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Editorial

Advances in Antiferromagnetic Spintronics

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Magnetoresistance (MR) controls signal-to-noise ratios and the corresponding size of conventional spintronic devices [1]. For example, the read head of a hard disk drive (HDD), which has been the most commonly used magnetic storage, decreases the size by improving the MR ratios from a few percent with anisotropic MR (AMR) up to 77% with giant MR (GMR) [2] and to up to 604% with tunnelling MR (TMR) [3] at room temperature. This trend increases its areal recording density due to the reduction in the resulting data bit size. However, the MR ratio has not been improved over the last decade, as shown in Figure 1. This has caused magnetic storages to improve and memories to become slower. In addition, cross-talk between TMR junctions due to the stray fields from their ferromagnetic layers cannot be ignored for further integration. This means alternative materials and/or mechanisms need to be developed for next-generation spintronic devices, especially for storage and memory applications. A strong candidate is antiferromagnetic materials, which do not produce any stray fields.

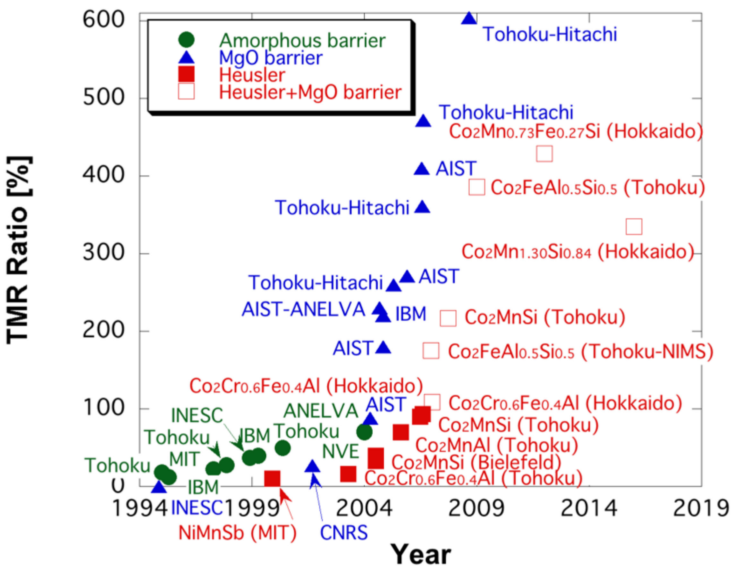

Figure 1. Evolution of TMR ratios at room temperature [4].

Antiferromagnetic materials have been investigated intensively both theoretically and experimentally since their initial discovery by Louis Néel [5]. One of the major applications of antiferromagnets has been to induce interfacial exchange coupling to pin the magnetisation of a neighbouring ferromagnetic layer. This results in a shift in the corresponding magnetisation curve, which can prove the concept of the spin-valve structure [6]. The spin-valve is a basic building block for a HDD read head. Recently, using an electrical current flowing within an antiferromagnetic layer, spin polarisation has been demonstrated to be induced, leading to antiferromagnetic spintronics [7]. For these applications, an $IrMn_3$ alloy has been predominantly used due to its corrosion resistance and robustness against device fabrication processes at the nanometre scale in both the thickness and in-plane

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Citation: Hirohata, A. Advances in Antiferromagnetic Spintronics. *Magnetochemistry* **2022**, *8*, 37. https://doi.org/10.3390/magnetochemistry8040037

Received: 12 March 2022
Accepted: 15 March 2022
Published: 28 March 2022

dimensions. However, in order to increase the signals of the antiferromagnetic devices, the development of a new material is highly required.

This Special Issue consists of one review and six research articles. The first four articles cover the development of new antiferromagnets for magnetic recording and beyond. Vallejo-Fernandez et al. provided a review on the recent progress in antiferromagnetic films to induce exchange bias onto a neighbouring ferromagnetic film at room temperature [8]. They focused on MnN, achieving the exchange bias of >1 kOe and the anisotropic constant of ~10^6 erg/cm^3. Such a film can offer an alternative to the antiferromagnetic $IrMn_3$ used in a magnetic recording to avoid the use of critical raw materials.

