Structure, Magnetic Property, Surface Morphology, and Surface Energy of Co\textsubscript{40}Fe\textsubscript{40}V\textsubscript{10}B\textsubscript{10} Films on Si(100) Substrate

Sin-Liang Ou\textsuperscript{1}, Wen-Jen Liu\textsuperscript{2}, Yung-Huang Chang\textsuperscript{3}, Yuan-Tsung Chen\textsuperscript{4,4*}, Yu-Tang Wang\textsuperscript{4}, Wei-Hsuan Li\textsuperscript{4}, Jiun-Yi Tseng\textsuperscript{4}, Te-Ho Wu\textsuperscript{4,4*}, Po-Wei Chi\textsuperscript{5} and Chun-Lin Chu\textsuperscript{6,6*}

\textsuperscript{1} Bachelor Program for Design and Materials for Medical Equipment and Devices, Da-Yeh University, Changhua 51591, Taiwan; slo@mail.dyu.edu.tw
\textsuperscript{2} Department of Materials Science and Engineering, I-Shou University, Kaohsiung 840, Taiwan; jurgen@isu.edu.tw
\textsuperscript{3} Bachelor Program in Interdisciplinary Studies, National Yunlin University of Science and Technology, 123 University Road, Section 3, Douliou, Yunlin 64002, Taiwan; g9213752@gmail.com
\textsuperscript{4} Graduate School of Materials Science, National Yunlin University of Science and Technology, 123 University Road, Section 3, Douliou, Yunlin 64002, Taiwan; cherry5244@yahoo.com.tw (Y.-T.W.); bighti40325@gmail.com (W.-H.L.); jytseng@yuntech.edu.tw (J.-Y.T.); wuth@yuntech.edu.tw (T.-H.W.)
\textsuperscript{5} Institute of Physics, Academia Sinica, Nankang, Taipei 11529, Taiwan; jacky01234567891@hotmail.com
\textsuperscript{6} National Applied Research Laboratories, Taiwan Semiconductor Research Institute, Hsinchu 30078, Taiwan; jenlen@narlabs.org.tw

* Correspondence: ytchen@yuntech.edu.tw; Tel.: +886-5-534-2601

Received: 18 December 2019; Accepted: 4 January 2020; Published: 8 January 2020

Abstract: When B and V are added to CoFe material, the mechanical strength and spin tunneling polarization of a CoFe alloy can be improved and enhanced by the high tunneling magnetoresistance (TMR) ratio. Based on these reasons, it is worthwhile investigating Co\textsubscript{40}Fe\textsubscript{40}V\textsubscript{10}B\textsubscript{10} films. In this work, X-ray diffraction (XRD) showed that Co\textsubscript{40}Fe\textsubscript{40}V\textsubscript{10}B\textsubscript{10} thin films have some distinct phases including CoFe (110), CoFe (200), FeB (130), and V (110) diffracted peaks with the strongest diffracted peak for 30 nm. The lowest low-frequency alternate-current magnetic susceptibility (\(\chi_{ac}\)) was detected at 30 nm because the large grain distribution inducing that high coercivity (H\(_c\)) enhances the spin coupling strength and low \(\chi_{ac}\). The external field (H\(_{ext}\)) had difficulty rotating in the spin state, hence, the spin sensitivity was reduced and the \(\chi_{ac}\) value decreased due to increased surface roughness. The 20 mm thickness had the highest \(\chi_{ac}\) and strong adhesion. According to the magnetic and surface energy results, the optimal thickness is 20 nm due as it had the highest \(\chi_{ac}\) and strong adhesion.

Keywords: Co\textsubscript{40}Fe\textsubscript{40}V\textsubscript{10}B\textsubscript{10} films; low-frequency alternate-current (AC) magnetic susceptibility (\(\chi_{ac}\)); Maximum \(\chi_{ac}\); resonance frequency (f\(_{res}\)); contact angles; adhesion

