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Araştırma Makalesi / Research Article

Investigation of Cap and Buffer Layer Effect in Co/Ni Thin Films by Ferromagnetic Resonance Technique

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Abstract

In this study, the magnetic properties of Si(100)/X5/(Co0.3/Ni0.5)$_3$/Y5 (X: Pt, Cu and Y: Pt, Cu, all thicknesses are nm) multilayers were investigated using ferromagnetic resonance technique (FMR). In sample sets all layers (buffer, cap, and Co) were grown by magnetron sputtering while Ni sub-layers were grown by molecular beam epitaxy (MBE) at high vacuum. The effective magnetic anisotropy is 300 mT when copper is used as the buffer and cap layer, 290 mT when the buffer layer is copper, and the cap layer is Pt. On the other hand, it is seen that the effective magnetic anisotropy is 350 mT when Pt is used as buffer and cap layer, and 150 mT when Pt buffer and Cu cap layer are used. Furthermore, magnetic easy axis is out of plane when the Pt buffer layer is used, while the magnetic easy axis is parallel to the plane when the Cu buffer layer is used. The results show that the buffer and cap layers of Co/Ni thin films, which are frequently used in the field of spintronics influence the magnetic properties.

Keywords: Ferromagnetic Resonance, Magnetic Multilayers, Buffer Layer, Magnetic Anisotropy, Cap Layer.

Co/Ni İnce Filmlerde Kapak ve Tampon Katmanı Etkisinin Ferromanyetik Rezonans Tekniği ile İncelenmesi

Öz

Bu çalışmada, Si(100)/X5/(Co0.3/Ni0.5)$_3$/Y5 (X: Pt, Cu ve Y: Pt, Cu, tüm katmanların kalınlığı nanometre) çok tabakalarının manyetik özellikleri ferromanyetik rezonans tekniği kullanılarak incelenmiştir. Numune setlerinde tampon, kapak ve Co katmanları magnetron püskürtme tekniği ile büyütülürken, Ni alt katmanları yüksek vakumda moleküler ışın epitaksisi (MBE) ile büyütüldü. Etkin manyetik anizotropi, tampon ve üst katman olarak bakır kullanıldığında 300 mT, tampon katman bakır ve üst katman Pt olduğunda 290 mT'dir. Öte yandan tampon ve kapak tabakası olarak Pt kullanıldığında etkin manyetik anizotropinin 350 mT, Pt tampon ve Cu üst tabakası kullanıldığında ise 150 mT olduğu görülmektedir. Ayrıca, Pt tampon tabakası kullanıldığında manyetik kolay eksen düzlem dışındayken, Cu tampon tabakası kullanıldığında manyetik kolay eksen düzleme paraleldir. Sonuçlar, spintronik alanında sıklıkla kullanılan Co/Ni ince filmlerde tampon ve kapak katmanların manyetik özellikleri etkilediğini göstermektedir.

Anahtar Kelimeler: Ferromanyetik Rezonans, Manyetik Çokkatmanlar, Tampon Katman, Manyetik Anizotropi, Kapak Katman.

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1. Introduction

Thin magnetic films are widely used in modern data storage and spintronics technologies (Berger, 2020) and are emerging as a promising platform for biological (Freitas et al., 2012) and chemical sensing (Lueng et al., 2016, 2019). The reason why multilayer thin films are used so much in today's technology is to obtain better physical properties and to meet technological needs with cheaper costs. Rather than single-layer films, multilayered thin films in which more than one layer come together are used in the technological issues that need to be overcome. Multi-layer magnetic systems mean films formed by combining two or more magnetic layers or adding a non-magnetic layer between two magnetic layers. Properties such as giant magnetoresistance and exchange coupling are not possible in single layer films but are possible in multilayered structures.

Ultrathin magnetic multilayers are fundamental units used in spintronic applications such as magnetic random-access memories (MRAM), magnetic data storage devices, and magnetic sensors. Various experimental studies for multilayer magnetic nanostructures have also been done in the literature such as PMA in magnetic thin film with optimal Mo buffer layer (Saravanan et al., 2018), influence of anisotropy on magnetoresistance in magnetic multilayer structures (Prudnikov et al., 2019), biomedical applications (Peixoto et al., 2020), Skyrmions at zero magnetic field (Ho et al., 2019), Ta buffer layer effect in Pt/Co/Pt trilayers (Mukhopadhyay et al., 2020), magnetic nanowires applications (Piraux, 2020), magnetic anisotropy and thermal stability (Wang et al. 2013), giant magnetoresistance effect (Kalayci 2022; Lee et al. 2018; Milyaev et al. 2019), CoFeB-MgO structures with different buffer layers (Shi et al., 2018), Co/Ni multilayers with different sublayer thicknesses (You et al., 2012).

