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Saturation magnetic moments of Co/Cr multilayers

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Abstract

An anomalous magnetization process was observed in multilayers of Cr(8 nm)/[Co(1 nm)/Cr(t nm)]^{19}/Co(1 nm). A magnetic moment per Co atom, σ_s^{Co}, larger than 200 emu/g is obtained for t-values of 1.5 and 3 nm from magnetization curves measured for magnetic fields up to 5 T at temperatures down to 5 K with a SQUID magnetometer. Also, a transition between a state of a larger magnetic moment and a smaller moment were observed at temperatures below 60 K.

In the last decade, the possibility of novel crystal structures of 3d-transition metals with a large ferromagnetic moment has been investigated by many researchers with calculation for the electronic configurations in 'novel' crystals [1]. Especially, metals with less than half a 3d shell occupied, such as V, Cr and Mn are very interesting. The novel crystals are expected to be stable in epitaxially grown overlayers or multilayers. So far, any novel ferromagnetic 3d-metal crystal has never been found yet experimentally. In the previous report [2], a large saturation magnetic moment, σ_s, was discussed for a Co/Cr multilayer prepared by vacuum deposition in a relatively low vacuum of 10^{-5} Torr. Therein, it is questionable whether such a large magnetic moment of Co/Cr multilayer is valid or not. To answer this, Co/Cr multilayers composed of ultra-thin Cr and Co layers were prepared in a vacuum of 1×10^{-10} Torr with a UHV deposition apparatus. The stacking sequence of multilayers in the present study is Cr(8 nm)/[Co(1 nm)/Cr(t nm)]^{19}/Co(1 nm). Here, [ ]^{19} means that each of Co(1 nm) and Cr(t nm) layers are alternatively stacked 19 times, and the layers of Cr(8 nm) and Co(1 nm) at both sides of the square brackets are a buffer layer and a cover layer, respectively. The thickness of the Cr layer t was varied ranging from 1 to 8 nm. High purity Co and Cr were evaporated with EB guns and deposited onto a boron-silicate glass substrate at room temperature at a deposition rate of 0.02 nm/s.

The actual stacking periods of the multilayers, Λ, are estimated from a conventional X-ray diffraction analysis. From Fig. 1, we obtain $\Lambda = 1.17 + 0.766t$ (nm). Both Cr and Co layers grew with their (110) and (0001) plane parallel to the substrate surface, respectively. The spacings of the lattice planes, d^{Co}_{0002} and d^{Cr}_{110}, are equal in the multilayer and increase with an increase in t-value, but they are smaller than that of bulk metal as indicated by arrows in Fig. 2. Observing the curve in detail, spacings at $t = 1.5$ and 3 nm slightly deviate in the upward direction from the others.

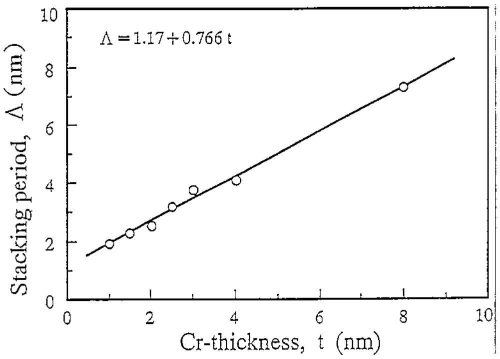

Fig. 1. Stacking period, Λ (nm), versus designed Cr thickness, t (nm), of multilayers.

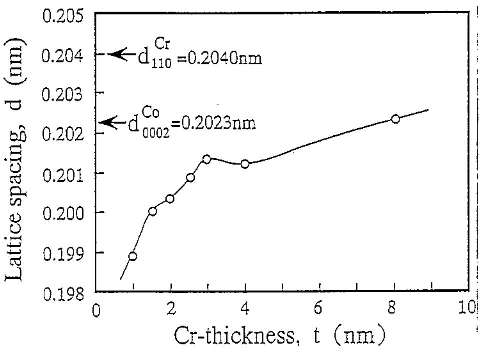

Fig. 2. Spacing of lattice plane, d^{Co}_{0002} and d^{Cr}_{110}, versus Cr thickness, t.