1. Introduction

The unique magnetic properties of CoFeB films have attracted wide attention in recent years [1–8]. In spin-valve magnetic tunneling junctions (MTJs), CoFeB thin films can be sputtered into free or pinned layers, resulting in apparent tunneling magnetoresistance (TMR), perpendicular magnetic anisotropy (PMA), and soft ferromagnetic properties. The films can be applied for magnetoresistance random access memory (MRAM) and sensor components [9–15]. According to these properties, CoFeB films can be used to many kinds of spintronic devices. In 2010, Ohno et al. found that the PMA of
the CoFeB/MgO system can combine with the perpendicular MTJ and produce a tremendous TMR effect [16]. Therefore, increasing the thickness of the PMA CoFeB layer has become a very important goal in research. In previous research by our group, the Co$_{40}$Fe$_{40}$V$_{20}$ film has been only studied with regard to its structural and magnetic properties [17]. CoFeV is also compatible with other seed layers or semiconductor processes to improve physical performance. For example, Ru/CoFeV and Ta/CoFeV can be useful in magnetics and semiconductor applications [18]. Adding B and V elements to the CoFe material has advantages. When V is added to the CoFe alloy, the mechanical strength and magnetic properties can be improved to a high durability of materials, which could increase its ductility and decrease its coercivity ($H_c$) and brittleness [19–23]. Adding B to the CoFe alloy can improve spin tunneling polarization and increase the high TMR ratio. Nevertheless, due to the low coercivity and high TMR properties of CoFeB films at room temperature (RT), most of the studies have focused on the CoFeB magnetic films [6–8]. According to above reasons, it is worthwhile investigating the specific properties of CoFeVB in this study where V was added to the CoFeB alloy to form a new Co$_{40}$Fe$_{40}$V$_{10}$B$_{10}$ material. Based on the magnetic and mechanical properties, the CoFeVB has low $H_c$ and high strength, which can be suitable as a free layer of spin-value MTJ. CoFeVB is generally inserted as a seed layer, buffer layer, capping layer, and protective layer in a multilayered structure, which can be used extensively in MRAM and semiconductor applications. It is compatible with the semiconductor process and can also be used as a free or pinned layer in spin-value MTJ. Therefore, the surface energy and adhesion are relatively important in this investigation and it is a worthwhile cause to detect the structure, magnetic characteristics, and adhesive property.

2. Materials and Methods

Under the condition of 50 W power, CoFeVB was deposited on a Si(100) structure by the sputtering method, and the thickness of CoFeVB was 10–40 nm. The deposited temperature ($T_s$) of CoFeVB was maintained at RT. The power density was 1.09 W/cm$^2$ and the deposition rate was 1.2 nm/min. The sputtering chamber was square, and the distance between target and substrate was about 15 cm. The substrate faced the target. The target composition of the CoFeVB alloy was 40 at% Co, 40 at% Fe, 10 at% V, and 10 at% B. The typical base chamber pressure was 1 × 10$^{-7}$ Torr, and the Ar working chamber pressure was 2 × 10$^{-3}$ Torr. The structure of the Co$_{40}$Fe$_{40}$V$_{10}$B$_{10}$ thin films was detected by X-ray diffraction (XRD) (Philips, Amsterdam, The Netherlands) of CuK$_{\alpha 1}$ (Philips X’pert). The field emission scanning electron microscopy (FESEM) (JEOL, Tokyo, Japan) equipped with energy dispersive spectrometer (EDX) spectrometer was used for surface morphology and determination of the elemental composition of films. In addition, the in-plane low-frequency alternate-current magnetic susceptibility ($\chi_{ac}$) of Co$_{40}$Fe$_{40}$V$_{10}$B$_{10}$ was studied using a $\chi_{ac}$ analyzer. The model, manufacturer, and country of manufacture of the $\chi_{ac}$ analyzer were XacQuan, MagQu Co. Ltd. New Taipei City, and Taiwan, respectively. First, the $\chi_{ac}$ analyzer with an external magnetic field was used to calibrate the reference standard sample. Then, the tested sample was inserted into the $\chi_{ac}$ analyzer. The driving frequency was between 10 and 25,000 Hz. The $\chi_{ac}$ was determined by magnetization measurement. All tested samples had the same shape and size to eliminate demagnetization factors. The $\chi_{ac}$ valve is an arbitrary unit (a.u.), because the alternating current result corresponds to the reference standard sample and is a comparative value. The $\chi_{ac}$ analyzer measured the relationship between susceptibility and frequency. The optimal resonance frequency ($f_{res}$) is measured by the $\chi_{ac}$ analyzer, which represents the frequency of the maximum $\chi_{ac}$. The surface roughness and morphology of CoFeVB films were studied by atomic force microscopy (AFM) (NT-MDT, Moscow, Russia). The in-plane hysteresis loop of the Co$_{40}$Fe$_{40}$V$_{10}$B$_{10}$ films was obtained by alternating gradient magnetometer (AGM) (PMC, Ohio, USA). Finally, using deionized (DI) water and glycerol as the experimental liquids, the surface energy of the Co$_{40}$Fe$_{40}$V$_{10}$B$_{10}$ thin films was calculated by measuring the contact angle [24–26], which is defined as the surface excess free energy of a specific crystal surface area [27].
3. Results

