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UNDERLAYER EFFECT ON STRUCTURAL AND MAGNETIC PROPERTIES OF $Co_{90}Fe_{10}$ THIN FILMS

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In the present study, the single layer $Co_{90}Fe_{10}$ and X/$Co_{90}Fe_{10}$ (X = Cu, Cr, Au, $Ni_{80}Fe_{20}$) double layer films were investigated. Films were fabricated by DC magnetron sputtering at room temperature on Si substrates. In order to improve the soft magnetic properties of CoFe films, four different underlayers were examined. The coercivity values of the films were obtained by using a laboratory design magneto-optic Kerr effect (MOKE) magnetometry. Magnetic force microscopy and x-ray diffraction results show that the crystalline structure and magnetic domains of CoFe films are sensitive to the initial layer. It was seen that the soft magnetic properties of CoFe films were improved with underlayers. Particularly, the Au underlayer was effective in reducing coercivity H_c from 37 to 5 Oe.

Keywords: CoFe alloys, sputtered films, soft magnetic materials

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1. Introduction

Soft magnetic materials based on FeCo alloys are of considerable interest due to their potential in storage device applications like magnetic recording heads and magnetic sensors [1, 2]. In head materials of high density magnetic recording devices, thin films with soft magnetic properties and high saturation magnetization are essential [3]. Generally, polycrystalline $Ni_{81}Fe_{19}$ is chosen for magnetic recording heads due to a very small magnetostriction constant. The CoFe alloys are known as material with high saturation magnetic flux density B_s. For example, B_s of the $Co_{35}Fe_{65}$ alloy is about 24 kG, which is close to the limiting value achievable with ferromagnetic alloys [4]. It has been reported in some recent studies that soft magnetic CoFe alloy thin films with high B_s of 24 kG could be obtained by using a conventional sputtering process, e. g. CoFe single layer film [4], NiFe/Fe-Co-N/NiFe trilayer film [5], Fe-Co-N/Ni-Fe bilayer film [6], and Fe-Co-Al-O granular film [2, 7]. However, the coercivity H_c of CoFe alloys prepared by a classic sputtering method is about 50–100 Oe. Such a high H_c film is not suitable for soft magnetic material applications [8]. Therefore, it is necessary to obtain low coercivity with high B_s to improve soft magnetic properties of CoFe alloy films [8]. Much effort has done for lowering coercivity of FeCo alloys to improve soft magnetic properties in recent years. Underlayers, adding additives, and using different deposition techniques are frequently used methods for lowering coercivity [4, 5, 8–12]. The reduction of coercivity in these studies generally suggested that consequence of reducing grain size according to Hoffman's ripple theory or change on preferred crystal orientation [4, 8, 13, 14]. Choosing a suitable underlayer for FeCo alloy films is an effective method for lowering coercivity and improving soft magnetic properties of films. In these studies, using an underlayer generally results in a structural change [3, 5, 12, 15–17]. Structural changes also affect some other magnetic properties like magnetic anisotropy, which was effective on soft magnetic properties [18, 19]. It is believed that a thin (probably amorphous) underlayer allows greater mobility for atoms deposited on its surface. Thus an appropriate underlayer provides the film to form its energetically favoured texture [20]. It is also suggested that the nature of the underlayer influences the growth of layers, which affects the properties of films such as magnetic softness [21].

There have been many successful studies done on preparing soft magnetic films based on FeCo alloys [3, 8–12, 15, 16, 22]. CoFe alloy films [2, 4, 23], especially $Co_{90}Fe_{10}$, are less investigated for these applications. Additionally, Au and Cr are almost never used as underlayer material with $Co_{90}Fe_{10}$. To study the magnetic properties of films, generally the vibrational sample magnetometer (VSM) was used in recent studies [8-12, 15, 16]. On the other hand, obtaining similar results by using alternating techniques like a magneto-optic Kerr effect (MOKE) magnetometer is important for a good understanding of magnetic properties of thin films.