On the other hand, anisotropy is among the main physical properties that limit the usability of magnetic materials in devices. Along with the chemical composition, surface, interface, and thickness roughness are parameters that affect the anisotropy of a magnetic material (Yang et al., 2013). The ferromagnetic resonance technique (FMR) is basically based on magnetic resonance. Every magnetic system has a natural frequency due to the spin of its magnetic moments. In other words, in the presence of a magnetic field applied to the material, the magnetic moments act like magnets and split into allowed energy levels according to the spin values of the unpaired electrons. The difference between these energy levels is proportional to the Larmour frequency. A frequency is applied perpendicular to the externally applied static magnetic field. If the frequency of this field transmitted on the material is in the microwave region of the electromagnetic spectrum, the name of the technique used is Electron Spin Resonance (ESR). To obtain FMR spectrum, this technique has been frequently used in studies (Haertinger et al., 2013; Kalaycı, 2022; Kalaycı et al., 2017; Sabino et al., 2014).

In this study, the effect of buffer and cap layers in Co/Ni thin films, which are frequently used in spintronic applications, will be brought to the literature. Making the buffer and cap layers more effective in such thin films are still investigated. For this purpose, we examined the effect of buffer (Pt, Cu) and cap (Pt, Cu) layers in $[Co/Ni]_3$ multilayers with Co and Ni layers having thicknesses of 0,3 and 0,5 nm, respectively. Ferromagnetic resonance (FMR) techniques were used to define the magnetic properties of the materials.

2. Materials and Methods

Sputtering technique is based on the principle of bombarding the target material surface with high-energy gas ions in atomic size, usually by means of plasma or ion gun. The noble gas ions used in the sputtering technique give their energy to the material by hitting the target material surface, thus splitting atoms from the material surface. Moreover, Molecular Beam Epitaxy is an ultra-high vacuum evaporation process where deposition rates can be better controlled and ensures uniform layer thickness.

To investigate the effects of cap and buffer layers on Co/Ni layer structure, the cap and buffer layers were changed and fabricated as sample set-1, set-2, set-3, and set-4, respectively. The schematic representation of sample sets is shown in Fig. 1a, b, c, and d. All samples prepared in this study were grown on Si (100) substrate. Sample preparations were carried out in two stages. First, the single crystal Si (100) substrates on which the film will be grown were cleaned in an ultrasonic cleaner using acetone, isopropanol, and distilled water, respectively. Before thin films were grown, the Si substrate was heated at 750 K for 90 minutes. Pt and Cu layers were grown on silicon substrate by magnetron sputtering technique using DC generator while Co layers were grown by RF generator. There is a base pressure of $2x10^{-9}$ mbar in the sputter chamber, while during deposition, the Argon (Ar) pressure was $5x10^{-3}$ mbar. On the other hand, molecular beam epitaxy (MBE) with high vacuum chamber was used to deposit Ni sublayers.

Layers of Co, Pt, Cu, and Ni were deposited at rates of 0.440, 1.750, 0.660, and 0,303 Å/min, respectively. An FMR measurement was conducted at room temperature using a microwave frequency of 9.8 GHz and a JEOL ESR spectrometer (JESFA300). During the FMR measurements for out of plane geometry (OPG), the films were rotated from the sample plane to the sample normal with respect to the DC magnetic field applied. The magnetic field was scanned in the range of 0.0 to 2.0 T.

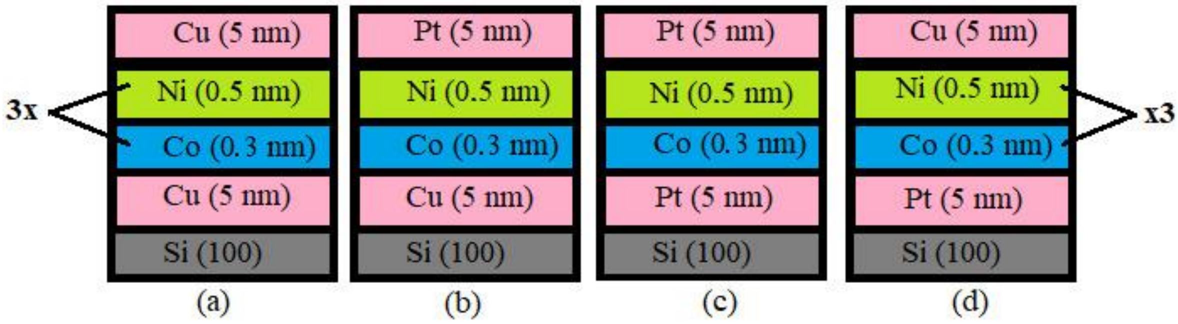

Figure 1. Schematic representation of sample sets (x3 means that the Ni and Co layers are repeated 3 times)

