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STRUCTURAL AND MAGNETIC PROPERTIES OF $Nd_{15}Fe_{77}B_8$ /Cr THIN FILMS DEPOSITED BY PULSED LASER ABLATION

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ABSTRACT

Ferromagnetic Nd15Fe77B8 and Nd15Fe77B8/Cr thin films were prepared on the Si(100) substrate using KrF excimer laser ablation, and the structural and magnetic properties were investigated as a function of substrate temperature and laser beam density. High magnetic properties of Nd15Fe77B8 thin films were observed at 620℃ of substrate temperate showing iHc=1120Oe, 4πMs=8000Gauss and 4πMr=6000Gauss in perpendicular direction. Magnetic properties of Nd15Fe77B8 /Cr/Si thin films showed iHc=700Oe, 4πMs=6000Gauss and 4πMr=2000Gauss in perpendicular with Cr buffer layer of 100 nm thick. X-ray diffraction data did not show preferred c-axis orientation. Auger electron microscopy revealed inter-diffusion of Cr and Si elements into Nd15Fe77B8 thin films.

I. INTRODUCTION

Permanent magnetic thin films are powerful candidates for applications in micro-mechanical devices such as micro-motors, actuator, sensor and in addition, data recording media as possible fields. Cadieu et al. [1] reported that oriented Nd2Fe14B films could be fabricated by using r.f. sputtering. Shima et al. [2] reported the influence of under-layers of Cr and Ti on the structure and magnetic properties of the Nd-Fe-B thin film fabricated by a conventional r.f. sputtering. The Nd12Fe82B6 / Pt under-layer film [3] fabricated by r.f. sputtering showed possibility of data storage application with coercivity of 3000 Oe for a 1000 Å film. It also showed crystallographic texture when annealed at 625℃. Tsai et al. [4] showed that $Nd_2Fe_{14}B$/Ta bi-layer films grown on Si (111) substrate by dc magnetron sputtering has coercivity of 7~10 kOe at room temperature and the coercivity increased with increasing Ta film thickness. In this study, we have investigated the influences of Cr under-layer thickness and substrate temperature on the structure and magnetic properties of Nd-Fe-B thin films fabricated by pulsed laser ablation technique.

II. EXPERIMENTAL

The target ($Nd_{15}Fe_{77}B_8$) alloys were made using high vacuum (10^{-6} torr) arc furnace under high purity argon atmosphere, and then machined into size of ø=50mm, t=5mm. Surface was polished within the alchol and hexane solution. Si (100) substrates were cut by diamond saw and cleaned by aceton, methanol, ultrasonic cleaning in DI water, and dried with nitrogen gas. Nd-Fe-B thin films were prepared by 248nm KrF excimer laser apparatus with an equipment of controlling the substrate temperature up to 900℃. Target was inclined to laser beam and spot focused to target was 0.012mm^2 and rotated with speed of 10 rpm in order to keep surface smoothness. Laser beam density was in the range of 2.6~5.9 J/cm^2, while repetition rate of pulse was fixed at 10Hz. Si substrate rotated with speed of 7 rpm at a distance of 4.5 cm from target holder. Cooling rate of substrate was controlled as 3.3℃/min. down to 330℃ and then cooled freely to room temperature in the chamber. The thickness of Nd-Fe-B layer was fixed at 150 nm while the thickness of Cr under-layer was varied in the range of 10~100 nm. The substrate temperature was varied in the range of 500~700℃. The thicknesses of films were averaged values measured at 4~5 points using α- step. The crystal structure was investigated by x-ray diffractometer with Cu Kα radiation and Ni filter. Auger electron scanning was used to find in-depth composition profiles. Magnetic properties were measured using a vibrating sample magnetometer with maximum field up to 16.5 kOe at room temperature.

III. RESULTS AND DISCUSSION

Figure 1 shows the x-ray diffraction patterns of single layer Nd-Fe-B thin films deposited on Si(100) substrate in the temperature range of 550~700℃. As seen in this figure, most of the peaks could be indexed to tetragonal $Nd_2Fe_{14}B$ compound although some peaks might belong to Nd_2O_3 compound. It shows high degree of c-axis orientation at substrate temperature of 620℃. Figure 2 shows the x-ray diffraction patterns for single Nd-Fe-B thin film with various beam energy densities indicating high c-axis preferred orientation at 3.02J/cm^2. Figure 3 shows the x-ray diffraction patterns for Nd-Fe-B thin films with various thickness of Cr under-layer, and it shows weak tetragonal $Nd_2Fe_{14}B$ peaks and also Cr-silicide ($CrSi_2$) phase. It is considered that the principal phase of the films is the $Nd_2Fe_{14}B$, whose tetragonal c-axis is aligned perpendicularly to the film plane when the film was directly deposited on Si substrate, and this phase properly formed at 620℃ of substrate temperature. Cr under-layer seems not to increase $Nd_2Fe_{14}B$ phase and to form $CrSi_2$ compound. The Nd-Fe-B thin films deposited directly onto Si(100) substrate at 620℃ exhibited the anisotropic magnetization whose preferred direction is perpendicular to the film surface. The film with 150 nm thick shows iHc=1120 Oe, $4\pi Ms$=8000 Gauss and $4\pi Mr$=6000 Gauss in perpendicular direction. Magnetic properties in perpendicular direction are given in Figure 4. Cr under-layer formed intermetallic $CrSi_2$ compound and supressed the growth of anisotropic Nd-Fe-B layer in contrast to the report by Shima et al. [2]. Magnetic properties of $Nd_{15}Fe_{77}B_8$/Cr/Si(100) thin films showed iHc=700Oe, 4π Ms=6000Gauss and $4\pi Mr$=2000Gauss in perpendicular. Magnetic properties for various Cr under-layer thickness are given in Figure 5. As seen in this figure, Cr under layer of 50 nm thick shows low magnetic properties. Figure 6 shows Auger electron scanning analysis of Cr under layer for Nd-Fe-B/Cr/Si (100) films. It reveals inter-diffusion of Si elements with Cr under layer and formation of $CrSi_2$ compound as shown in X-ray diffraction pattern (see Figure 3) and this might affect the crystal orientation and so magnetic properties of Nd-Fe-B phase to be reduced.