In this study, soft magnetic $Co_{90}Fe_{10}$ films were fabricated by DC magnetron sputtering. The 40 nm CoFe film growth on a magnetic underlayer ($Ni_{80}Fe_{20}$) and three different nonmagnetic underlayers (Cu, Cr, Au) were investigated and compared with the CoFe single layer film. All underlayers had a 6 nm thickness to provide comparing the character of underlayers. A composite target consisting of $Co_{90}Fe_{10}$ was used to fabricate all series of films. The change in magnetic properties and improvement of soft magnetism was observed in CoFe films. In our experiment it was observed that all underlayers were effective in lowering coercivity; on the other hand, a remarkable reduction in coercivity H_c and uniaxial magnetic anisotropy was observed on the $Co_{90}Fe_{10}$ film with the Au underlayer.

Our objective in this study is to show the preparation of $Co_{90}Fe_{10}$ soft magnetic thin films with the use of a suitable thin underlayer. There are many successful experiments reported on preparation of soft magnetic FeCo alloys with different thickness of NiFe and Cu underlayers recently. The novelty of this paper is fabricating a soft magnetic $Co_{90}Fe_{10}$ film with a 6 nm Au underlayer and making comparison with CoFe films deposited on other underlayers.

2. Experimental study

The samples were fabricated by DC magnetron sputtering onto (110) oriented Si wafers at room temperature. A pre-clean process including bias plasma (at a 20–200 mTorr pressure) was applied to all Si wafers for 40 s at a 40 W dc sputter power. The pre-clean process is generally sufficient to remove 20–30 angstroms of surface atoms of Si. The CoFe layer and underlayers were sputtered in the same chamber without breaking vacuum with the help of a 6-target sputtering system. The base pressure was 1.7×10^{-7} Torr before depositions. A magnetic holder was used to determine the easy axis of films and to induce magnetic anisotropy in the sputtering system. Depositions of all 40 nm $Co_{90}Fe_{10}$ layers were carried out with a background Ar pressure of 3 mTorr at a 300 W dc sputter power. The 6 nm Au layer was deposited at a 150 W sputter power and in a 1 mTorr Ar pressure. The 6 nm $Ni_{80}Fe_{20}$ layer was deposited at a 400 W sputter power and in a 3 mTorr Ar pressure using a $Ni_{80}Fe_{20}$ composite target. The 6 nm Cr layer was deposited at a 300 W sputter power and in a 3 mTorr Ar pressure. The 6 nm Cu layer was deposited at a 300 W sputter power and in a 2 mTorr Ar pressure. The M-H loops of films were determined by the laboratory design MOKE magnetometry with a He-Ne (630 nm) polarized laser source. The MOKE magnetometer measures the longitudinal intensity of the reflected laser beam from the samples. The crystalline structure was characterized by grazing incidence x-ray diffraction (GI-XRD) (Rigaku Ultimate IV with Cu-K_α radiation) due to ultrathin nature of samples. The micro-magnetic structure of the films was observed by magnetic force microscopy (MFM) (*Park Systems*' XE-100E). It must be pointed out that during magnetic domain analyses the samples are in remnant magnetization.

3. Results and discussion

Five films were studied: (a) 40 nm CoFe single layer, (b) 6 nm Au/40 nm CoFe double layer, (c) 6 nm NiFe/40 nm CoFe double layer, (d) 6 nm Cr/40 nm CoFe double layer, and (e) 6 nm Cu/40 nm CoFe double layer, all deposited on Si (110) wafers at room temperature. Figure 1 shows M-H loops of the films. As it is seen from Fig. 1, all double layer films have a smaller coercivity value than a single layer CoFe film. A single layer CoFe film has an easy axis coercivity of H_{ce} = 49 Oe and a hard axis coercivity of H_{ch} = 37 Oe. With the Au underlayer the hard axis coercivity (H_{ch}) of the CoFe film significantly decreased from 37 to 5 Oe. Also, a uniaxial magnetic anisotropy was observed. A dramatic reduction in the coercivity of the CoFe film was achieved using the $Ni_{80}Fe_{20}$ underlayer. The coercitivity of the NiFe/CoFe film along the hard axis is about 8.5 Oe. Analogously the Cu

