様　式　Ｃ－１９、Ｆ－１９－１、Ｚ－１９　（共通）

# 科学研究費助成事業　　研究成果報告書

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研究課題名（和文）Investigation of magnetization dynamics in exchange-biased Antiferromagnetic/Ferromagnetic/Non-magnetic (AFM/FM/NM) systems with perpendicular magnetic anisotropy

研究課題名（英文）Investigation of magnetization dynamics in exchange-biased Antiferromagnetic/Ferromagnetic/Non-magnetic (AFM/FM/NM) systems with perpendicular magnetic anisotropy

研究代表者

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研究成果の概要（和文）：電圧による磁化制御は、超低電力スピントロニックデバイスの実現への道を開いたため、様々な研究が進められている。 Cr2O3薄膜を使用することにより、Cr2O3と強磁性（FM）の交換結合のおかげで、FM層で電圧誘起磁化反転を実現することもできた。 動的磁気特性は磁化反転と密接に関連しているため、これらの特性を深く理解する必要がある。
強磁性共鳴技術を使用したPt/FM/Cr2O3積層膜の動的磁気特性を検討した。 結果は、動的磁気特性がFM層とPt層の厚さの両方に依存することを示した。 これは、動的磁気特性がFM層によって決定され、FM/Cr2O3の界面磁化と交換結合によって制御できることを意味する。

研究成果の学術的意義や社会的意義
So far the investigation of dynamic magnetic properties in exchange-coupled Cr2O3/FM/NM systems was lack. The investigation here would set more light in the origin of the voltage-induced magnetization switching, and contribute to the realization of ultra-low power spintronic devices using Cr2O3.

研究成果の概要（英文）：The control of magnetization using a voltage has attracted much attention because it has opened the way to realize the ultra-low power spintronic devices. By using Cr2O3 thin film, we also could achieve the voltage-induced magnetization switching in an adjacent ferromagnetic (FM) layer, thanks to the exchange coupling between Cr2O3 and FM. Since the dynamic magnetic properties are closely related to magnetization switching, a deep understanding on these properties is necessitated.
We focused on the investigation of the dynamic magnetic properties of Pt/FM/Cr2O3 systems using the ferromagnetic resonance technique. The results showed that the dynamic magnetic properties depends on both of the FM layer thickness and Pt layer thickness. This means that the dynamic magnetic properties of the Pt/FM/Cr2O3 system are strongly determined by the FM layer, and these properties could be correlated by the perpendicular magnetic anisotropy and the exchange coupling in the FM/Cr2O3 system.

研究分野：応用物理工学

キーワード：antiferromagnetic　magnetization dynamics　damping constant　exchange bias system　ferromagnetic resonance　PMA

１．研究開始当初の背景

Modulation of magnetic properties by means of electric-field (i.e., voltage) is attracting much attention for application to low power electronics. Of particular interest is to use the magneto-electric (ME) effect to achieve the voltage-induced magnetization switching. The ME switching of magnetization enables the direct coupling between the magnetization and the electric field using ME materials whose magnetization can be controlled by the electric field.

Among various ME materials, $Cr_2O_3$ is one of the most intensively studied systems showing the ME effect thanks to the antiferromagnetic (AFM) property of this material at above room temperature. In a stacking structure of $Cr_2O_3$ and a ferromagnetic (FM) layer, the exchange coupling results in the exchange bias, whose polarity can be controlled by a voltage thanks to the ME effect of $Cr_2O_3$. The ME switching in $Cr_2O_3$/FM has been demonstrated in the bulk systems at first [1, 2], and recently in the thin film systems [3, 4] with very fast magnetization dynamics [5]. It is well-known that the magnetization dynamics are closely related to the magnetic properties, especially the dynamic magnetic properties of every system, and these dynamic magnetic properties such as the damping constant, are very sensitive with the stacking structure and/or the perpendicular magnetic anisotropy. Therefore, a detailed investigation of the dynamic magnetic properties, and their correlation with the other parameters such as the perpendicular magnetic anisotropy are important to realize the application of $Cr_2O_3$-based ME switching.