Ⅳ. CONCLUSIONS

Magnetic properties of $Nd_{15}Fe_{77}B_8$ thin films ablated on Si(100) substrate with substrate temperature 620℃ exhibited anisotropy with iHc=1120Oe, $4\pi Ms$=8000Gauss and $4\pi Mr$=6000Gauss in perpendicular direction. Cr under-layer showed negative effects on the anisotropic growth of Nd-Fe-B phase through inter-diffusion of Cr and Si elements and formation of intermetallic $CrSi_2$ compound.

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Figure captions

Figure 1. X-ray diffraction patterns of Nd-Fe-B/Si (100) thin films with various substrate temperature.

Figure 2. X-ray diffraction patterns for single Nd-Fe-B thin film with various beam energy density.

Figure 3. X-ray diffraction patterns of Nd-Fe-B/Cr/Si (100) thin films with substrate temperature of 620℃.

Figure 4. Magnetic properties of single Nd-Fe-B thin film with various substrate temperatures.

Figure 5. Magnetic properties of Nd-Fe-B(150 nm)/Cr thin films with various under-layer thicknesses.

Figure 6. Auger electron scanning analysis for Nd-Fe-B(150nm)/Cr(100nm)/S (100)) films.

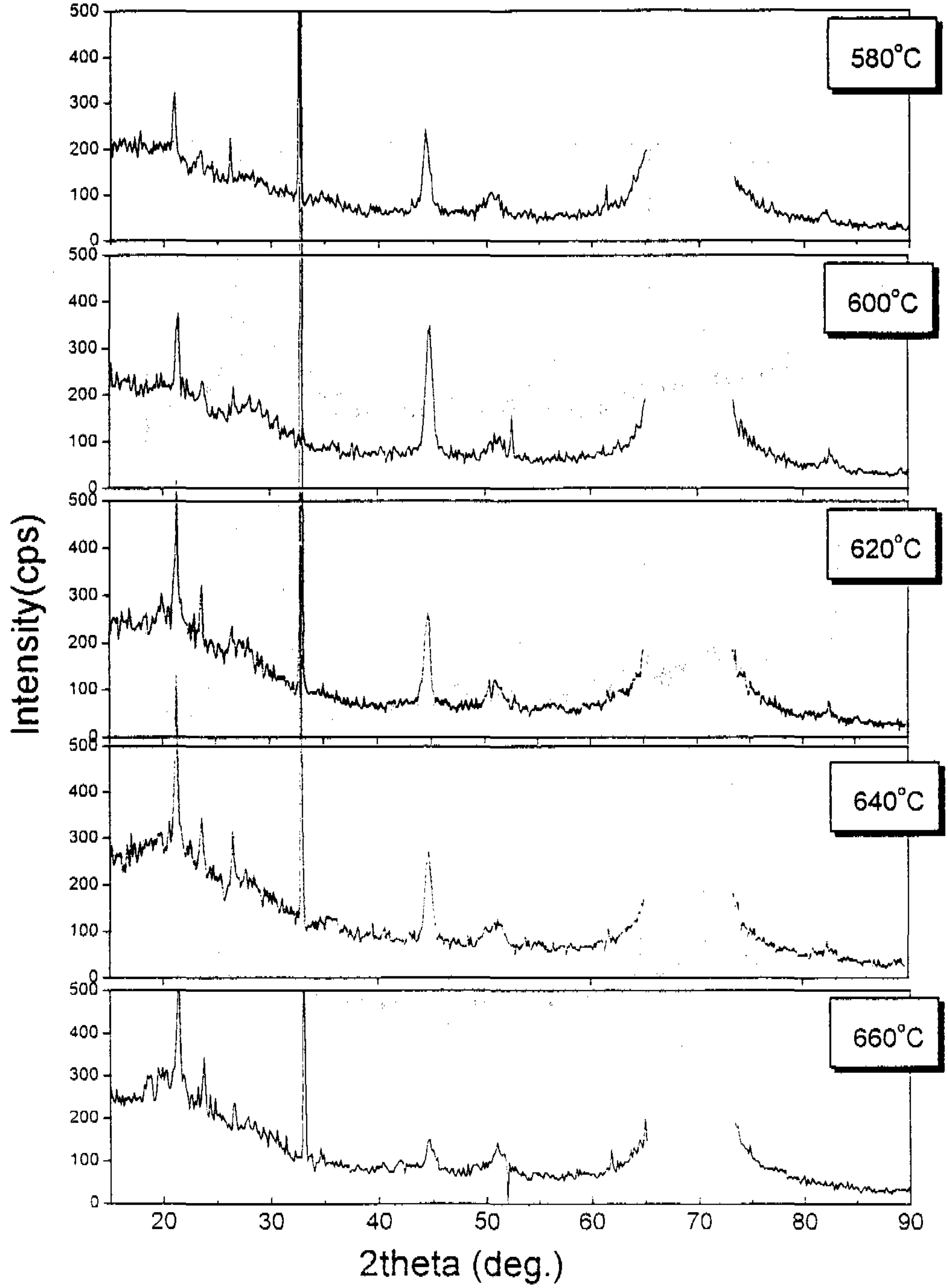

Figure 1. X-ray diffraction patterns of Nd-Fe-B/Si (100) thin films with various substrate temperature.

