Unconventional computing using topological spin structures

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Novel spintronic devices can play a role in the quest for GreenIT if they are stable and can transport and manipulate spin with low power. Devices have been proposed, where switching by energy-efficient approaches, such as spin-polarized currents is used to manipulate topological spin structures [1,2].
Firstly, to obtain ultimate stability of states, topological spin structures that emerge due to the Dzyaloshinskii-Moriya interaction (DMI) at structurally asymmetric interfaces, such as chiral domain walls and skyrmions with enhanced topological protection can be used [3-5]. Here we will introduce these spin structures ad we have investigated in detail their dynamics and find that it is governed by the topology of the spin structure [3]. By designing the materials, we can even obtain a skyrmion lattice phase as the ground state [4]. Beyond 2D structures, we recently developed also systems with chiral interlayer exchange interactions that lend themselves to the formation of chiral 3D structures [6].
Secondly, for ultimately efficient spin manipulation, we use spin-orbit torques, that can transfer more than 1ħ per electron by transferring not only spin but also orbital angular momentum. We combine ultimately stable skyrmions with spin orbit torques into a skyrmion racetrack memory device [4,5,7]. We furthermore use spin-orbit torque induced skyrmion dynamics for non-conventional stochastic computing applications, where we have developed a skyrmion reshuffler device [8] based on skyrmion diffusion, which also reveals the origin of skyrmion pinning [9]. Such diffusion can be used for Token-based Brownian Computing and Reservoir Computing [10], which eventually opens a broad range of applications to the use of topological spin structures.

[1] G. Finocchio et al., J. Phys. D: Appl. Phys., vol. 49, no. 42, 423001, 2016.
[2] K. Everschor-Sitte et al., J. Appl. Phys., vol. 124, no. 24, 240901, 2018.
[3] F. Büttner et al., Nature Phys., vol. 11, no. 3, pp. 225–228, 2015.
[4] S. Woo et al., Nature Mater., vol. 15, no. 5, pp. 501–506, 2016.
[5] K. Litzius et al., Nature Phys., vol. 13, no. 2, pp. 170–175, 2017.
[6] D. Han et al., Nature Mater., vol. 18, no. 7, pp. 703–708, 2019.
[7] K. Litzius et al., Nature Electron., vol. 3, no. 1, pp. 30–36, 2020.
[8] J. Zázvorka et al., Nature Nanotechnol., vol. 14, no. 7, pp. 658–661, 2019.
[9] R. Gruber et al., Nature Commun. vol. 13, pp 3144, 2022.
[10] K. Raab et al., Nature Commun. vol. 13, pp 6982, 2022.; M. Brems et al., Appl. Phys. Lett. 119, 132405, 2021.

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