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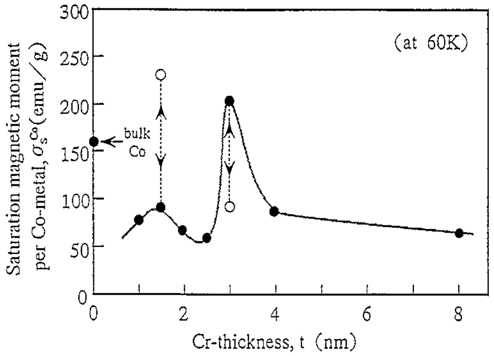

Fig. 3. Thickness dependence of saturation magnetic moment, σ_s^{Co}, measured at 60 K.

From magnetization curves measured with a SQUID magnetometer for magnetic fields, H, up to 5 T at temperatures ranging from 4 to 300 K, saturation magnetic moments per Co atom, σ_s^{Co} (emu/g), are obtained in a usual manner. The σ_s^{Co}-values at 60 K are plotted against t-values in Fig. 3. The temperature dependence of σ_s^{Co} is as small as that of bulk Co. Two t maxima of σ_s^{Co}-values are observed at $t = 1.5$ and 3 nm. Sometimes the σ_s^{Co}-value jumps up to 230 emu/g at 1.5 nm and drops down to 100 emu/g at 3 nm, respectively. Thus two magnetization states, viz., a stable and a quasi-stable state, can be considered to exist at these Cr thicknesses. Solid circles in the figure denote the stable magnetization state and open circles denote the quasi-stable magnetization state. Fig. 4 shows the transition from the one state to the another for the multilayer with $t = 3$ nm. The transition can be observed as switching between a magnetization curve with larger magnetic moment (H) and that with smaller magnetic moment (L). The magnetization curve traces three different courses on curves shown in the figure. The magnetization always starts from a state H; the first one, 1-0-4-5-4-0-1, is an ordinary process, the second is 1-0-2-4-5-4-0-1, and the third is 1-0-2-3-2-0-6 and finally returns to 1. In the second and the third cases, jumping occurs between states L and H. In the multilayer with $t = 1.5$ nm, the situation is the quite reverse, viz., the magnetization starts from state L and jumping takes place between L and H, and finally returns to L.

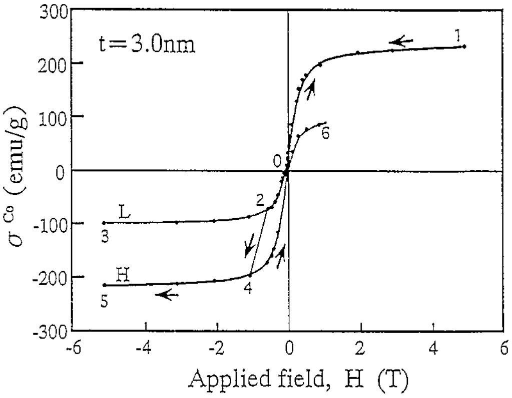

Fig. 4. Hysteresis curves of multilayers with $t = 3$ nm.

In the present experiment, a magnetic moment larger than 200 emu/g and an intermittent transition between a magnetic state of larger magnetic moment, H, and that of smaller one, L, are observed at specific Cr thicknesses for Co/Cr multilayers with Co layers of 1 nm. The origin of this anomalous magnetization process is not clear at present, it may be relevant to a phenomenon discussed in previous works [3] in which a large perpendicular magnetization anisotropy appears together with continuous lattice transformation in Co from hcp to bcc with a decrease in Co thickness in Co/Cr multilayers with Co layers thinner than 1.4 nm. This anomalous process is also suggested by a certain structural change due to adsorption of small atoms such as N and C [4].

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