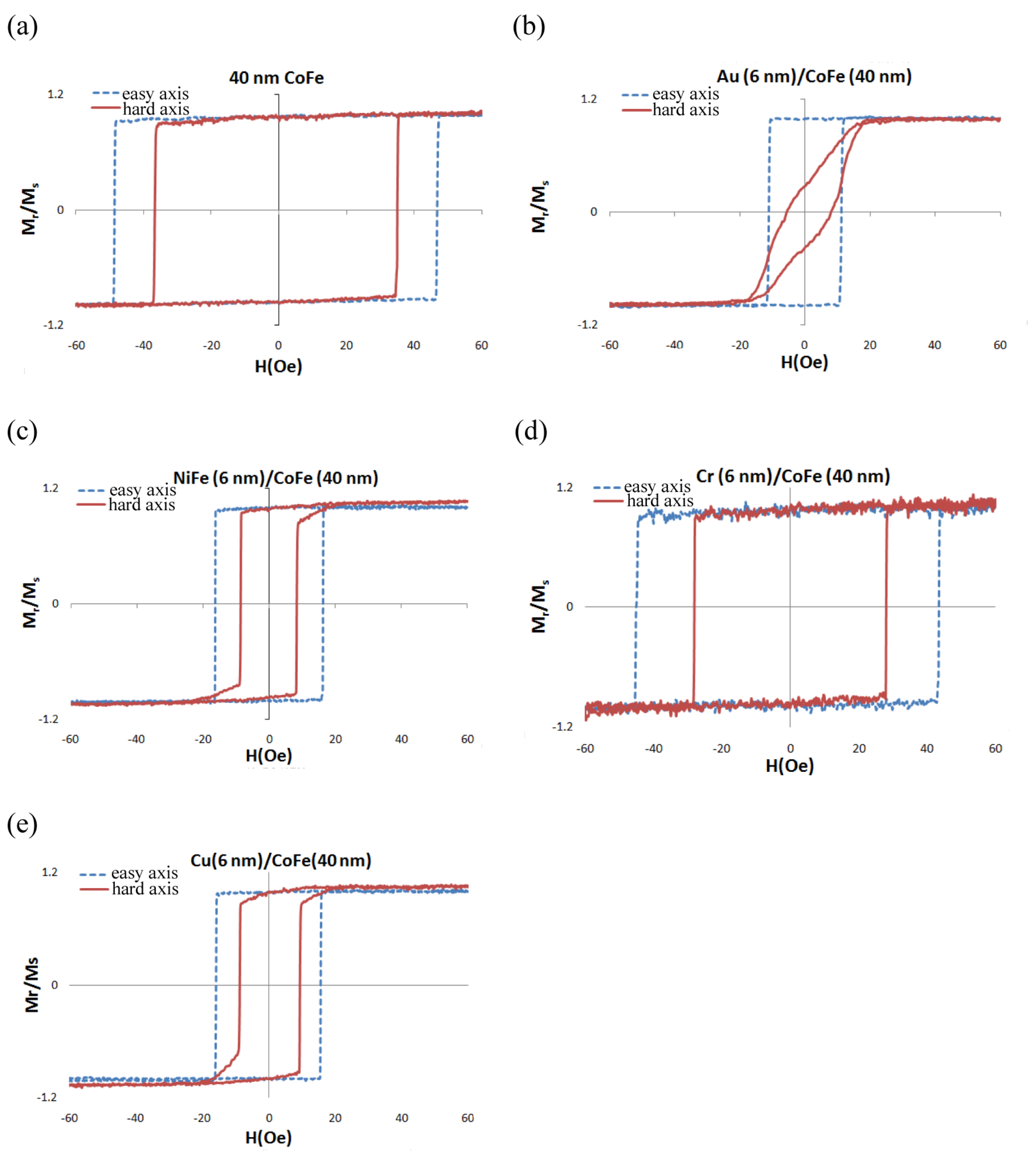

Fig. 1. Typical hysteresis loops for (a) CoFe, (b) Au/CoFe, (c) NiFe/CoFe, (d) Cr/CoFe, and (e) Cu/CoFe films.