２．研究の目的

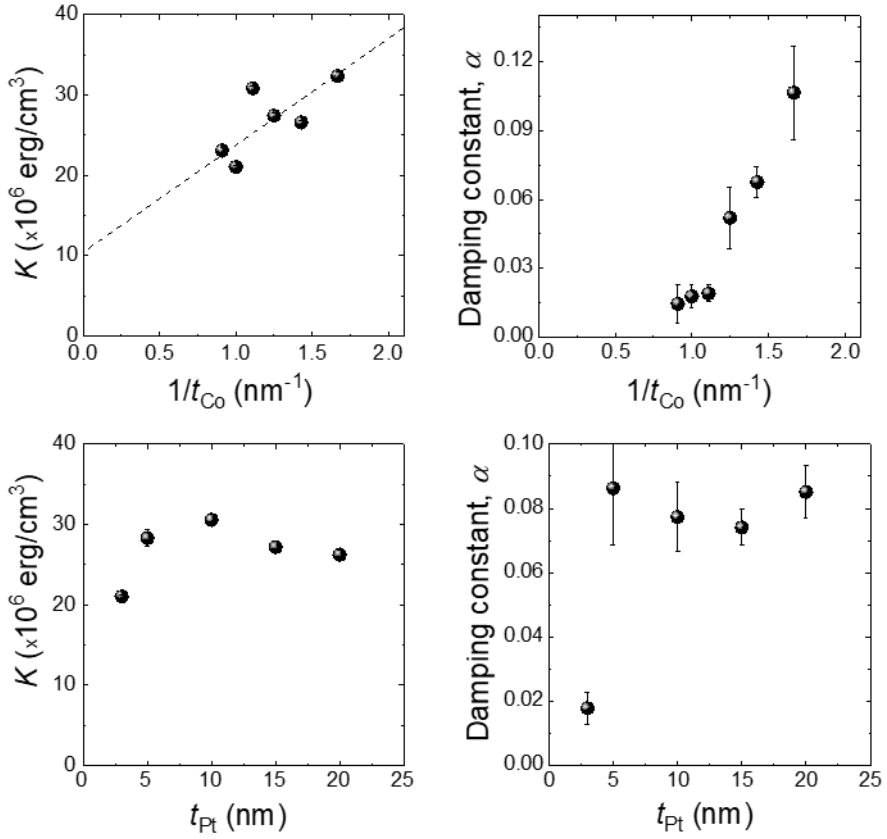
In this study, to deepen understating the ME switching in α-$Cr_2O_3$-based stacking structures, we investigated the dynamic magnetic properties in the Pt/Co/α-$Cr_2O_3$ stacks. We also discussed the dynamic magnetic properties in correlation with the perpendicular magnetic anisotropy energy of the stack.

３．研究の方法

Pt-cap($t_{Pt}$)/Co($t_{Co}$)/α-$Cr_2O_3$/Pt-buffer layer stacked films were deposited by DC magnetron sputtering onto α-$Al_2O_3$ (0001) substrates. Herein, the perpendicular magnetic anisotropy energy was controlled by changing the thickness of each layer in the stack. The crystalline orientations of each layer were characterized by reflection high-energy electron diffraction (RHEED). As for the magnetic properties of the Co layer in this system, their magnetization measurements were investigated by a vibrating sample magnetometer (VSM), which provided the saturation magnetization $M_S$. An effective perpendicular magnetic anisotropy field $H_{K,eff}$ and the damping constant $\alpha$ were evaluated by a broadband ferromagnetic resonance (B-FMR) measurement technique composing of a vector network analyzer and a coplanar waveguide. The perpendicular magnetic anisotropy energy density $K$ was estimated using the $M_s$ and $H_{k,eff}$ values.