The X-ray diffraction (XRD) patterns are displayed in Figure 1. From the results in Figure 1, the Co$_{40}$Fe$_{40}$V$_{10}$B$_{10}$ demonstrated diffracted peaks in all Co$_{40}$Fe$_{40}$V$_{10}$B$_{10}$ thin films, indicating that there are distinct phases including CoFe (110) at about $2\theta$ with 46°, V (110) at $2\theta$ with 48°, FeB (130) at $2\theta$ with about 54°, and the signal CoFe (200) at $2\theta$ with 57°. The XRD intensities increased from 10 nm up to 30 nm and then drastically decreased for the 40 nm film. It can be reasonably concluded that the 40 nm is not a homogeneous and discontinuous film, thus inducing a weak crystalline peak. Apparently, a distinct high crystalline XRD peak occurred at 30 nm. According to Scherrer’s formula (1), the average grain size (D) can be estimated by measuring the full width of the half-height width (FWHM, B) of the 30-nm diffraction peak. Scherrer’s formula is [28,29],

$$D = \frac{k\lambda}{B\cos\theta} \tag{1}$$

where $k$ (0.89) is Scherrer’s constant; $\lambda$ is the X-ray wavelength of the Cu K$_{\alpha1}$ line; B is the FWHM of the 30-nm diffraction peak; and $\theta$ is the half angle of the diffraction peak. This formula shows that D is proportional to $1/B$, so the smaller B corresponds to larger grains. The 30 nm of the Co$_{40}$Fe$_{40}$V$_{10}$B$_{10}$ thin film has a smaller B and can induce larger grains to be deposited.

![Figure 1. X-ray diffraction patterns of the Co$_{40}$Fe$_{40}$V$_{10}$B$_{10}$ films.](image1)

The composition of the CoFeVB alloy films was determined. The composition data for CoFeVB films by FESEM equipped with an EDX spectrometer was shown in Table 1. The corresponding EDX patterns of the Co$_{40}$Fe$_{40}$V$_{10}$B$_{10}$ films are shown in Figure 2. However, the B content could not be measured in the EDX measurement, because the boron atom is too light. According to the result, it was found that the 40 nm film was not a homogeneous composition. Non-uniform composition is caused by the multi-directional and multi-angle scattering of the sputtered atoms [30,31].
Table 1. EDX analysis data for the alloy films.

| CoFeVB (nm) | Co (at%) | Fe (at%) | V (at%) |
|-------------|----------|----------|---------|
| 10          | 32.02    | 33.66    | 34.32   |
| 20          | 32.44    | 32.92    | 34.64   |
| 30          | 30.51    | 31.75    | 37.74   |
| 40          | 20.52    | 29.61    | 49.87   |

Figure 2. EDX patterns of the Co$_{40}$Fe$_{40}$V$_{10}$B$_{10}$ thin films with various thicknesses. (a) 10 nm, (b) 20 nm, (c) 30 nm, and (d) 40 nm.

Figure 3 presents the low-frequency alternate-current magnetic susceptibility ($\chi_{ac}$) results in the CoFeVB films. When the thickness increased from 10 nm to 40 nm, $\chi_{ac}$ decreased sharply with the increase in frequency. According to Equation (2) [29,32–35],

$$H_c = P_c D^6 K_1^4/\mu_0 M_s A^3,$$

where $P_c$ is the order constant of unity; $D$ is the grain size; $K_1$ is the magneto-crystalline anisotropy; $\mu_0$ is the free space permeability; $M_s$ is the saturation magnetization; $A$ is the exchange stiffness constant; and $H_c$ is the coercivity. By Equation (2), it can be reasonably concluded that $H_c$ is proportional to crystalline grain size $D^6$ and demonstrates that large grain size distribution has a higher $H_c$. The lowest $\chi_{ac}$ was detected at 30 nm due to the large grain distribution and high coercivity, which enhanced the spin coupling strength [17,36,37]. The range of the external field ($H_{ext}$) used was not sufficient to rotate the spin state, consequently, the spin sensitivity was reduced and the $\chi_{ac}$ value was decreased.