underlayer affected the magnetic hysteresis of the CoFe film. The coercivity of the Cu/CoFe film along the hard axis was measured to be 9 Oe, which was a drastic reduction. The effect of the Cr underlayer on the magnetic hysteresis of the CoFe film is limited. The Cr/CoFe film has a hard axis coercivity of 28 Oe. Since underlayer material has an extensive impact on magnetic layers [24], a significant difference in magnetic hysteresis between four types of underlayers was investigated. The reason for coercivity reduction with the NiFe underlayer can be explained by the fact that NiFe itself is a great contributor to the magnetic properties of the system [24]. It is suggested that the improvement of soft magnetic properties with nonmagnetic underlayers is caused by texture chance and grain size reduction which can be seen in XRD analyses below.

Figure 2 shows MFM images of films in the remnant states. It was observed that Au/CoFe, NiFe/CoFe, and Cu/FeCo double layer films did not show exact magnetic domain formation. Coercivity values of these films along the hard axis are 5, 8.5, and 9 Oe, respectively. Low coercivity values (<10 Oe) of these films explains the nonexistence of magnetic domains. On the other hand, a single layer CoFe film shows clearly a magnetic domain configuration as expected from high coercivity value. In the MFM image of the Cr/CoFe film, the appearance of magnetic domains comparably with a single layer CoFe was observed. This domain configuration can be explained by a relatively high coercivity value of the film along the hard axis of about 28 Oe. The stripe domain configuration was not observed in all series of films due to films which were in the remnant state. The magnetic domain and hysteresis curve comparison of these films are very similar with the