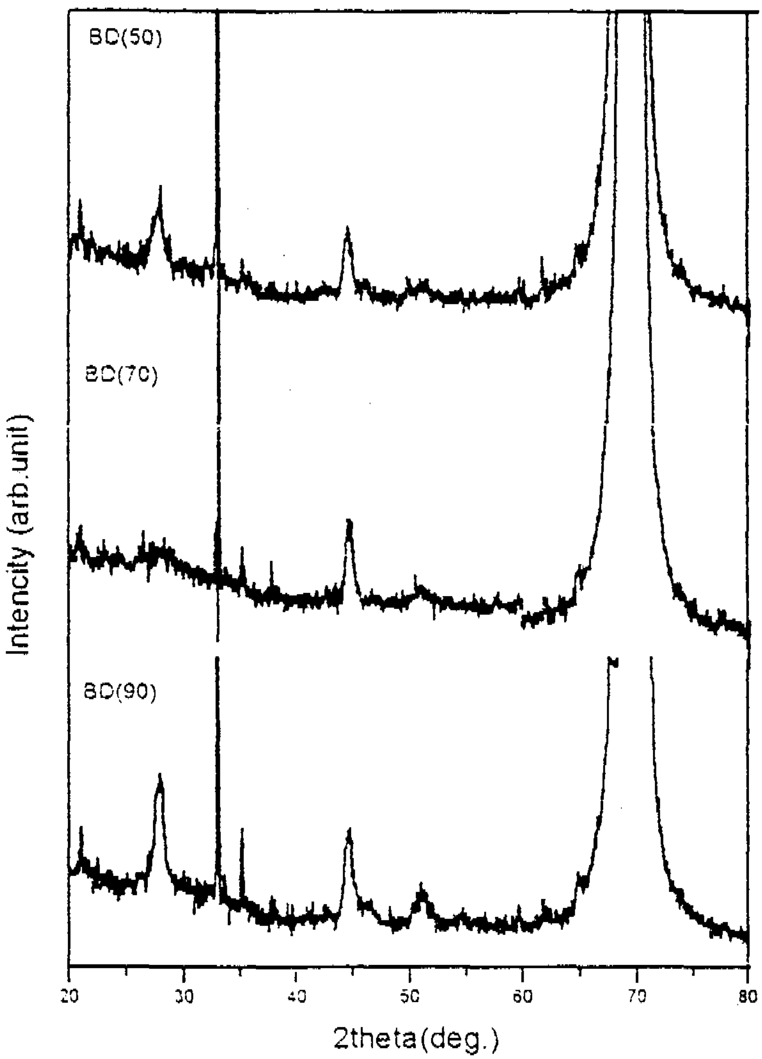

Figure 2. X-ray diffraction patterns for single Nd-Fe-B thin film with various beam energy density

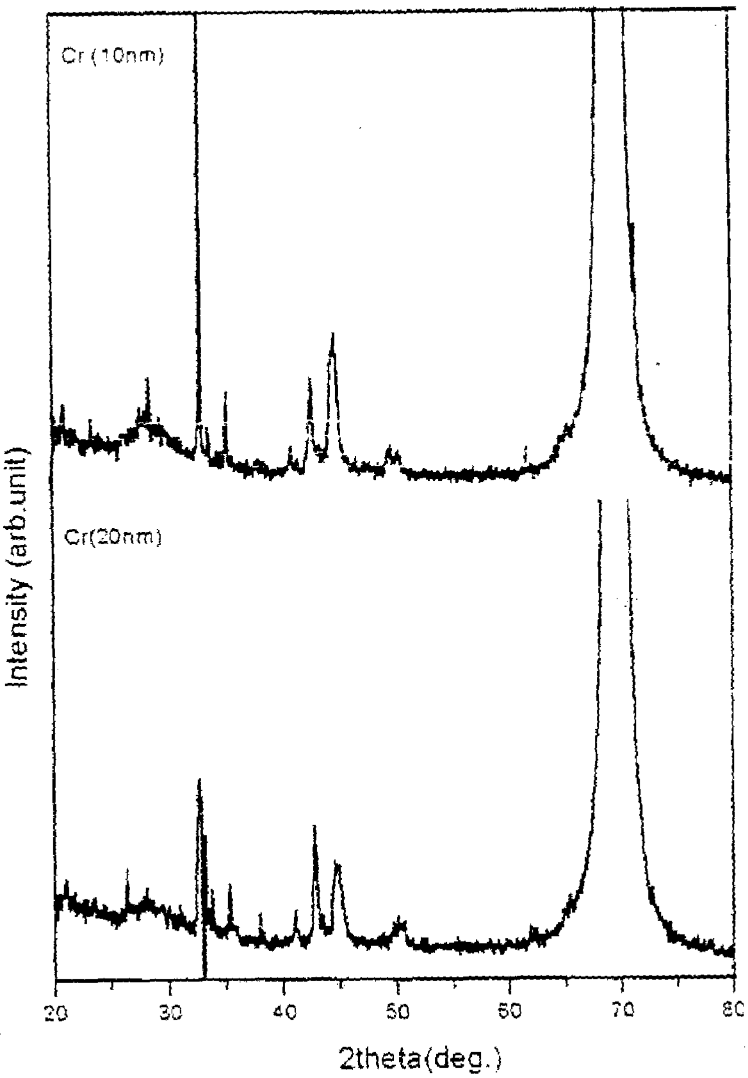

Figure 3. X-ray diffraction patterns of Nd-Fe-B/Cr/Si (100) thin films with substrate temperature of 620℃