3. Findings and Discussion

Due to competition between the interface atoms and the bulk atoms, Co/X (X = Pt, Pd, Ni, Au) multilayers can exhibit PMA. The magnetization direction occurs perpendicular to the film plane if the number of interface atoms exceeds the number of bulk atoms and a positive HKeff value is obtained. In multilayered Co/Ni films, decreasing or increasing HKeff can be attributed to changes in the buffer or cap layer. With increasing n, the interface between Co or Ni and the buffer and cap layers becomes less evident. Because PMA is induced more by these interfaces than by Co/Ni interfaces, PMA strength will decrease as these interfaces become less prominent. Moreover, the PMA's strength decreases with increasing roughness (Sabino et al., 2014). The magnetization directions of easy axes of sample sets and the angular dependency of the resonance fields are shown in Figure 2-5, respectively.

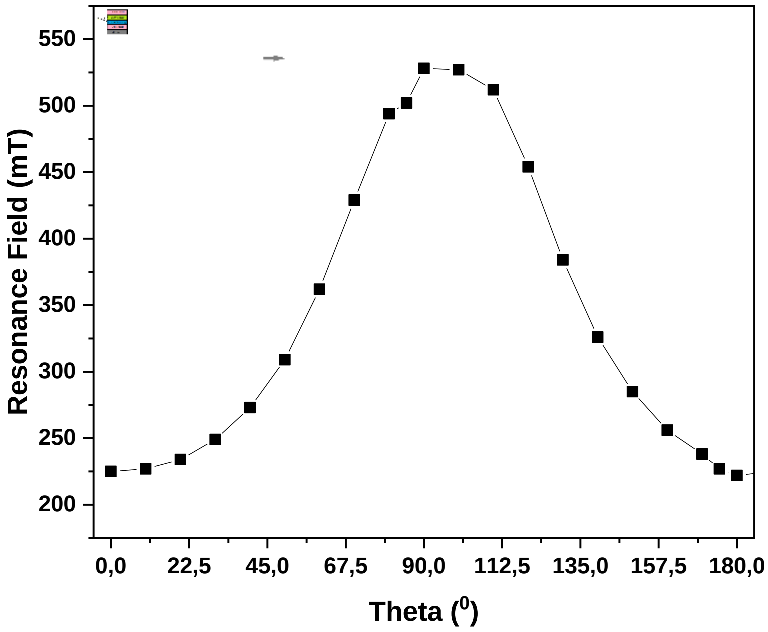

Figure 2. Ferromagnetic Resonance Field of Sample Set-1 measured in out of plane geometry.

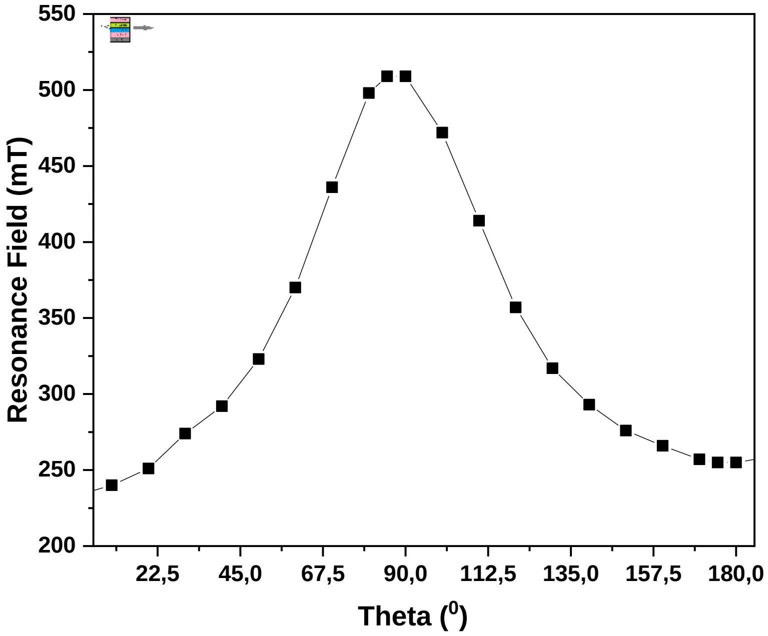

Figure 3. Ferromagnetic Resonance Field of Sample Set-2 measured in out of plane geometry.