Figure 4 shows the maximum $\chi_{ac}$ value associated with the thickness of the CoFeVB. For CoFeVB films with a thickness of 20 nm, the maximum $\chi_{ac}$ value of $1.96 \times 10^{-2}$ was obtained. When the thickness increased from 10 to 20 nm, the maximum $\chi_{ac}$ was increased from $1.5 \times 10^{-2}$ to $1.96 \times 10^{-2}$. In addition, the maximum $\chi_{ac}$ decreased from $1.96 \times 10^{-2}$ to $1.31 \times 10^{-2}$ as the thickness ranged from 20 to 40 nm. The results show that the spin sensitivity is the strongest at the optimal resonance frequency ($f_{res}$). The maximum $\chi_{ac}$ at the optimal resonance frequency has the following physical significance. At low frequencies, the alternating-current dipole moment is caused by the oscillation of the volume dipole moment in each domain. The external alternating current magnetic field plays a driving role. The recovery of magnetic interaction is between domains. There is a resonance frequency as the
driving force acting on the system. Therefore, the peak frequency of the low frequency susceptibility corresponds to the resonance frequency of the magnetic dipole moment oscillation in the domain. At frequency, the $\chi_{ac}$ peak represents the spin exchange coupling interaction and domain dipole moment [38]. As shown in Figure 4, the best magnetic properties were achieved on the CoFeVB film with a thickness of 20 nm.

Figure 3. For samples with a thickness of 10 nm to 40 nm, the low-frequency alternate-current magnetic susceptibility ($\chi_{ac}$) as a function of the frequency from 10 to 25,000 Hz.

Figure 4. Maximum alternate-current magnetic susceptibility for the CoFeVB films.

Figure 5. Optimal resonance frequency for films of various thicknesses.

Figure 4. Maximum alternate-current magnetic susceptibility for the CoFeVB films.
The optimal resonance frequency of CoFeVB films is shown in Figure 5. According to the $f_{\text{res}}$ value, the maximum $\chi_{\text{ac}}$ value is measured with the strongest spin sensitivity at this frequency [38,39]. The $f_{\text{res}}$ presented an oscillating trend with a minimum critical frequency of 50 Hz. For all CoFeVB thicknesses, the $f_{\text{res}}$ value of all CoFeVB thicknesses was less than 200 Hz, which indicates that the films are beneficial to the application of sensors, transformers, and magnetic recording media at low frequencies.

Figure 5. Optimal resonance frequency for films of various thicknesses.

Figure 6 shows the hysteresis loop of the films with an in-plane external field ($H_{\text{ext}}$) for various CoFeVB thicknesses, as determined through AGM. The external field ($H_{\text{ext}}$) was 1000 Oe in the AGM measurement, which was enough to observe the saturated magnetic spin status of the Co$_{40}$Fe$_{40}$V$_{10}$B$_{10}$ films. While the magnetization for the 10 nm and 20 nm films was very close to each other, the magnetization for the 30 nm and 40 nm was lower. It can be reasonably concluded that the 40 nm film was not homogeneous and was a discontinuous film, inducing weak magnetization. Table 1, which presents the EDX analysis, also indicates that the 40 nm film was not a homogeneous composition. The enlarged illustration of Figure 6 shows that the largest $H_c$ was achieved at 30 nm. The external field ($H_{\text{ext}}$) used had difficulty rotating the spin state, consequently reducing the magnetization and decreasing the $\chi_{\text{ac}}$ value. From Figure 6, the results indicate that the in-plane hysteresis loop of the CoFeVB films was an easy axis. Moreover, the hysteresis loops also indicate that the CoFeVB films are magnetically soft.

The surface roughness and morphology of the CoFeVB films were investigated by AFM, as shown in Figure 7a–d. When the thickness was increased from 10 nm to 40 nm, the root-mean-square values ($R_q$) of surface roughness were 0.57 nm, 0.39 nm, 1.07 nm, and 0.69 nm, respectively. The increased surface roughness can lead to the pinning effect of the domain wall, which is not easy to move, resulting in an increase in coercivity and a decrease in the $\chi_{\text{ac}}$ value [40,41]. In Figures 4 and 7, the maximum alternate-current magnetic susceptibility and surface roughness had a relation, which indicates that the increased surface roughness can lead to the pinning effect of the domain wall, which has difficulty moving, resulting in the increase in coercivity and the decrease in the $\chi_{\text{ac}}$ value.
Figure 6 shows the hysteresis loop of the films with an in-plane external field (H\text{ext}) for various CoFeVB thicknesses, as determined through AGM. The external field (H\text{ext}) was 1000 Oe in the AGM measurement, which was enough to observe the saturated magnetic spin status of the Co40Fe40V10B10 films. While the magnetization for the 10 nm and 20 nm films was very close to each other, the magnetization for the 30 nm and 40 nm was lower. It can be reasonably concluded that the 40 nm film was not homogeneous and was a discontinuous film, inducing weak magnetization. Table 1, which presents the EDX analysis, also indicates that the 40 nm film was not a homogeneous composition. The enlarged illustration of Figure 6 shows that the largest H\text{c} was achieved at 30 nm. The external field (H\text{ext}) used had difficulty rotating the spin state, consequently reducing the $\chi_{\text{ac}}$ value.

