FAKULTÄT
PHYSIK
Lehrstuhl für Experimentalphysik

Universität Regensburg · D-93040 Regensburg

Prof. Dr. Jörg Wunderlich
Telefon +49 941 943-2621
Telefax +49 941 943-4544
Sekretariat:
Telefon +49 941 943-2651
Telefax +49 941 943-4544
Universitätsstraße 31
D-93053 Regensburg

joerg.wunderlich@physik.uni-regensburg.de
www.uni-regensburg.de

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Report on the doctoral thesis on

„Electro and thermal Magnetotransport in antiferromagnetic systems"

of Joao Pedro Martins Godinho

Contrary to the fascination with ferromagnets that has existed for millennia and their many uses, antiferromagnetic materials, which have only been known for about 100 years, have hardly been considered for practical applications. The reason for this lies in the alternating arrangement of microscopic magnetic moments, which does not lead to any macroscopic magnetisation and whose magnetic order is difficult to detect and can hardly be influenced by external means. "Interesting, but useless" - this not very optimistic quote from the Nobel Prize speech by Louis Néel [1], the discoverer of antiferromagnetism, aptly describes the fact that antiferromagnetic materials have so far only been regarded as an interesting addition to the scientific literature, but not as promising candidates for future storage applications.

On the other hand, modern non-volatile data storage devices are based on the concept of directional magnetic order, which is inherent to both ferromagnets and antiferromagnets. Similar to ferromagnets, switching magnetic moments in antiferromagnets by 180 degrees aligned along an easy axis is thermodynamically most stable, as the reversed magnetic states join equivalent energy minima. But encoding and storing information in reversed antiferromagnetic states was assumed to be impossible because it was thought that the reversed states could not be distinguished.

In his thesis, Mr. Godinho made an extremely important contribution towards resolving this dilemma for collinear antiferromagnets in which the combined time-reversal and inversion transformation leaves the antiferromagnetic order and crystal structure unchanged. These PT symmetric antiferromagnets are especially interesting because the macroscopic Néel order can be switched by electric current pulses.

Inspired by a simple toy model, Mr Godinho not only repeated previous results of current-polarity dependent switching of antiferromagnetic order, but also achieved the electrical detection of reversed antiferromagnetic states using nonlinear magnetotransport measurements. This important work was published in Nature Communication already in 2018 [2]. However, to highlight the importance of his pioneering achievement, a theoretical paper proposing the same detection method of reversed Néel order by nonlinear magnetotransport was published two years later in 2020 [3] and finally two experimental papers published just this year in the prestigious journals Science and Nature reported the experimental detection of reversed antiferromagnetic order by nonlinear magnetotransport measurements in a PT-symmetric antiferromagnetic $MnBi_2Te_4$ multilayers [4,5].

While the electrical method developed by Mr. Godinho allows the detection of the averaged reversed magnetic order, Mr. Godinho has also worked on the local detection of microscopic small antiferromagnetic domains using the anomalous Nernst effect present in the non-collinear Kagome antiferromagnet Mn_3Sn [6] and exploiting the magnetic Seebeck effect in PT-symmetric CuMnAs [7]. The latter finding is currently being investigated by Mr Godinho whether the detected photocurrent is caused directly as the nonlinear response to the optical light field resulting from the broken spatial inversion symmetry from the staggered magnetic moments in PT symmetric antiferromagnets [8].

Finally, Mr Godinho demonstrates the application of his important results by fabricating a synthetic antiferromagnetic multilayer system with PT symmetry, where current-induced switching and nonlinear magnetotransport detection were used to realize an antiferromagnetic multilevel spin-orbit torque memristor with highly reproducible multilevel switching as a result of the absence of magnetic stray field and Walker-breakdown free exchange-stabilised antiferromagnetic domain wall motion. A paper describing Mr Godinho's latest results is currently in preparation.

In summary, Mr Godinho's PhD thesis, despite its admittedly long duration, has produced important ground-breaking results concerning the detection of AF order. In addition, he has demonstrated the immediate application to an antiferromagnetic memristor type of device that can mimic the function of a synapse in an artificial neural network.

Jörg Wunderlich

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