University of Cambridge
Department of Physics

Microelectronics group
Cavendish laboratory
Madingley road
Cambridge, CB3 0HE

Dr A. J. Ferguson
Microelectronics Group, Hitachi senior research fellow

Tel: 01223 337454
Fax: 01223 337706
E-mail: ajf1006@cam.ac.uk

20th January, 2013

Report on the doctoral thesis of Nad'a Tesařová

It has been a pleasure to read the doctoral thesis of Nad'a Tesařová, titled 'Investigation of magnetization dynamics in GaMnAs by ultrafast laser spectroscopy'.

A technique is described that allows access to both the in and out of plane components of the magnetisation in (Ga,Mn)As. This enables the trajectory of the magnetisation to be reconstructed, with picosecond resolution, after an optical impulse is applied to the (Ga,Mn)As. By studying the helicity dependent response of the magnetisation to the impulse, it has been possible to experimentally observe a spin transfer torque and a spin orbit torque. In addition, access to the dynamical behaviour of the magnetisation has enabled comprehensive studies of the magnetic properties of (Ga,Mn)As.

This work is timely and makes an original contribution to the field of spintronics. The spin transfer torque in metallic ferromagnetic spin valves is now well understood, and it is natural for physicists to ask what other spin transfer torques are out there. As usual in this field, theory leads experiment and there have been theoretical predictions both of an optical spin transfer torque and electrical spin orbit torques in uniformly magnetised materials. The experimental observation of an optical spin transfer torque is important realisation of a theoretical prediction. Moreover, the optical spin orbit torque is interesting since it relies on a novel mechanism that is distinct from the usual inverse spin galvanic effect that underlies current induced spin orbit torques. This work will lead into further studies of optical torques in magnetic materials, and will further the use of optical techniques to study the magnetic properties of magnetic materials.

This work is clearly and accurately communicated. This is to be expected, given that the work described has been extensively peer reviewed. In the introduction, which has not been peer-reviewed, there are a number of typographic errors which I list later in this report. However, these do not detract from the thesis.

The contribution of the candidate. This work has been performed under the supervision of very active principal investigators, and with highly competent colleagues. It is without question that Ms Tesařová has had a first rate training in physics research and in scientific practise. However, in an environment such as this it is relevant to ask about the specific contribution of the candidate. Fortunately this is clearly documented and it apparent that Ms Tesařová's work in setting up the optical systems and in applying the magnetic linear dichorism (MLD) measurement to (Ga,Mn)As has heavily contributed to the more sophisticated experiments on the optical torques. Moreover, it is

clear that Ms Tesařová's work advances the previous studies on magnetisation dynamics performed in the group e.g. (Appl. Phys. Lett. 93, 232505 (2008); Appl. Phys. Lett. 92, 122507 (2008)).

Specific questions to the candidate

1: In the introduction it is written: 'The demonstration of ferromagnetism is diluted magnetic semiconductors (DMS) realised hopes for applications based on single elements combining the information storage capabilities of magnetic metals with the logic functionalities of semiconductors.' Could you comment on how far these hopes have been realised? And if they have not been realised in (Ga,Mn)As, what is the hope for other spintronic systems that combine logic and memory.

2: In FMR studies of STT and SOTs, it is usual to rotate the magnetisation direction with respect to the spin injection polarisation. This is very helpful in determining the symmetries of the torques present. Can you comment on the possibility of doing this in the optical STT or SOT experiments. Or perhaps it is unnecessary?

3: Can you comment on the relative strength of optical STTs; electrical STTs; optical SOTs; and electrical SOTs in (Ga,Mn)As?

List of typographic errors

Introduction
P1L1 Suggest 'Electronics based on charge-carrier transport…'
P1L3 'According to Moore's law'
P1L4 'number of transistors'
P1L35 'a single element'
P3L15 & L18 2 states should be 1 bit and 4 states 2 bits

Chapter 2
P5L39 'valence'
P7 Table 1 F020 Ms 33.3?
P8L36 'squared.'
P9L26 'a widely used'

Contribution of…
L9 'thesis'

Appendix 9
L2 'titanium-sapphire'
L24 'photodiodes'

This thesis shows that Ms Tesařová is capable of independent, creative scientific work. In my opinion, its quality is places it in the top 10 percent of experimental physics theses. I recommend that Ms Tesařová is awarded the Ph.D. degree, and wish her all the best for her future endeavours.

Yours sincerely,

Dr Andrew Ferguson