Similar efforts using oxides were made by Shiratsuchi et al. to achieve a large perpendicular exchange bias induced by the magnetoelectric effect in Cr_2O_3 [9]. The effect can be used to control antiferromagnetic domain states, which can be read out by the magnetisation of the adjacent ferromagnetic layer coupled via the exchange bias induced at their interface. They identified two switching processes: the magnetoelectric field cooling and isothermal modes. The asymmetry yields was reported to be 3.7 ± 0.5 ps/m at 273 K, which is comparable with that of the bulk Cr_2O_3.

Additionally, Huminiuc et al. grew and characterised polycrystalline Ni_2MnAl Heusler alloy films [10]. For the demonstration of room-temperature antiferromagnetism, Fe and Co have been used for partial substitution of Ni. The Fe substitution showed an increase in the magnetic moment with increasing Fe content, while Co substitution can effectively reduce the crystallisation temperature down to 300 °C but with ferromagnetic Co_2MnAl segregation. Further compositional optimisation can achieve stoichiometry while maintaining reduced crystallisation in the pseudo-*B*2 phase temperature for antiferromagnetic spintronics.

Ranjbar et al. also reported a large perpendicular exchange energy in rare earth alloys, Tb_xCo_{100-x}/Cu/[Co/Pt]$_2$ heterostructures [11]. They controlled two competing mechanisms: the effect of Tb content on saturation magnetisation and the coercivity of heterostructures. They demonstrated that the perpendicular exchange energy can be controlled by a Cu interlayer with thicknesses between 0.2 and 0.3 nm up to 1 erg/cm^2 at $x = 24$ and at room temperature. Such a structure can be used in magnetic memory and sensors.

As a new application, magnetisation dynamics in antiferrmagnets were also covered by three articles theoretically and experimentally. Chen et al. demonstrated the manipulation of magnetisation dynamics in the time and frequency domains in a synthetic antiferromagnet using micromagnetic simulations [12]. They found that the time-evolution magnetisations of the two ferromagnets oscillate in-phase at the acoustic mode and out-of-phase at the optic mode. Their simulations confirmed that magnon coupling can be induced in a hybridised resonance mode with a phase difference of up to 90° with respect to the coupling strength. Their method can provide an opportunity to control the magnon interaction in a synthetic antiferromagnet.

Safin et al. discussed a new model for detecting THz frequency signals using antiferromagnetic resonance [13]. The conversion of an electromagnetic signal in THz frequency into a direct current (DC) voltage was calculated and found to be achievable via the inverse spin Hall effect in an antiferromagnet/heavy metal bilayer. Their calculations agreed with an experimentally measured detector sensitivity of 10^{-5}–10^{-6} V/W. The sensitivity can be improved by increasing the magnitude of the bias magnetic field or by decreasing the thickness of the antiferromagnetic layer.

Kim et al. reported the deposition of a crystalline gadolinium iron garnet (GdIG) using a metal organic decomposition method [14]. They demonstrated antiferromagnetic exchange of the rare earth Gd in a ferrimagnetic insulator. For the optimised GdIG films, the magnetic compensation was measured to be at 270 K and the damping constant was measured to be of an order of 10^{-3} based on ferromagnetic resonance measurements. Such a deposition method can offer a high-throughput procedure for ultrafast magnonic applications. Magnons (the quanta of spin waves) can be used to encode information beyond Moore computing applications.

Funding: This work was partially supported by EPSRC (EP/V007211/1 and EP/V047779/1), Royal Society International Exchange Programme and JST CREST (JPMJCR17J5).

Data Availability Statement: Data is contained within the article and available on request with following the guideline set by the University of York (UK).

Conflicts of Interest: The author declares no conflict of interests. The funders had no role in the design of the study; in the collection, analysis, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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