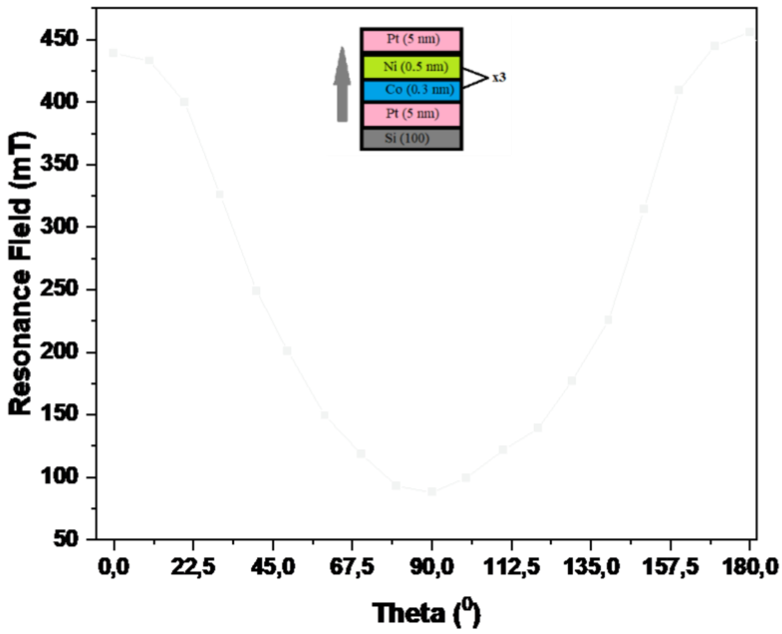

Figure 4. Ferromagnetic Resonance Field of Sample Set-3 measured in out of plane geometry.

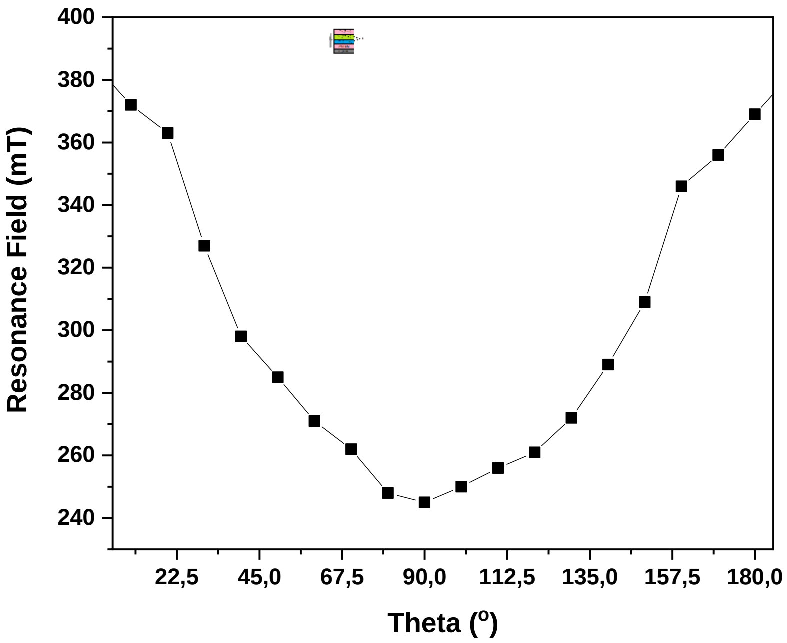

Figure 5. Ferromagnetic Resonance Field of Sample Set-4 measured in out of plane geometry.

Looking at Figures 2 and 3, a lower resonance field is required at 0 degrees, while a higher resonance field is required at 90 degrees. This indicates that the 1st and 2nd sample sets have in plane magnetic anisotropy. On the other hand, the opposite is true for figures 4 and 5. A higher resonance field is required at 0 degrees, while a lower resonance field is required at 90 degrees. This shows that the 3rd and 4th sample sets have perpendicular magnetic anisotropy (PMA).