From Figure 6, the results indicate that the in-plane hysteresis loop of the CoFeVB films was an easy axis. Moreover, the hysteresis loops also indicate that the CoFeVB films are magnetically soft.

Figure 7. AFM 3D images showing different surface roughness of the Co40Fe40V10B10 thin films with various thicknesses: (a) 10 nm, (b) 20 nm, (c) 30 nm, and (d) 40 nm.

Figure 6. In-plane magnetic hysteresis loop of the Co40Fe40V10B10 thin films.

Figure 8a–d showed the contact angles (θ) with DI water: 73.85°, 72.92°, 79.44°, and 70.34° for the 10, 20, 30, and 40 nm films, respectively. Figure 8e–h shows the contact angles (θ) with glycerol as 62.59°, 74.27°, 59.64°, and 60.23° for 10, 20, 30, and 40 nm films, respectively. The contact angle results from DI water and glycerin are shown in Figure 8. The CoFeVB films can be used as a seed or buffer...
layer, so the surface energy and adhesion are very important. The results show that the water drops of CoFeVB film are almost spherical. The contact angles of the Co_{40}Fe_{40}V_{10}B_{10} film were less than 90°, which indicates that the film has a good wetting effect and is hydrophilic. When the surface free energy is high, the liquid absorption is large and the liquid absorption area is also large, which leads to the decrease in contact angle [24,25,42].

![Figure 8. Contact angles of the Co_{40}Fe_{40}V_{10}B_{10} thin films with DI water: (a) 10 nm, (b) 20 nm, (c) 30 nm, and (d) 40 nm. Contact angles of the Co_{40}Fe_{40}V_{10}B_{10} thin films with glycerol: (e) 10 nm, (f) 20 nm, (g) 30 nm, and (h) 40 nm.](image)

The surface energy of the Co_{40}Fe_{40}V_{10}B_{10} films was obtained by measured contact angles, as shown in Figure 9 [24–29,32]. High surface energy corresponds to strong adhesion [43]. It was found that the surface energy tended to increase with the increase in thickness. Figure 9 shows that when the thickness increased from 10 nm to 40 nm, the surface energy range increased from 34.2 mJ/mm² to 51.5 mJ/mm², which indicates that the surface energy is larger and the adhesion is enhanced. The surface energy is the key factor affecting the adhesion of the film. As CoFeVB is compatible with MTJ applications, it can also be used as a free layer and in combination with other layers.
4. Conclusions

XRD demonstrated that a high significant crystalline peak was achieved at 30 nm because it could be reasonably concluded that it had a large grain distribution. As the frequency increased, the $X_{ac}$ decreased sharply. The lowest $X_{ac}$ was detected at 30 nm due to the large grain distribution inducing high coercivity, resulting in an enhanced spin coupling strength. The increased surface roughness could be the induced domain wall pinning effect and also indicated the same tendency. The range of the external field used was not sufficient to rotate the spin state, consequently reducing the spin sensitivity and decreasing the $X_{ac}$ value. The results showed that the maximum $1.96 \times 10^{-2}$ amplitude was obtained at a $f_{res}$ of 50 Hz for the 20 nm film. The contact angles of the Co$_{40}$Fe$_{40}$V$_{10}$B$_{10}$ thin films were less than $90^\circ$, which indicates that the films are hydrophilic. The surface energy is closely related to the adhesion of the film. When the thickness increased from 10 to 40 nm, the surface energy changed from 34.2 mJ/mm$^2$ to 51.5 mJ/mm$^2$, indicating that the larger the surface energy, the stronger the adhesion. It can be seen that the surface energy tends to increase with an increase in the thickness. The magnetic properties and surface energy efficiency showed that the optimal thickness of the Co$_{40}$Fe$_{40}$V$_{10}$B$_{10}$ film was 20 nm, which had the highest $X_{ac}$ value and strong adhesion.