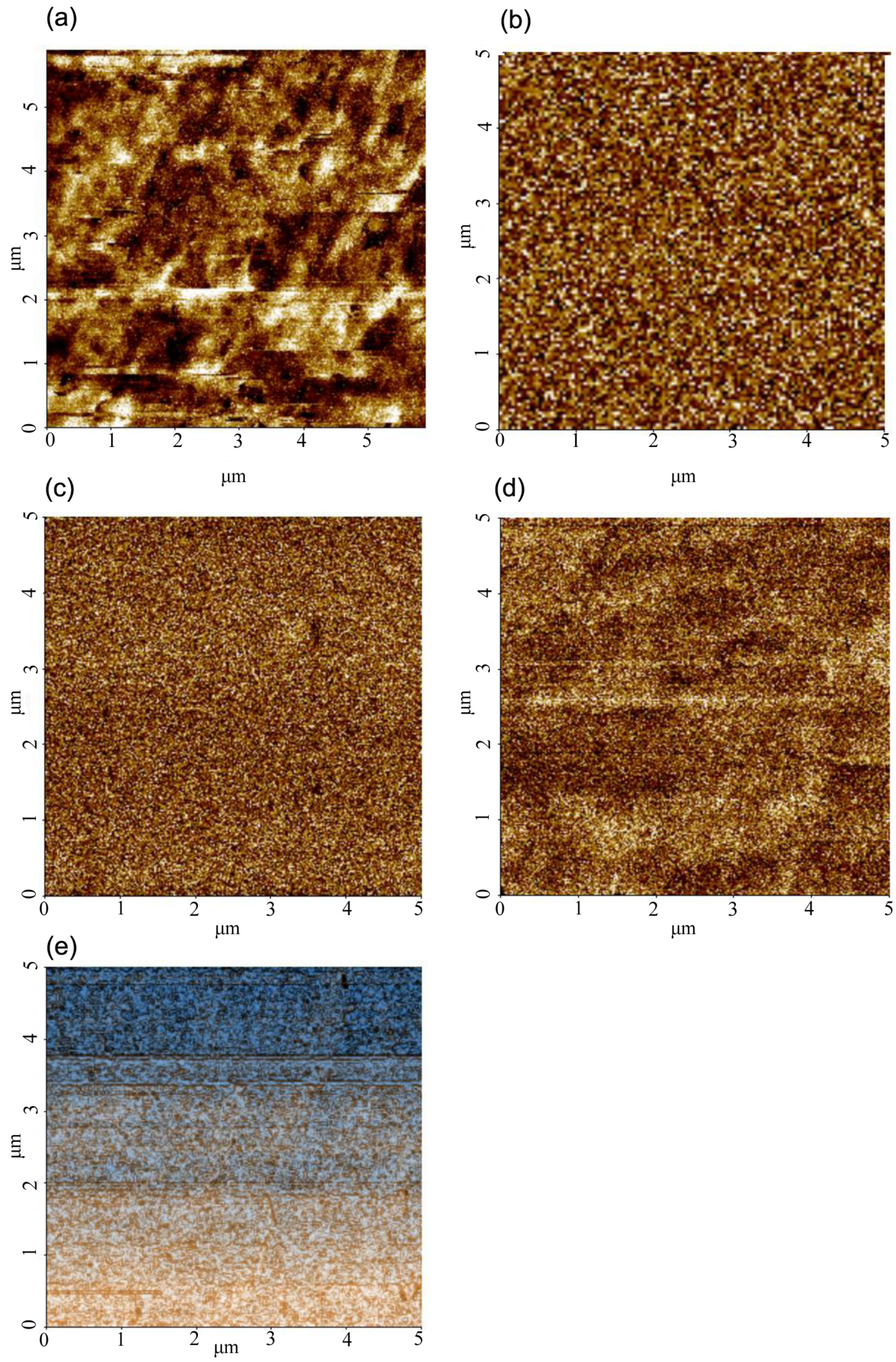

Fig. 2. MFM images of (a) CoFe, (b) Au/CoFe, (c) NiFe/CoFe, (d) Cr/CoFe, and (e) Cu/CoFe films.

experiment made by Kong et al. [16]. These results suggest that the underlayers played an important role on magnetic domain formation and reduction of coercivity. These results also show that magnetic properties of films are very sensitive to underlayers.

Figure 3 shows GI-XRD diffraction patterns of five films. The GI-XRD patterns of CoFe films with different underlayers indicate that the crystalline structure of films was greatly modified by underlayers. The single layer CoFe film shows a bcc crystal lattice structure with the main (110) and weak (220) peaks. For the NiFe/CoFe film, the main diffraction peak changed from (110) to (220). The Au/CoFe film shows weak (200) and (220) diffraction lines. It is known that grain sizes are in inverse proportion to the peak width of XRD by the Scherrer equation. The (220) diffraction peak of CoFe is much broader and shifted to lower angles with the Au underlayer, implying a much smaller grain size. It is highly possible that the coercivity reduction of the Au/CoFe film is due to grain size reduction, which could be expected from Hoffman's ripple theory. The Cu/CoFe film shows a weak (220) diffraction line. GI-XRD patterns of Au/CoFe, NiFe/CoFe, and Cu/CoFe films have a different crystalline structure as magnetic hysteresis of these films has a great difference from single CoFe. The Cr/CoFe film shows the main (110) and weak (220) diffraction lines which were similar with a single layer CoFe film. According to GI-XRD analyses of films, magnetic softness was improved with the diffraction order. It is from (110) to (220) for our samples. The texture change accompanying the reduction of grain size is observed in a recent study of Jung et al. [11]. This texture change might result in stress relief [17]. So, our results are similar with recent studies which reveal that texture change in crystal structure accompanies coercivity reduction [3, 9, 11, 12, 15]. Overall, according to GI-XRD results, it is not hard to say that film texture is tailored by underlayers. Despite all, the underlying cause is not completely understood and is still under investigation [24].