The findings suggest that an interface effect between the buffer or cap layer and the Co or Ni layer is the cause of the uniaxial anisotropy perpendicular to the [Co/Ni] multilayer film (Posth et al., 2009). PMA is attributed to both bulk (111) magneto crystalline anisotropy and interface anisotropy in Co/Ni multilayers (Gottwald et al., 2012). The perpendicular magneto crystalline anisotropy can be raised by using a Pt buffer layer or Pt cap layer (Bersweiler et al., 2016). It has been demonstrated that having a Pt buffer layer and a Pt cap layer will cause the magnetization's easy direction to change out of plane. In addition to the anisotropy-inducing Co-Ni interface, it is observed that the out of plane easy axis is supported by a Pt cap layer instead of a Cu cap layer contrary to (Posth et al., 2009). Therefore, because of the strong magneto-crystalline anisotropy in sample sets 3 and 4 (Figure 4 and 5), PMA is observed in these samples.

FMR offers a method for figuring out a sample's magnetization direction as well to evaluate the sample's anisotropy strength. HKeff describes effective anisotropy and indicates the strength of anisotropy (Bersweiler et al., 2016). It is the difference between the resonance field of zero degrees and ninety degrees that determines the value of effective magnetic anisotropy. The effective magnetic anisotropy fields are given in Table 1 below. In addition, these values are shown in Figure 6 in graphic form.

Table 1. Effective Magnetic Anisotropy Values of All Samples

	Cu buffer - Cu Cap Layer	**Cu buffer - Pt Cap Layer**	**Pt buffer - Pt Cap Layer**	**Pt buffer - Cu Cap Layer**
Effective Magnetic Anisotropy (mT)	300	290	350	150

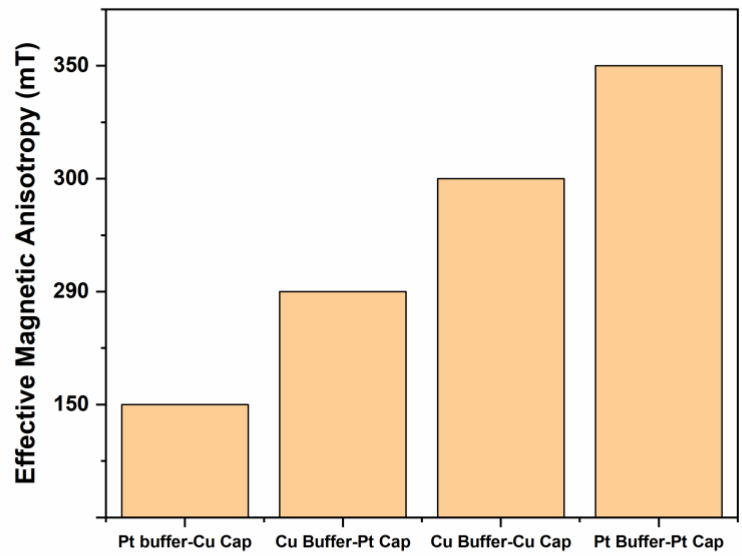

Figure 6. Effective Magnetic Anisotropy Fields of All Samples

It is seen that the effective magnetic anisotropy is 300 mT when copper is used as the buffer and cap layer, and 290 mT when the Buffer layer is copper, and the cap layer is Pt. On the other hand, it is seen that the effective magnetic anisotropy is 350 mT when Pt is used as buffer and cap layer, and 150 mT when Pt buffer and Cu cap layer are used.

4. Conclusions and Recommendations

The role of the buffer and cap layers in Co/Ni thin magnetic films have been studied by ferromagnetic resonance technique. The thicknesses of the buffer and cap layers were fixed at 5 nm. Pt, Cu buffer and cap were used as layers to examine the layer effect. When the buffer and cap layers are Cu, effective magnetic anisotropy is 300 mT; when the buffer layer is Cu and the cap layer is Pt, it is 290 mT. The effective magnetic anisotropy is 350 mT when Pt buffer and cap layers used, and 150 mT when Pt buffer and Cu cap layers are used. In addition, the magnetic easy axis is out of plane when the Pt buffer layer is used (Yang et al., 2013), while it is parallel to the plane when the Cu buffer layer is used.

Despite a Pt cap layer, which in theory would offer more interface anisotropy, Co/Ni multilayers deposited on Cu buffer layers do not exhibit perpendicular anisotropy. The reason for this is thought to be increased roughness or interfacial lattice mismatch when Cu buffer layer is used. The results showed that it is important to select a suitable buffer layer to obtain PMA. In Co/Ni thin films which are frequently used in the field of spintronics such as MRAM, spin-torque oscillators and magnetic electrode, the buffer and cap layer influence the magnetic properties. In future studies, it can be investigated how the buffer and cap layer thicknesses affect the magnetic properties of these thin films.

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Statement of Conflicts of Interest

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

The author declares that this study complies with Research and Publication Ethics.

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