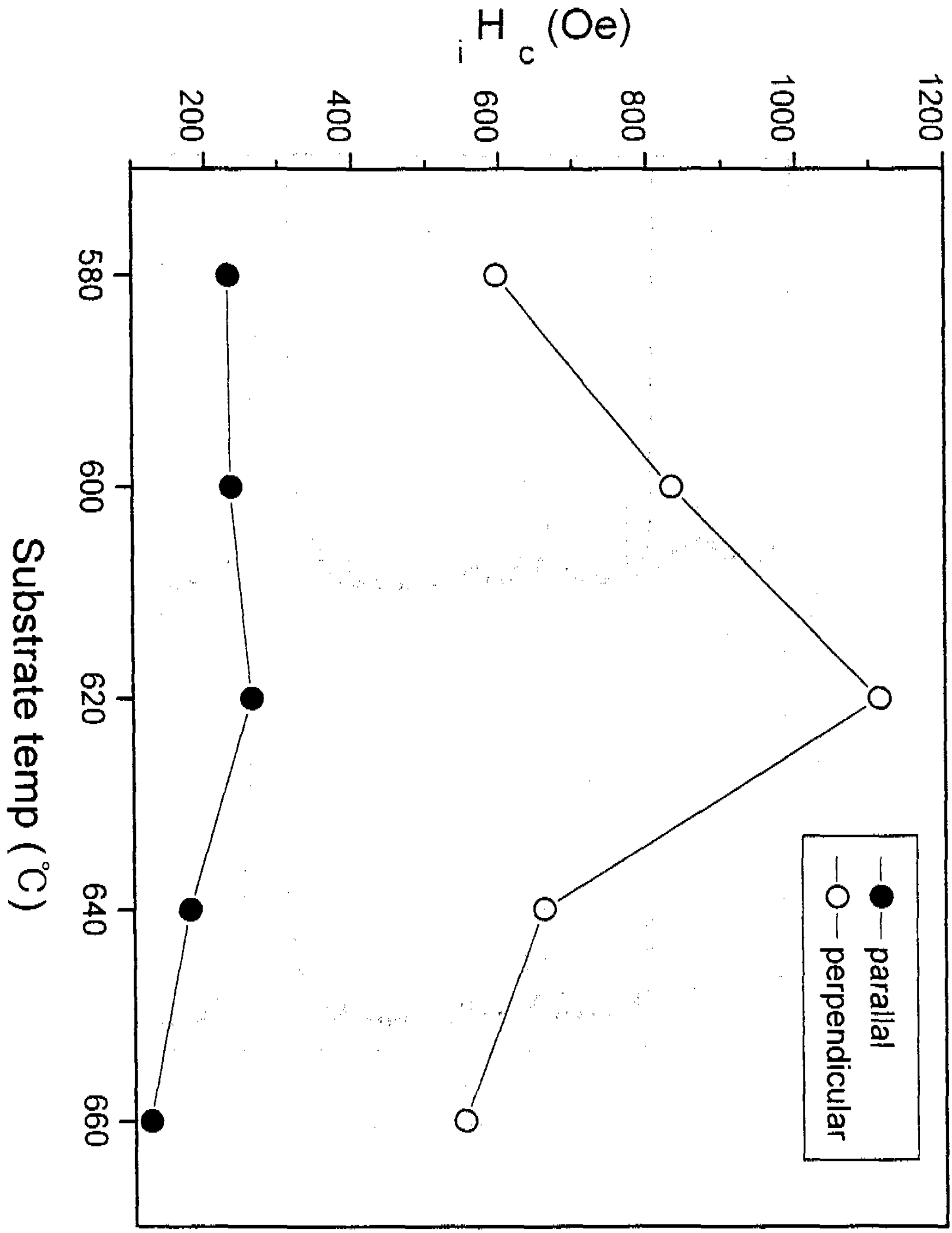

Figure 4(a). Magnetic properties of single Nd-Fe-B thin film with various substrate temperature.

