Imaging ultrafast spin dynamics at the nanometer scale

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Background incl. aims

Understanding magnetic dynamics is not only important to fundamental physics but also critical to the development of future energy-efficient spintronic devices. Detection of ultrafast magnetic dynamics with high temporal-spatial resolution remains a great challenge. In recent years, the UEM (ultrafast electron microscope) has been rather active in ultrafast magnetism[1-4]. Based on a commercial TEM platform, UEM inherits the capability of high space resolution (nanometer scale) and versatile imaging modes. Moreover, the pulse duration of the photo-emitted electron can reach lower than 1 ps in the premium condition, which is compatible with most of the scenarios for the spin dynamics.

However, it is noteworthy that all these experiments rely on topological magnetic structures. Such limitation originates from the imaging mechanism of the Fresnel mode in the Lorentz TEM, which is the beam-deflecting effect driven by the transverse Lorentz force between the electron beam and local spin state. In short, the Lorentz image contrast in Fresnel mode relies on the in-plane spatial gradient of magnetization other than the magnetization itself. This means the Lorentz UEM could only image the ultrafast perturbations of the topological magnetic structure, and rule out other critical magnetic dynamics, such as ultrafast demagnetization, spin waves etc, which usually do not relate to a static topological structure.

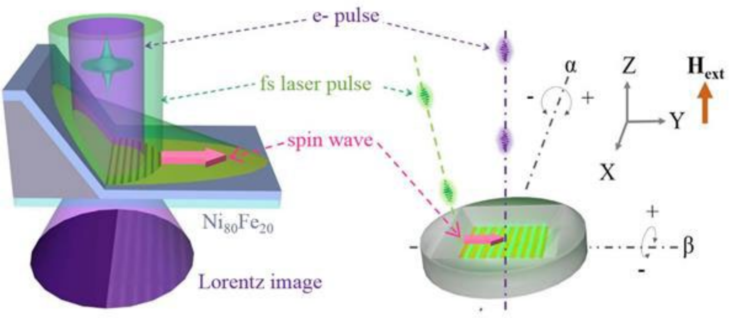
Method and result

Here, we report a novel method of Lorentz ultrafast electron microscope (UEM), which can directly image the spin wave in real space [5]. Unlike traditional methods, our Lorentz contrast does not rely on topological magnetic structure. We introduce a structured-light pulse (transient optical grating (TOG)) onto the ferromagnetic sample, which can induce transient spatial magnetic gradient and then create time-resolved magnetic contrast under Lorentz mode. Then, the propagating spin waves, which are driven by the magnetic-elastic coupling, become 'visible' in the UEM.

Conclusion

In summary, we have for the first time directly imaged spin waves in the UEM via structured light, which opens a new door to detect and manipulate ultrafast magnetic dynamics with high temporal-spatial resolution.

Graphic:



Keywords:

UEM, Lorentz mode, spin waves

Reference:

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