Author Contributions: Conceptualization, S.-L.O. and Y.-T.C.; Methodology, Y.-T.C., W.-H.L., Y.-T.W., T.-H.W., and P.-W.C.; Validation, formal analysis, Y.-H.C. and J.-Y.T.; Investigation, Y.-T.C. and W.-J.L.; Resources, C.-L.C.; Writing—original draft preparation, Y.-T.C.; Writing—review and editing, Y.-T.C. and S.-L.O.; Supervision, Y.-T.C. and S.-L.O.; Project administration, Y.-T.C. and Y.-T.W.; Funding acquisition, W.-J.L. and Y.-H.C. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the Ministry of Science and Technology (grant No. MOST108-2221-E-224-015-MY3 and MOST105-2112-M-224-001), and the National Yunlin University of Science and Technology (grant No. 109T01).

Conflicts of Interest: The authors declare that there are no conflict of interest regarding the publication of this paper. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

References

1. Ohshima, N.; Sato, H.; Kanai, S.; Llandro, J.; Fukami, S.; Matsukura, F.; Ohno, H. Current-induced magnetization switching in a nano-scale CoFeB-MgO magnetic tunnel junction under in-plane magnetic field. *AIP Adv.* 2017, *7*, 055927. [CrossRef]

2. Siripongsakul, T.; Naganuma, H.; Kovacs, A.; Kohn, A.; Oogane, M.; Ando, Y. Observation of single-spin transport in an island-shaped CoFeB double magnetic tunnel junction prepared by magnetron sputtering. *Philos. Mag.* 2016, *96*, 310–319. [CrossRef]
3. Hamada, T.; Ohno, T.; Maekawa, S. First-principles study of electronic and magnetic structures of CoFeB/Ta and CoFeTaB heterostructures. *Mol. Phys.* **2015**, *113*, 314–318. [CrossRef]
4. Sun, J.Z. Resistance-area product and size dependence of spin-torque switching efficiency in CoFeB-MgO based magnetic tunnel junctions. *Phys. Rev. B.* **2017**, *96*, 064437. [CrossRef]
5. Lu, J.W.; Chen, E.; Kabir, M.; Stan, M.R.; Wolf, S.A. Spintronics technology: Past, present and future. *Int. Mater. Rev.* **2016**, *61*, 456–472. [CrossRef]
6. Meo, A.; Chureemart, P.; Wang, S.; Chepulskyy, R.; Apalkov, D.; Chantrell, R.W.; Evans, L.R.F. Thermally nucleated magnetic reversal in CoFeB/MgO nanodots. *Sci. Rep.* **2017**, *7*, 16729. [CrossRef] [PubMed]
7. Xiong, R.; Fang, B.; Li, G.; Xiao, Y.; Tang, M.; Li, Z. Electric-field tuning of ferromagnetic resonance in CoFeB/MgO magnetic tunnel junction on a piezoelectric PMN-PT substrate. *Appl. Phys. Lett.* **2017**, *111*, 062401. [CrossRef]
8. Okada, A.; Kanai, S.; Fukami, S.; Sato, H.; Ohno, H. Electric-field effect on the easy cone angle of the easy-cone state in CoFeB/MgO investigated by ferromagnetic resonance. *Appl. Phys. Lett.* **2018**, *112*, 172402. [CrossRef]
9. Cao, J.; Chen, Y.; Jin, T.; Gan, W.; Wang, Y.; Zheng, Y.; Lv, H.; Cardoso, S.; Wei, D.; Lew, W.S. Spin orbit torques induced magnetization reversal through asymmetric domain wall propagation in Ta/CoFeB/MgO structures. *Sci. Rep.* **2018**, *8*, 13395–13399. [CrossRef] [PubMed]
10. Bibes, M.; Villegas, J.E.; Barthélémy, A. Ultrathin oxide films and interfaces for electronics and spintronics. *Adv. Phys.* **2011**, *60*, 5–84.
11. Igarashi, J.; Llandro, J.; Sato, H.; Matsukura, F.; Ohno, H. Magnetic-field-angle dependence of coercivity in CoFeB/MgO magnetic tunnel junctions with perpendicular easy axis. *Appl. Phys. Lett.* **2017**, *111*, 132407. [CrossRef]