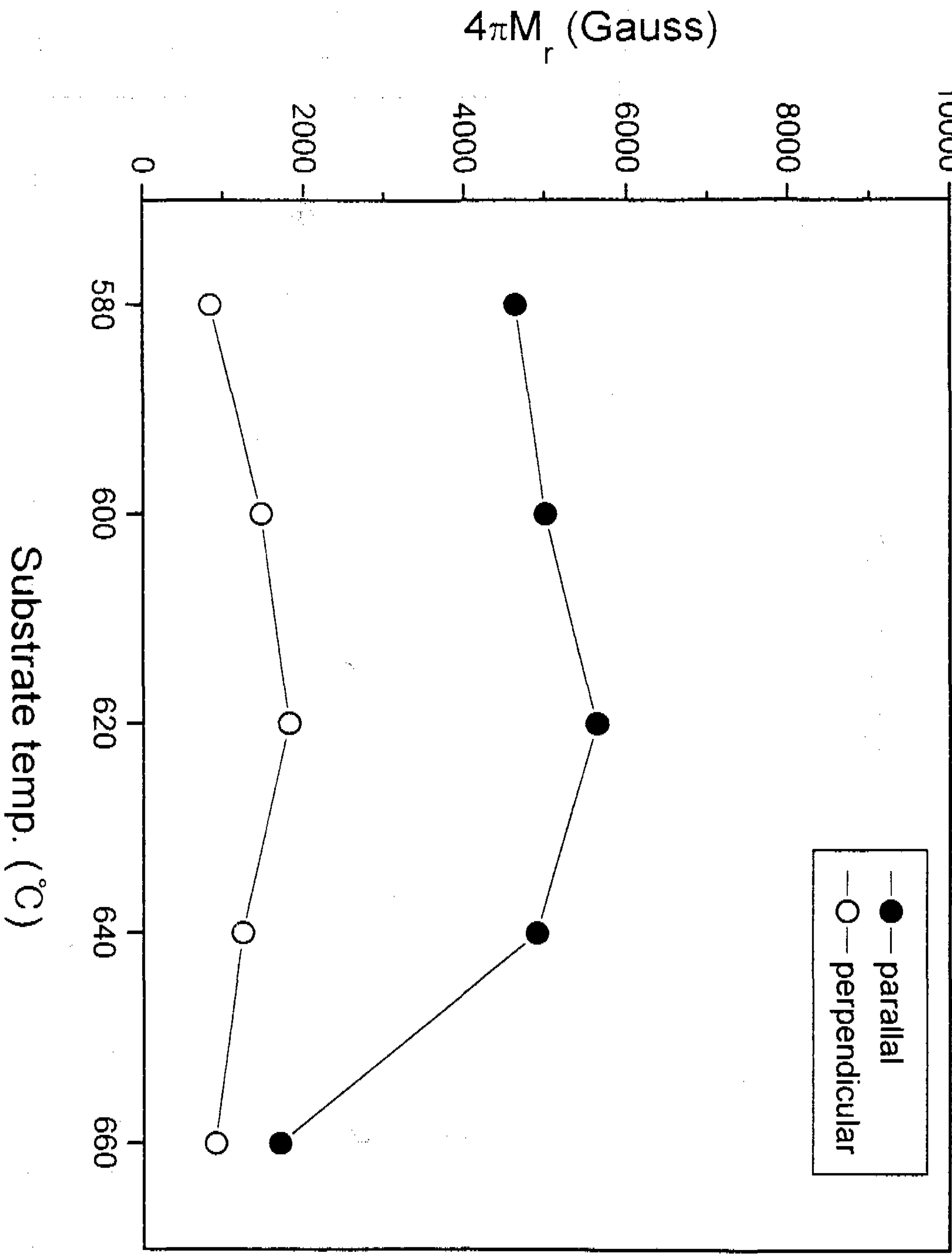

Figure 4(b). Magnetic properties of single Nd-Fe-B thin film with various substrate temperatures.

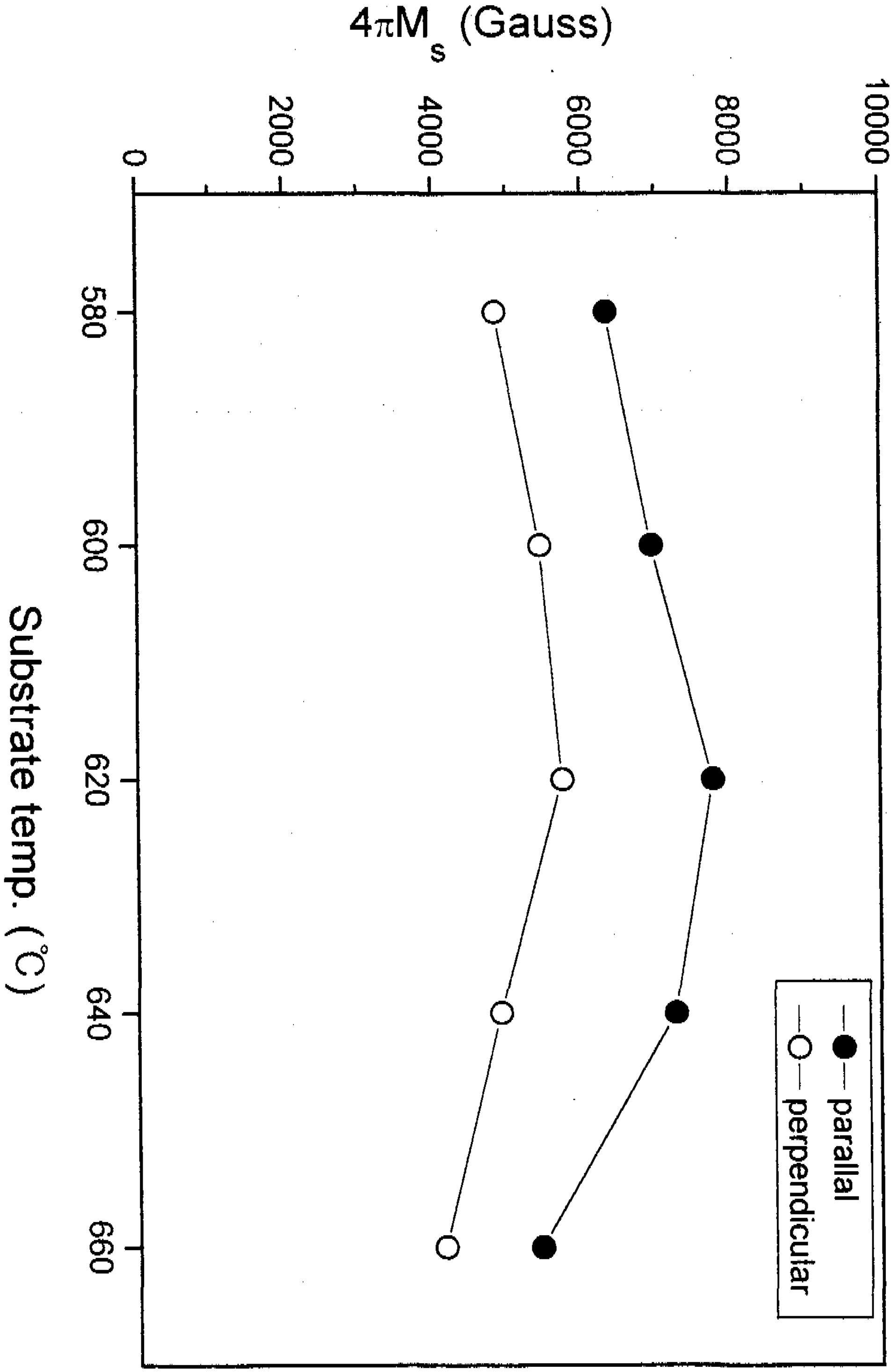

Figure 4(c). Magnetic properties of single Nd-Fe-B thin film with various substrate temperature.