4. Conclusion

We successfully deposited magnetic CoFe films on four different underlayers. To improve soft magnetic properties of CoFe thin films, Au, Co, Cu, and NiFe underlayers were examined. Experimental results show that underlayers are effective on film texture and on magnetic hysteresis. We found a correlation between crystalline structure change and coercivity reduction. Au, NiFe, and Cu underlayers affected the crystalline texture. We suggest that nonmagnetic underlayers provide the CoFe layer to form an energetically favoured crystal texture with smaller grains. These crystalline structure changes resulted in coercivity reduction. GI-XRD results indicate that grains of double layer CoFe films are smaller than those of a single layer film. It must be pointed out that this is the primary factor for coercivity reduction according to Hoffman's ripple theory. We report that 6 nm Au, NiFe, and Cu are suitable underlayers to fabricate soft magnetic films due to their impact on reducing coercivity of CoFe films. Due to poor

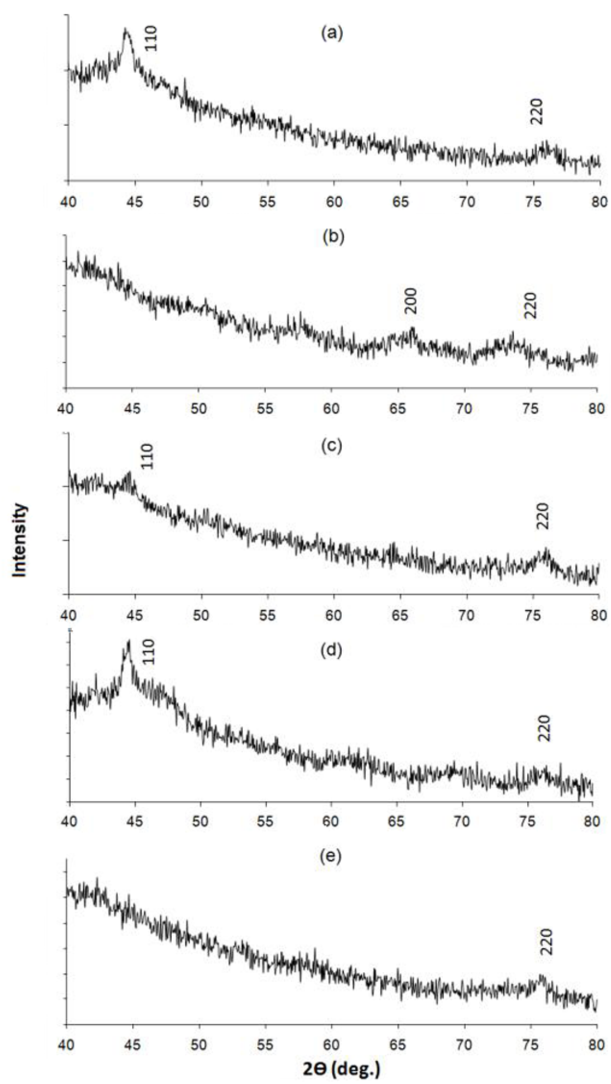

Fig. 3. GI-XRD patterns of (a) CoFe, (b) Au/CoFe, (c) NiFe/CoFe, (d) Cr/CoFe, and (e) Cu/CoFe films.

coercivity reduction, a 6 nm Cr layer is unsuitable for the preparation of soft magnetic CoFe films.

We observed that low coercivity films do not show a clear magnetic domain formation as expected. These results are very compliant with recent studies which resulted in decrease of coercivity as a consequence of underlayer effect that reduces grain size and modifies domain formation of the films. Our findings indicate that NiFe, Cu, and especially Au are good candidates as underlayer materials for the preparation of soft magnetic CoFe thin films. Since the Au/CoFe film showed the best soft magnetic properties in our experiment, further studies are in progress on different types of Au/CoFe films for recording head material applications.

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PASLUOKSNIO ĮTAKA $Co_{90}Fe_{10}$ PLONŲJŲ PLĖVELIŲ SANDARAI IR MAGNETINĖMS SAVYBĖMS

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