題目(和文)	マンガン窒化物薄膜の成長と磁気特性に関する研究
Title(English)	Study on the Growth and Magnetism of Manganese Nitride Films
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論文要旨

THESIS SUMMARY

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要旨（英文800語程度）
Thesis Summary（approx.800 English Words ）

Manganese nitrides (Mn_xN_y) are potential functional materials due to the great variety of crystal structural, electronic, optical and magnetic properties. The Mn_xN_y has four stable phases depending on the nitrogen content at room temperature, including θ-MnN, η-Mn_3N_2, ζ-Mn_2N, ε-Mn_4N Phases. Among them, the nitrogen-enriched and nitrogen-depleted phases: MnN and Mn_4N have been paid more attention. The MnN film, as an excellent candidate antiferromagnetic material for magnetic tunnel junction (MTJ) and possesses the advantages of good thermal stability, significant exchange bias, easy manufacturer and low environmental damage. The Mn_4N film, as the only ferrimagnetic phase in Mn_xN_y, has attracted significant attention due to the potential application in spin-transfer torque (STT) magnetic random access memories (MRAM) and domain wall motion MRAM. At present, for the manganese nitrides films, the formation behaviors of manganese nitrides are no clear. The growth of Mn_4N film relies on the high-cost single crystal substrates, which restricts the further practical application. Moreover, the mechanism of perpendicular magnetic anisotropy is not fully understood. And the exchange coupling between MnN and ferromagnetic layers needs to be further investigated. In this work, the research objectives mainly include three aspects: (1) To study the formation of manganese nitride films under different experiment conditions; (2) To obtain the large perpendicular magnetic anisotropy (PMA) in Mn_4N films on glass substrate by improving the crystallinity of Mn_4N; (3) To understand the exchange coupling between MnN/ferromagnetic layer.

The phase construction of Mn_xN_y films has been systematically studied under different nitrogen concentrations, substrate temperature and annealing temperature. It prefers to form the MnN and Mn_3N_2 film under low temperature and nitrogen-rich environments. On the contrary, high temperature and nitrogen-poor environments tend to obtain the Mn_2N and Mn_4N film. In the as-deposited state films, only the Mn_3N_2 film has strong crystallinity along (200) orientation. The other manganese nitrogen compounds show poor crystallinity. By applying appropriate sputtering condition, the Mn_4N film can be prepared with PMA. However, the weak crystallinity, poor squareness of hysteresis loop and low effective magnetic anisotropy of the Mn_4N film directly deposit on glass substrate limit the particle application.

To further improve the PMA of Mn_4N films, another Mn_xN_y phase—Mn_3N_2, which exists high-quality crystalline structure on glass substrate, is applied as the seed layer to promote the growth of the Mn_4N film. The results show that Mn_3N_2 seed layer significantly improves the crystallinity and PMA of the Mn_4N film. The effect of Mn_3N_2 seed layer is not only to provide more nucleation points for the growth of Mn_4N but also transports more N atoms to the Mn_4N layer by applying the concentration difference during the film growth process to maintain the structural stability of Mn_4N. The origin of PMA attributes to the in-plane tensile stress and high-quality crystalline structure in the Mn_3N_2/Mn_4N film. Moreover, the effect of Mn_3N_2 layer thickness, substrate temperature and annealing temperature on the structure and magnetic properties of Mn_3N_2/Mn_4N films has been systematically investigated. The optimum conditions have been obtained tp fabricate Mn_3N_2/Mn_4N films with the strongest PMA. The thickness of Mn_3N_2 layer plays a critical role in the structural and magnetic properties of Mn_4N. With the thickness of the buffer layer increasing, the crystallinity and PMA of Mn_4N increase first and decrease afterward. The substrate temperature also influences the structure of Mn_3N_2/Mn_4N films. With substrate temperature increasing, the peak position of Mn_4N moves to the high angle direction, which indicates the decrease of the interplanar spacing. Suitable annealing temperature can be applied to adjust coercivity and improve PMA in Mn_3N_2/Mn_4N films. However, too high temperature will lead to the degradation of film structure and affect the magnetic properties.

The MnO film can be applied as the buffer layer to promote the growth of Mn_4N films due to the proper lattice mismatch and the similar Mn atomic arrangement between MnO (001) and Mn_4N (001) crystal plane. This work prepares the MnO layer by in-situ oxidizing the Mn_3N_2 layer with residual oxygen in the sputtering chamber. It is found that epitaxial growth of Mn_4N on the MnO seed layer is realized at a substrate temperature as low as 250 ℃ with MnO [100](001)∥Mn_4N [100](001). The PMA is significantly enhanced compared with the Mn_4N single layer on glass substrate, which is the result of high crystalline quality and tetragonality of the [001]-orientated Mn_4N film.

Primitive exchange coupling, which signifies the exchange coupling established at as deposited state without conventional field cooling process. This work chooses MnN as antiferromagnet (AF) and CoPt as ferromagnet (F), and single F layer, F/AF bilayer, F/AF/F trilayer, Mn_3N_2/F/AF/F multilayer films have been prepared on glass substrate to study the primitive exchange coupling. It shows that primitive exchange coupling can be established at the interface between ferromagnetic CoPt and antiferromagnetic MnN under a magnetic field as small as 6 Oe during deposition. The interfacial spin configuration that initiates exchange coupling can be established at the interface when the MnN layer grows on the surface of the CoPt layer under a small field. The primitive exchange coupling shows an increasing tendency with increasing the MnN layer thickness, and a decreasing tendency with increasing the coupled CoPt layer thickness. And the coercivity of the coupled CoPt layer remain almost unchanged within the whole thickness range of both MnN and CoPt, which suggests the coercivity of the coupled CoPt layer is not only affected by exchange coupling.

備考 ： 論文要旨は、和文 2000 字と英文 300 語を 1 部ずつ提出するか、もしくは英文 800 語を 1 部提出してください。
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