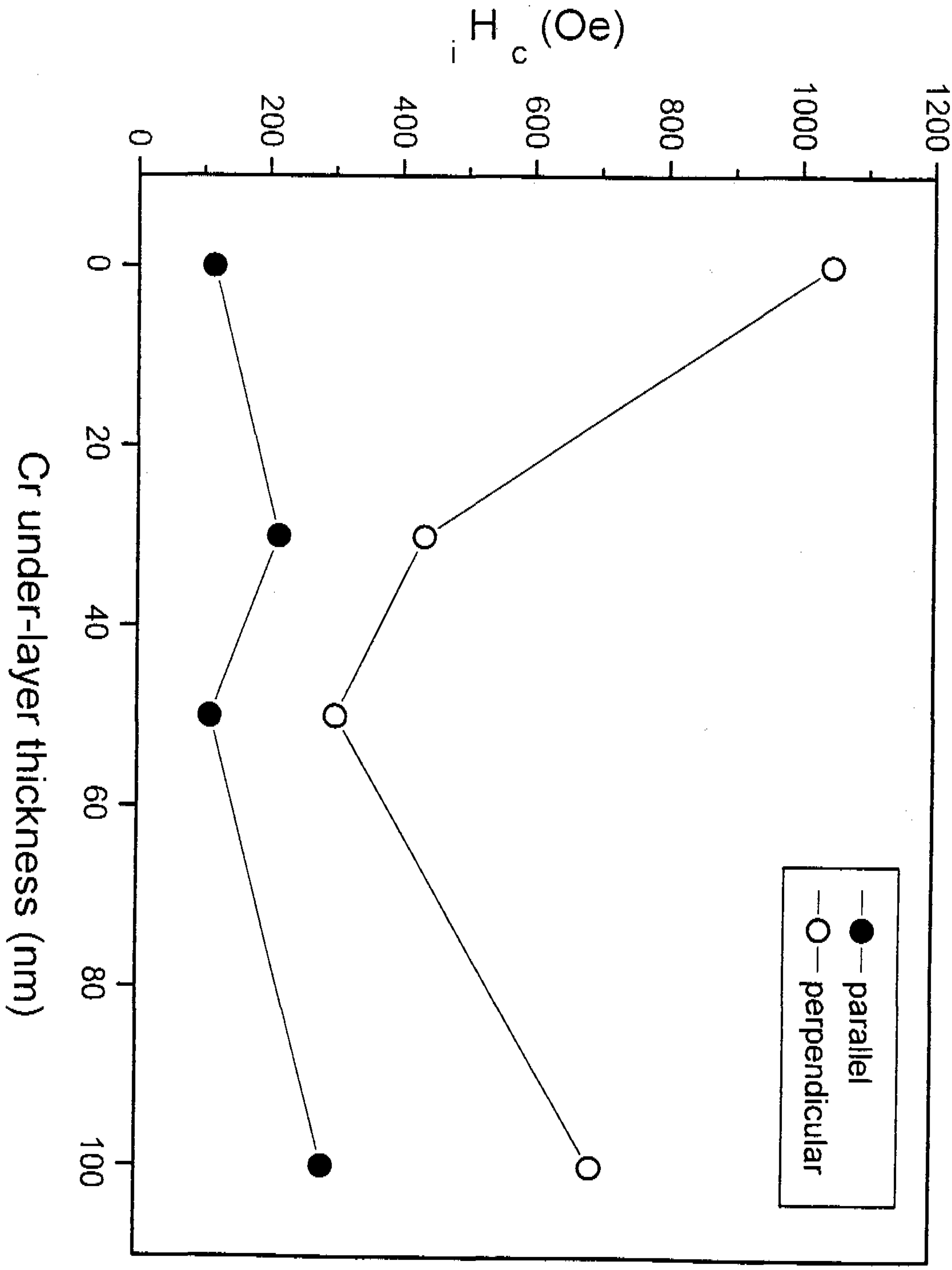

Figure 5(a). Magnetic properties of Nd-Fe-B(150 nm)/Cr thin films with various under-layer thickness.