12. Dohi, T.; Kanai, S.; Matsukura, F.; Ohno, H. Electric-field effect on spin-wave resonance in a nanoscale CoFeB/MgO magnetic tunnel junction. *Appl. Phys. Lett.* **2017**, *111*, 072403. [CrossRef]
13. Lattery, D.M.; Zhang, D.; Zhu, J.; Hang, X.; Wang, J.P.; Wang, X. Low Gilbert Damping Constant in Perpendicularly Magnetized W/CoFeB/MgO Films with High Thermal Stability. *Sci. Rep.* **2018**, *8*, 13395–13399. [CrossRef] [PubMed]
14. Ichikawa, N.; Dohi, T.; Okada, A.; Sato, H.; Fukami, S.; Ohno, H. Non-linear variation of domain period under electric field in demagnetized CoFeB/MgO stacks with perpendicular easy axis. *Appl. Phys. Lett.* **2018**, *112*, 202402. [CrossRef]
15. Huai, Y.; Gan, H.; Wang, Z.; Xu, P.; Hao, X.; Yen, B.K.; Malmhall, R.; Pakala, N.; Wang, C.; Zhang, J.; et al. High performance perpendicular magnetic tunnel junction with Co/Ir interfacial anisotropy for embedded and standalone STT-MRAM applications. *Appl. Phys. Lett.* **2018**, *112*, 092402. [CrossRef]
16. Ikeda, S.; Miura, K.; Yamamoto, H.; Mizunuma, K.; Gan, H.D.; Endo, M.; Kanai, S.; Hayakawa, J.; Matsukura, F.; Ohno, H. A perpendicular-anisotropy CoFeB–MgO magnetic tunnel junction. *Nat. Mater.* **2010**, *9*, 721–724. [CrossRef] [PubMed]
17. Liu, W.J.; Chen, Y.T.; Chang, Y.H.; Chiang, M.R.; Li, W.H.; Tseng, J.Y.; Chi, P.W.; Wu, T.H. Structure and Magnetic Properties of Co40Fe40V20 Thin Films. *J. Nanosci. Nanotechnol.* **2019**, *19*, 5974–5978. [CrossRef]
18. Chen, Y.T.; Chang, Y.H.; Liu, W.J.; Liang, W.C.; Chan, W.H.; Wang, Y.T.; Wu, T.H. Ta and Ru seed layers effect on the magnetic and optical properties of Ru/CoFeB20V20 and Ta/CoFeB20V20 films. *J. Magn. Magn. Mater.* **2018**, *464*, 112–115. [CrossRef]
19. Zheng, C.; Li, X.; Shull, R.D.; Chen, P.J.; Pong, P.W.T. Comprehensive noise characterisation of magnetic tunnel junction sensors for optimising sensor performance and temperature detection. *Mater. Res. Innov.* **2015**, *19*, 553–557. [CrossRef]
20. Morón, C.; Cabrera, C.; Morón, A.; García, A.; González, M. Magnetic sensors based on amorphous ferromagnetic materials: A review. *Sensors* **2015**, *15*, 28340–28366. [CrossRef]
21. Kantar, E. Composition, temperature and geometric dependent hysteresis behaviours in Ising-type segmented nanowire with magnetic and diluted magnetic, and its soft/hard magnetic characteristics. *Philos. Mag. B* **2017**, *97*, 431–450. [CrossRef]
22. Chen, C.W. Metallurgy and Magnetic Properties of an Fe-Co-V Alloy. *J. Appl. Phys.* **1961**, *32*, S348–S353. [CrossRef]
23. George, E.P.; Gubbi, A.N.; Baker, I.; Robertson, L. Mechanical properties of soft magnetic FeCo alloys. *Mater. Sci. Eng. A* **2002**, *329*, 325–333. [CrossRef]
24. Ma, K.; Chung, T.S.; Good, R.J. Surface energy of thermotropic liquid crystalline polyesters and polyesteramide. *J. Polym. Sci.* **1998**, *36*, 2327–2337. [CrossRef]
25. Owens, D.K.; Wendt, R.C. Estimation of the surface free energy of polymers. *J. Appl. Polym. Sci.* **1969**, *13*, 1741–1747. [CrossRef]
26. Kaelble, D.H.; Uy, K.C. A Reinterpretation of Organic Liquid-Polytetrafluoroethylene Surface Interactions. J. Adhes. 1970, 2, 50–60. [CrossRef]

27. Maruyama, S.; Kurashige, T.; Matsumoto, S.; Yamaguchi, Y.; Kimura, T. Liquid droplet in contact with a solid surface. Microscale Thermophys. Eng. 1998, 2, 49–62.

