.6}Ca_{0.4}MnO_3$ thin films on $LaAlO_3$ (001) substrates are with compressive strain effects from the substrates. From the phase diagram in Ref. [7], the magnetic structure is expected to be C-type antiferromagnetic states. Since the in-plane nearest neighbour spins are coupled antiferromagnetically in the C-type antiferromagnetism, the in-plane band dispersions are very weak as shown in Fig. 1 (b). It will be interesting to perform further ARPES studies of these materials by making thin films on various substrates.

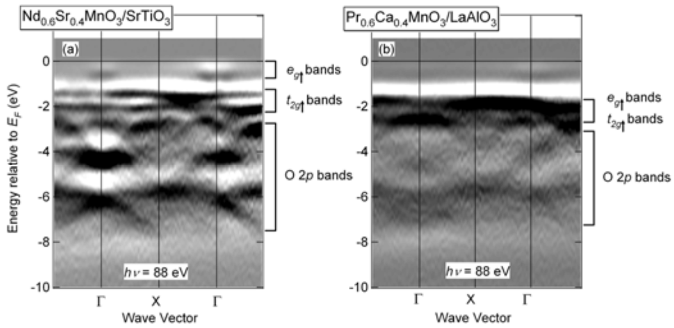

Fig. 1: Second derivatives of ARPES spectra of $Nd_{0.6}Sr_{0.4}MnO_3$ (a) and $Pr_{0.6}Ca_{0.4}MnO_3$ (b) epitaxial thin films. Dark parts correspond to energy bands.

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