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論文題目	Study on data writing and shifting in nanopillars with perpendicular magnetic anisotropy (垂直磁気異方性を持つナノピラーにおける情報の書き込みおよびシフトに関する研究)		
(論文内容の要旨)			
In this thesis, data writing and shifting operations were studied in nanopillars with perpendicular magnetic anisotropy (PMA). The main contents of this thesis can be divided into three parts: (1) The investigation of magnetization switching induced by spin-orbit torque (SOT) in GMR cells with a ferromagnetic reference layer. (2) The study of SOT-induced magnetization switching in a GMR cell with an artificial antiferromagnetic (SAF) reference layer. The influence of the stray field from the reference layer on the critical current density J_c of the switching process was also elucidated. (3) The realization of writing via SOT and bit shifting via spin-transfer torque (STT) in a 2-bit nanopillar with double free layers. In the first research shown in chapter5 of this thesis, $[\text{Co/Pt}]_n$ multilayers were used as the material for both the reference layer and the free layer of the devices. Here, n denotes the number of repetitions of the Co/Pt layers, and in our experiments, $n = 2, 3$, and 4. It was found that when the number of Co/Pt repetitions (n) was 4 or 2, the SOT-induced magnetization switching experiments did not exhibit any switching signals. Only when n was 3, complete SOT switching loops were observed. In conjunction with the STT-induced magnetization switching experiments, it was observed that when n was 2, the free layer, due to its smaller coercivity, was more susceptible to magnetization switching induced by thermal effects. On the other hand, the sample with n equal to 4 may have failed to exhibit SOT-induced magnetization switching due to the larger coercivity of its free layer, which prevented the magnetization from being flipped. In the second research shown in chapter6 of the thesis, the relationship between the critical current density J_c required for SOT-induced magnetization switching and the stray field by varying the Co thickness t_{Co} in the SAF reference layer was investigated. The hysteresis and SOT-induced switching loops of devices with different t_{Co} were measured. The relationship between the SOT loop shifts and the hysteresis loop shifts (which measures the stray field strength) was plotted, but the results showed little correlation between them. This implied the critical current density J_c in this system was insensitive to changes in the stray field. A plausible explanation is that, unlike the situation with the direct application of an external magnetic field, the stray field from the reference layer in the nanopillar may exhibited an inhomogeneous distribution across the free layer. This led to the experimental results differing from our expectation			

that the SOT loop shifts and hysteresis loop shifts would show a clearer correlation.

In chapter 7 of the thesis, the data writing and shifting processes in a single memory cell with double free layers was demonstrated. First, data writing by SOT with the application of an in-plane magnetic field to break the mirror symmetry was conducted. However, any switching signal was observed, which might be due to the insufficient torque to reverse the magnetization. To address this issue, a tilted magnetic field was used instead of the in-plane magnetic field, thereby introducing an out-of-plane magnetic field component to facilitate SOT-induced magnetization switching. Then, the SOT switching loop was successfully observed, and the resistance change was nearly identical in magnitude to that observed in the hysteresis measurement.

Finally, SOT data writing using a tilted magnetic field and STT data shifting without an external magnetic field were conducted. The magnetization switching signals in each experiment were observed, demonstrating data writing and shifting memory operations in a 2-bit nanopillar. Moreover, regardless of whether the initial magnetization configuration was up-up or down-down, complete data writing and shifting switching signals were observed.

(続紙 2)

(論文審査の結果の要旨)

本論文は、垂直磁気異方性を持つナノピラーにおける情報の書き込みおよびシフトに関するものである。本論文は主に三つの部分で構成されている。第一部と第二部では、それぞれ強磁性参照層および人工反強磁性参照層を使用した1ビットナノピラーにおけるスピン軌道トルク (SOT) 誘起磁化反転過程を研究した。第三部では、二つの自由層を持つ2ビットナノピラーを用いて、情報の書き込みとシフトに関する研究を行った。

「強磁性参照層を持つ1ビットナノピラーにおけるSOT誘起磁化反転」の研究では、Co/Ptの繰り返し回数を変化させることで、異なる保磁力を持つ自由層を有するデバイスを作製した。これらのデバイスを用いて測定した結果、自由層の保磁力が大きすぎるとスピントルクが効果的に磁化を反転させることができないことが分かった。一方、保磁力が小さすぎると、自由層の磁化が参照層からの漏れ磁場や電流によるジュール熱の影響で容易に反転してしまうことが明らかとなった。

「人工反強磁性参照層を持つ1ビットナノピラーにおけるSOT誘起磁化反転」の研究では、人工反強磁性参照層からの漏れ磁場の大きさを変調し、スピン軌道トルク誘起磁化反転における漏れ磁場の影響を調査した。その結果、臨界電流密度 (J_c) の変化は漏れ磁場の変化に伴って明確な傾向を示さなかった。これは、漏れ磁場が自由層上で不均一に分布しているため、臨界電流密度がその変化の影響をほとんど受けないためと考えられる。

「二つの自由層を持つナノピラーにおける情報の書き込みおよびシフト」の研究では、SOTによる下部自由層の磁化反転による情報書き込みとスピントランスファートルクによる情報のシフトを実証した。

本論文は、電流による磁化制御に関する基礎学理の観点のみならず、3次元磁気メモリの動作原理を実証した点でも重要である。よって、本論文は博士(理学)の学位論文として価値あるものと認める。また、令和7年1月14日、論文内容とそれに関連した事項について試問を行った結果、合格と認めた。なお、本論文は、京都大学学位規程第14条第2項に該当するものと判断し、公表に際しては、当該論文の全文に代えてその内容を要約したものとすることを認める。

要旨公表可能日： 年 月 日以降