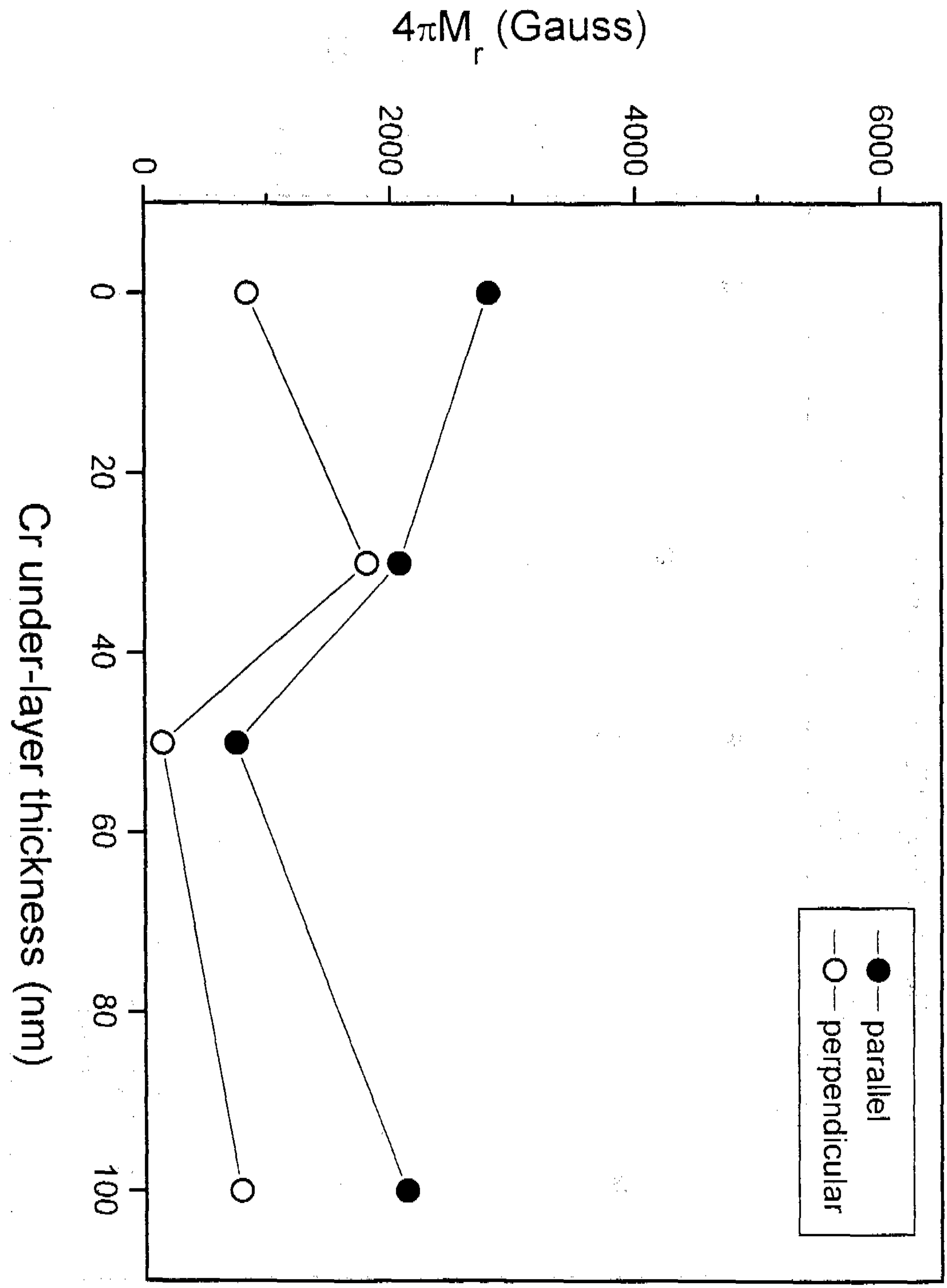

Figure 5(b). Magnetic properties of Nd-Fe-B(150 nm)/Cr thin films with various under-layer thickness.

