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Modification of Magneto-Transport Properties of Ferrimagnetic Mn_4N Thin Films by Ni Substitution and Their Magnetic Compensation

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Abstract : Ferrimagnetic antiperovskite $Mn_{4-x}Ni_xN$ thin film exhibits both small saturation magnetization and rather large perpendicular magnetic anisotropy (PMA) when x is small. Both of them are suitable features for application to current induced domain wall motion devices using spin transfer torque (STT). In this work, we successfully grew antiperovskite 30-nm-thick $Mn_{4-x}Ni_xN$ epitaxial thin films on MgO(001) and STO(001) substrates by MBE in order to investigate their crystalline qualities and magnetic and magneto-transport properties. Crystalline qualities were investigated by X-ray diffraction (XRD). The magnetic properties were measured by vibrating sample magnetometer (VSM) at room temperature. Anomalous Hall effect was measured by physical properties measurement system. Both measurements were performed at room temperature. Temperature dependence of magnetization was measured by VSM-Superconducting quantum interference device. XRD patterns indicate epitaxial growth of $Mn_{4-x}Ni_xN$ thin films on both substrates, ones on STO(001) especially have higher c-axis orientation thanks to greater lattice matching. According to VSM measurement, PMA was observed in $Mn_{4-x}Ni_xN$ on MgO(001) when $x \leq 0.25$ and on STO(001) when $x \leq 0.5$, and MS decreased drastically with x. For example, MS of $Mn_{3.9}Ni_{0.1}N$ on STO(001) was 47.4 emu/cm^3. From the anomalous Hall resistivity (ρAH) of $Mn_{4-x}Ni_xN$ thin films on STO(001) with the magnetic field perpendicular to the plane, we found out Mr/MS was about 1 when $x \leq 0.25$, which suggests large magnetic domains in samples and suitable features for DW motion device application. In contrast, such square curves were not observed for $Mn_{4-x}Ni_xN$ on MgO(001), which we attribute to difference in lattice matching. Furthermore, it's notable that although the sign of ρAH was negative when $x = 0$ and 0.1, it reversed positive when $x = 0.25$ and 0.5. The similar reversal occurred for temperature dependence of magnetization. The magnetization of $Mn_{4-x}Ni_xN$ on STO(001) increases with decreasing temperature when $x = 0$ and 0.1, while it decreases when $x = 0.25$. We considered that these reversals were caused by magnetic compensation which occurred in $Mn_{4-x}Ni_xN$ between $x = 0.1$ and 0.25. We expect Mn atoms of $Mn_{4-x}Ni_xN$ crystal have larger magnetic moments than Ni atoms do. The temperature dependence stated above can be explained if we assume that Ni atoms preferentially occupy the corner sites, and their magnetic moments have different temperature dependence from Mn atoms at the face-centered sites. At the compensation point, $Mn_{4-x}Ni_xN$ is expected to show very efficient STT and ultrafast DW motion with small current density. What's more, if angular momentum compensation is found, the efficiency will be best optimized. In order to prove the magnetic compensation, X-ray magnetic circular dichroism will be performed. Energy dispersive X-ray spectrometry is a candidate method to analyze the accurate composition ratio of samples.

Keywords : compensation, ferrimagnetism, Mn_4N, PMA
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