From ultrafast spin currents to spintronics THz emitters and subpicosecond giant spin injection in semiconductors

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In 2010 I proposed the existence of out-of-equilibrium spin current pulses [1-3] and that they could explain the origin of the ultrafast demagnetisation. [4] A number of experimental works have confirmed such picture [5-8] and realised predictions such as the transfer of magnetisation in the non-magnetic substrate and the ultrafast increase of magnetisation. [5-6]

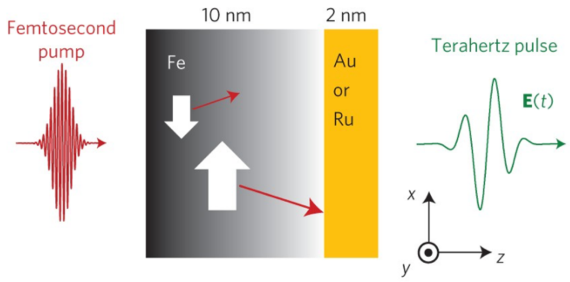

Fig. 1 - Schematics of the effect of the inverse spin Hall effect on the spin current in spintronics THz emitters. Reproduced from [8]

The most interesting application was the development of the now widely known spintronics THz emitters. [8] Ultrashort spin pulses are generated into a thin ferromagnetic layer. When diffusing through an attached heavy metal layer, their trajectory is deflected due to inverse spin Hall effect (see Fig. 1). This generates a pulsed subpicosecond charge current parallel to the sample surface. This, in turns, generates a broadband THz pulse. Spintronics THz emitters have attracted a lot of attention, because of the wide and continuum spectrum as well as their ease of both production and use over alternative technologies.

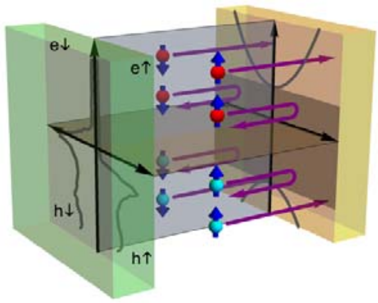

Fig. 2 - Sketch of strongly out of equilibrium spin injection in semiconductors. Reproduced from [9]

Few years ago I made another prediction: the possibility of injecting these ultrashort spin current pulses from a ferromagnetic metal into a semiconductor. [9] By taking advantage of the strongly out-of-equilibrium electronic distribution, such ultrashort spin currents pulses were predicted to be injected into a semiconductor with a huge intensity and high spin polarisation (see Fig. 2).

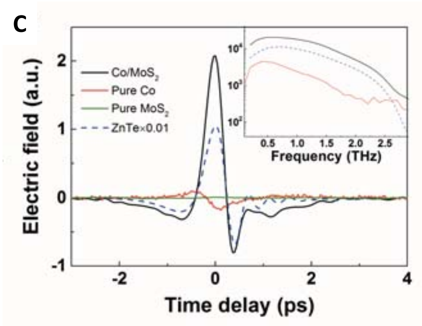

Fig. 3 - Comparison of THz emissions from samples, in the absence and presence of spin injection. Reproduced from [11]

We have recently proved this experimentally. [11] By injecting strongly out-of-equilibrium sub-picosecond spin current pulses across a bare ferromagnet/semiconductor interface, we have obtained a massive spin transfer. We demonstrated this by producing ultrashort spin current pulses into cobalt, injecting them into monolayer MoS_2 and measuring emitted THz radiation (see Fig. 3). As predicted, we measured a giant spin current, orders of magnitude larger than typical injected spin current densities in modern devices.

Such current pulses have the possibility of becoming the carriers of information in future spintronics running at unprecedented frequencies above the THz regime.

Acknowledgements

For the list of the very many authors who have contributed to the presented results, please see the cited references.

References

[1] M. Battiato, K. Carva, P.M. Oppeneer, Phys Rev. Lett. 105, 027203 (2010).
[2] M. Battiato, K. Carva, P.M. Oppeneer, Phys Rev. B 86, 024404 (2012).
[3] M. Battiato, P. Maldonado, P.M. Oppeneer, J. Appl. Phys. 115, 172611 (2012).
[4] E. Beaurepaire, J.-C. Merle, A. Daunois, and J.-Y. Bigot, Phys. Rev. Lett. 76, 4250 (1996).
[5] A. Melnikov et al., Phys. Rev. Lett. 107, 076601 (2011).
[6] D. Rudolf, … M. Battiato, et al., Nature Comm. 3, 1037 (2012).
[7] A. Eschenlohr, M. Battiato, et al., Nature Mater. 12, 332 (2013).
[8] T. Kampfrath, M. Battiato, et al, Nature Nanotechnol. 8, 256 (2013).
[9] M. Battiato and K. Held, Phys Rev. Lett. 116, 196601 (2016).
[10] M. Battiato J. Phys. Condens. Matter 29, 174001 (2017).
[11] L. Cheng, …, M. Battiato et al., Nature Physics (2019).