28. Cullity, B.D. Elements of X-ray Diffraction, 2nd ed.; Addison-Wesley: Boston, MA, USA, 1978.

29. Ghaferi, Z.; Sharafi, S.; Bahrololoom, M.E. The role of electrolyte pH on phase evolution and magnetic properties of CoFeW codeposited films. Appl. Sur. Sci. 2016, 375, 35–41. [CrossRef]

30. Ikeda, H.; Iwai, M.; Nakajima, D.; Kikuchi, T.; Natsui, S.; Sakaguchi, N.; Suzuki, R.O. Nanostructural characterization of ordered gold particle arrays fabricated via aluminum anodizing, sputter coating, and dewetting. Appl. Sur. Sci. 2019, 465, 747–753. [CrossRef]

31. Yamazaki, T.; Ikeda, N.; Tawara, H.; Sato, M. Investigation of composition uniformity of MoSix sputtering films based on measurement of angular distribution of sputtered atoms. Thin Solid Films 1993, 235, 71–75. [CrossRef]

32. Sakita, A.M.P.; Passamani, E.C.; Kumar, H.; Cornejo, D.R.; Fugivara, C.S.; Noce, R.D.; Benedetti, A.V. Influence of current density on crystalline structure and magnetic properties of electrodeposited Co-rich CoNiW alloys. Mater. Chem. Phys. 2013, 141, 576–581. [CrossRef]

33. Mehrizi, S.; Sohi, M.H.; Ebrahimi, S.A.S. Study of microstructure and magnetic properties of electrodeposited nanocrystalline CoFeNiCu thin films. Surf. Coat. Technol. 2011, 205, 4754–4756. [CrossRef]

34. Sharifati, A.; Sharafi, S. Structure and magnetic properties of mechanically alloyed (Fe\textsubscript{70}Co\textsubscript{30})\textsubscript{91}Cu\textsubscript{9} powder. Mater. Des. 2012, 36, 35–40. [CrossRef]

35. Khajepour, M.; Sharafi, S. Structural and magnetic properties of nanostructured Fe\textsubscript{50}(Co\textsubscript{50})–6.5 wt% Si powder prepared by high energy ball milling. J. Alloys Compd. 2011, 509, 7729–7737. [CrossRef]

36. Xu, S.T.; Ma, Y.Q.; Zheng, G.H.; Dai, Z.X. Simultaneous effects of surface spins: Rarely large coercivity, high remanence magnetization and jumps in the hysteresis loops observed in CoFe\textsubscript{2}O\textsubscript{4} nanoparticles. Nanoscale 2015, 7, 6520–6526. [CrossRef]

37. Muroi, M.; Street, R.; McCormick, P.G.; Amighian, J. Magnetic properties of ultrafine MnFe\textsubscript{2}O\textsubscript{4} powders prepared by mechanochemical processing. Phys. Rev. B 2001, 63, 184414. [CrossRef]

38. Yang, S.Y.; Chien, J.J.; Wang, W.C.; Hsu, C.Y.; Hsu, Y.S.; Hong, H.E.; Hong, C.Y.; Yang, H.C.; Chang, C.F.; Lin, H.Y. Magnetic nanoparticles for high-sensitivity detection of nucleic acid via superconducting quantum-interference device based immunomagnetic reduction assay. J. Magn. Magn. Mater. 2011, 323, 681–685. [CrossRef]

39. Chen, Y.T.; Xie, S.M.; Jheng, H.Y. The low-frequency alternative-current magnetic susceptibility and electrical properties of Si(100)/Fe\textsubscript{40}Pd\textsubscript{40}B\textsubscript{20}(X Å)/ZnO(500 Å) and Si(100)/ZnO(500 Å)/Fe\textsubscript{40}Pd\textsubscript{40}B\textsubscript{20}(Y Å) systems. J. Appl. Phys. 2013, 113, 17B303. [CrossRef]

40. Choe, G.; Steinback, M. Surface roughness effects on magnetoresistive and magnetic properties of NiFe thin films. J. Appl. Phys. 1999, 85, 5777–5779. [CrossRef]

41. Bhatia, G.; Srivastava, A.; Srivastava, C.P. Effect of ion irradiation on magnetic property of exchange coupled interfacial structures of Fe/NilO and NiO/Fe on Si substrates. Radiat. Eff. Defects Solids 2014, 169, 529–537.

42. Kong, S.H.; Okamoto, T.; Nakagawa, S. [Ni-Fe/Si] double seedlayer with low surface energy for Fe-Co-B soft magnetic underlayer with high H\textsubscript{k} for perpendicular magnetic recording media. IEEE Trans. Magn. 2004, 40, 2389–2391. [CrossRef]

43. Porter, D.A.; Easterling, K.E. Phase Transformations in Metals and Alloy, 2nd ed.; CRC Press: London, UK, 1992.