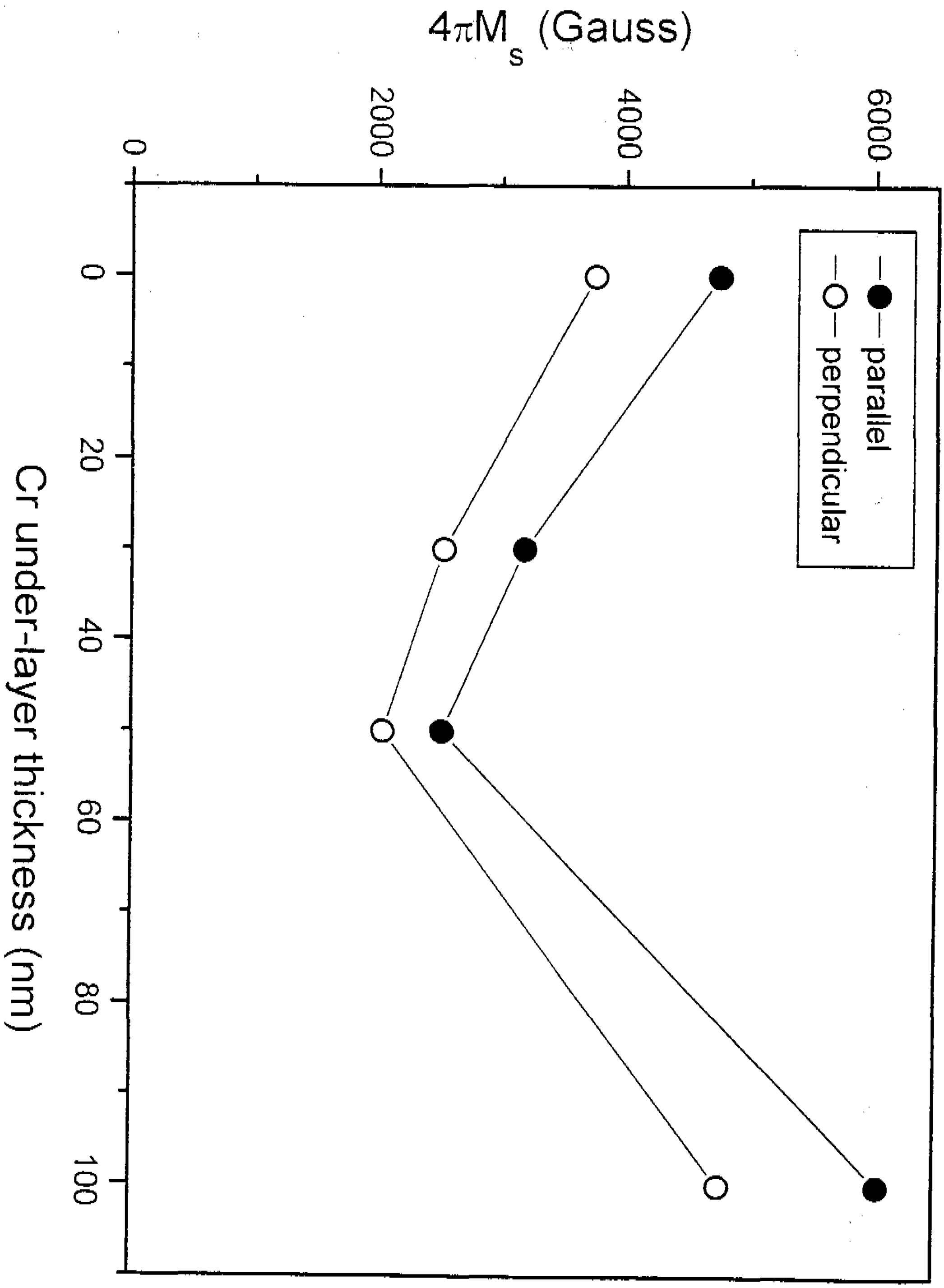

Figure 5(c). Magnetic properties of Nd-Fe-B(150 nm)/Cr thin films with various under-layer thickness.

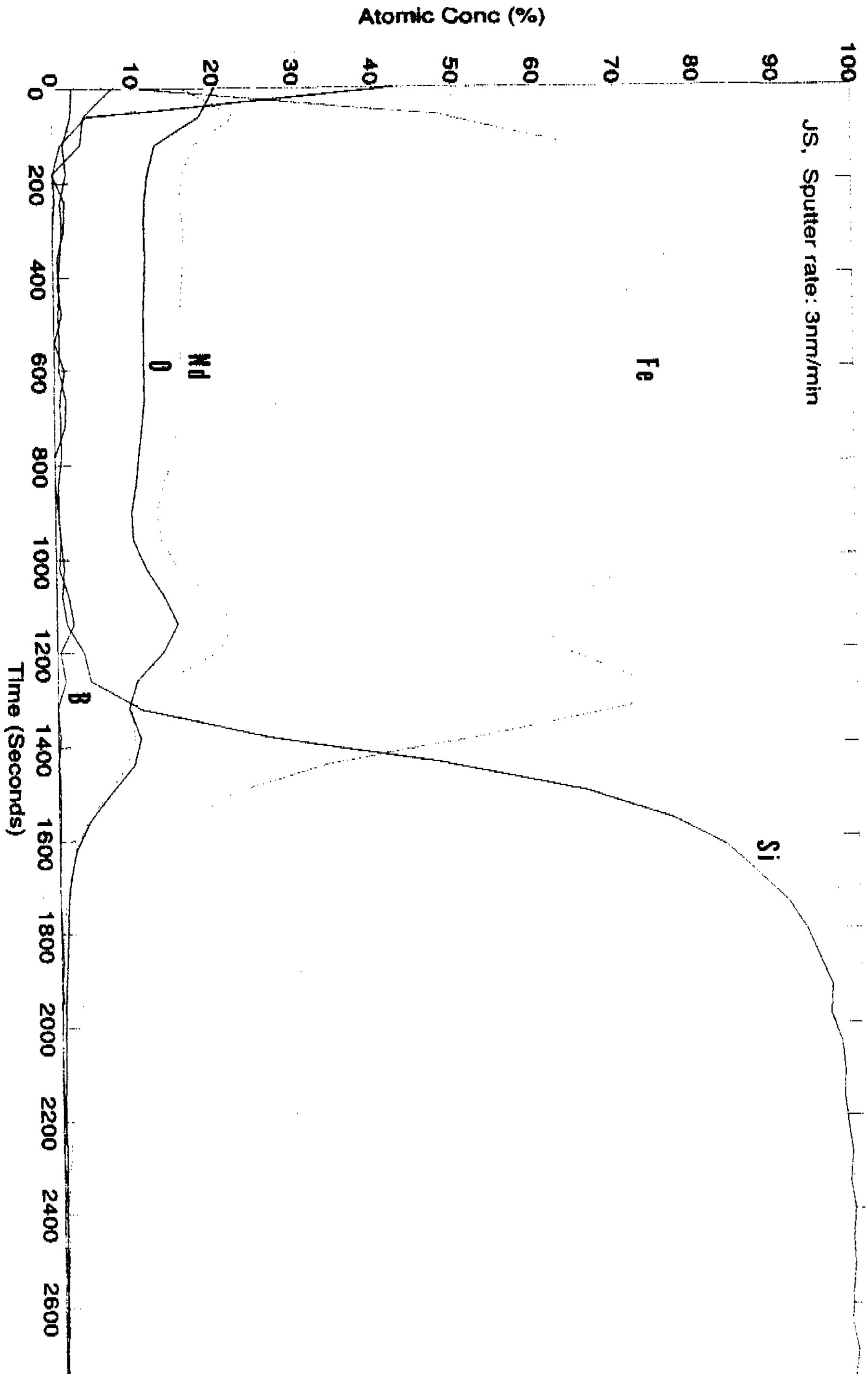

Figure 6. Auger electron scanning analysis for Nd-Fe-B(150nm)/Cr(100nm)/Si (100) films.