４．研究成果

The clear RHEED patterns were observed as a result of the good epitaxial structure between all layers. The VSM data show the perpendicular magnetic anisotropy in all samples. Co layer thickness $t_{Co}$ dependence of perpendicular magnetic anisotropy energy density $K$ reveals that the bulk magnetic anisotropy plays an important role in the system in addition to the interfacial anisotropy. Damping constant $\alpha$ monotonically increases with the decrease of $t_{Co}$ but not proportionally to $1/t_{Co}$. Both $K$ and $\alpha$ increase with the increase of Pt layer thickness $t_{Pt}$ from 3 nm to 5 nm and keep almost constant in the $t_{Pt}$ range between 5 nm to 20 nm. This means that the dynamic magnetic properties of the Pt/FM/$Cr_2O_3$ system are strongly determined by the FM layer, and these properties could be controlled by the interfacial magnetization and exchange coupling in FM/$Cr_2O_3$. These results are of importance to understand the magnetization switching behavior driven by the ME effect as well as to design the spintronic devices using the ME effect.

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５．主な発表論文等

〔雑誌論文〕　計1件（うち査読付論文　1件／うち国際共著　1件／うちオープンアクセス　1件）

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| １．著者名<br>T. V. A. Nguyen, Y. Shiratsuchi, H. Sato, S. Ikeda, T. Endoh, Y. Endo | ４．巻<br>10 |
| ２．論文標題<br>Magnetic properties of Co film in Pt/Co/Cr203/Pt structure | ５．発行年<br>2020年 |
| ３．雑誌名<br>AIP Advances | ６．最初と最後の頁<br>015152-1 _ 5 |
| 掲載論文のDOI（デジタルオブジェクト識別子）<br>10.1063/1.5130439 | 査読の有無<br>有 |
| オープンアクセス<br>オープンアクセスとしている（また、その予定である） | 国際共著<br>該当する |

〔学会発表〕　計5件（うち招待講演　1件／うち国際学会　0件）

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| １．発表者名<br>T. V. A. Nguyen, Y. Shiratsuchi, H. Sato, S. Ikeda, T. Endoh, Y. Endo |
| ２．発表標題<br>Study on the Gilbert damping constant in perpendicular magnetized Pt/Co/Cr203/Pt stacks |
| ３．学会等名<br>応用物理学会 強的秩序とその操作に関わる研究会 第12回講演会（招待講演） |
| ４．発表年<br>2021年 |

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| １．発表者名<br>T. V. A. Nguyen, H. Sato, S.Ikeda, T. Endoh, Y. Endo |
| ２．発表標題<br>Temperature dependence of Gilbert damping constant in amorphous Co-Fe-B thin films |
| ３．学会等名<br>The 81st JSAP Autumm Meeting |
| ４．発表年<br>2019年 |

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| １．発表者名<br>T. V. A. Nguyen, Y. Shiratsuchi, H. Sato, S. Ikeda, T. Endoh, Y. Endo |
| ２．発表標題<br>Dynamic magnetic property in Pt/Co/Cr203/Pt stack films  with perpendicular magnetic anisotropy |
| ３．学会等名<br>2019 Annual Conference on Magnetism and Magnetic Materials |
| ４．発表年<br>2019年 |

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| １．発表者名<br>T. V. A. Nguyen, H. Sato, S. Fukami, Y. Saito, S. Hashi, S. Ikeda,  T. Endoh, Y. Endo |
| ２．発表標題<br>Modification of Gilbert damping constant at TaOx/CoFeB interface |
| ３．学会等名<br>The 3rd Symposium for The Core Research Clusters for Materials Science and Spintronics |
| ４．発表年<br>2020年 |

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| １．発表者名<br>T. V. A. Nguyen, H. Sato, S. Fukami, Y. Saito, S. Hashi, S. Ikeda,  T. Endoh, Y. Endo |
| ２．発表標題<br>Influence of Oxygen content on the Gilbert damping constant at TaOx/CoFeB interface |
| ３．学会等名<br>The 67th JSAP Spring Meeting |
| ４．発表年<br>2020年 |

〔図書〕　計0件

〔産業財産権〕

〔その他〕

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６．研究組織

| | 氏名<br>（ローマ字氏名）<br>（研究者番号） | 所属研究機関・部局・職<br>（機関番号） | 備考 |
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７．科研費を使用して開催した国際研究集会

〔国際研究集会〕　計0件

８．本研究に関連して実施した国際共同研究の実施状況

| 共同研究相手国 | 相手方研究機関 |
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