Manipulating Ferromagnetism in Femtosecond Timescale

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Extracting the fundamental physics behind every physical phenomenon is the foundation stone for its futuristic technological applications. However, probing the underlying physics becomes a challenge when it occurs in extreme dimensions either in space (nanometre) or time (nanosecond). From the textbook physics we know that the magnetic moments, inside a ferromagnetic material, are aligned in a particular direction when subjected to an external magnetic field. Therefore, one can manipulate these moments by tuning the field magnitude and orientation, which is a slow process. In 1996, Bigot *et al*. demonstrated a new fascinating avenue of manipulating the magnetic moments within few hundreds of femtoseconds (10^{-15} secs). They showed that by shining a femtosecond laser pulse on a ferromagnetic material one can decrease its magnetic moment in the ultrafast timescale which is named as 'ultrafast demagnetization'. Since then it has become the heart of magnetism research and a wide range of theoretical as well as experimental investigations have been brought into the picture to explain this unusual ultrafast modification in the magnetic moments. Most of the results claim a direct interaction between the laser pulse and the material.

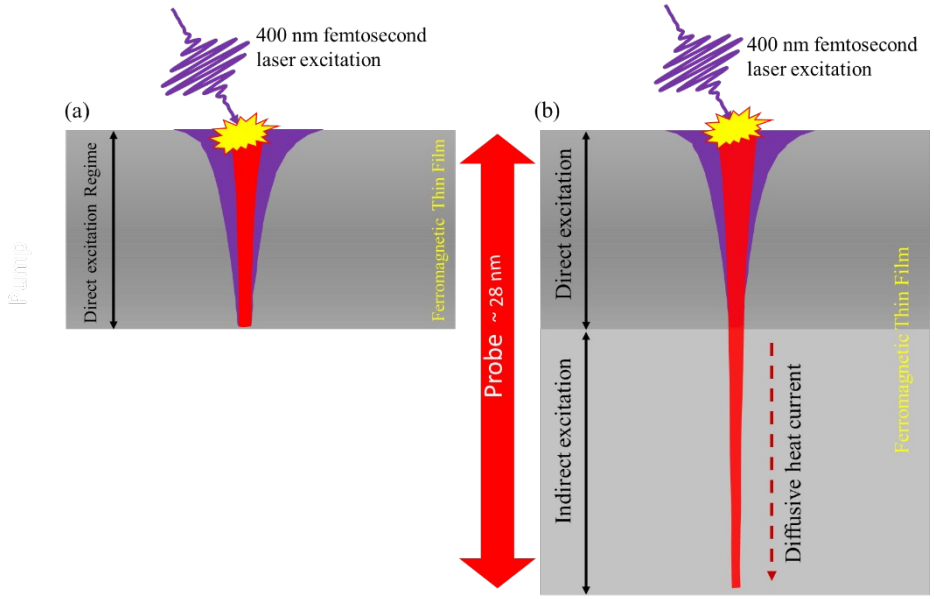

Figure 1. (a) Thinner ferromagnetic multi-layered film excited by 400 nm femtosecond pulsed laser which directly interact with the whole sample volume resulting only in direct interaction mechanism. (b) Thicker ferromagnetic multi-layered film where the excitation laser pulse cannot penetrate down to the bottom of the sample. The laser-induced ultrafast heat current generated in the upper layers diffuse down and causes an indirect excitation of

demagnetization mechanism. Violet (400 nm) and red (800 nm) colors represent the depth profile of the exciting and probing laser pulse.

Opposing the existing concept, a new microscopically different theoretical proposal followed by several experimental observations demonstrated that an indirect interaction between the laser pulse and the ferromagnetic material via laser excited hot electrons or heat current can also cause this ultrafast magnetic quenching. This raises intense debate on the prevalent mechanism in femtosecond timescale. Our recent research demonstrates that both direct and indirect interactions can coexist and play crucial role, where the indirect excitation originates from laser induced heat current which diffuses inside the ferromagnetic material. It is further observed that though the resultant decrease in magnetic moments arises from a cumulative effect of both the interaction mechanisms, it is non-trivial to isolate their individual contributions. However, we have experimentally demonstrated that one can easily transit from one regime to the other by manipulating few external parameters such as the laser excitation power, physical dimension of the material, laser wavelength etc. Apart from resolving the role of the excitation process in such ultrafast timescale, this work put a step ahead for developing ultrafast magnetic storage and memory devices.

Reference:

Controlled coexcitation of direct and indirect ultrafast demagnetization in Co/Pd multilayers with large perpendicular magnetic anisotropy, Santanu Pan, Olav Hellwig, and Anjan Barman, Physical Review B **98**, 214436 (2018).