nature portfolio

Peer Review File

High-speed antiferromagnetic domain walls driven by coherent spin waves

Corresponding Author: Professor David Hsieh

This file contains all reviewer reports in order by version, followed by all author rebuttals in order by version.

Version 0:

Reviewer comments:

Reviewer #1

(Remarks to the Author)
This is a very nice work describing interesting experimental observations. The motivation is very clear and the results, to my knowledge, are new. Theoretical part seems to be adequate despite all simplifications (continuum medium approximation, one-dimensional character of motion). The presentation looks clear and complete. I also think that the work satisfies specific requirements for Nature Commun. paper. I believe it can be recommended for the publication in its present form.

Reviewer #2

(Remarks to the Author)
The authors report on their study of AFM DW dynamics induced by short optical pulses. The mechanism of excitation involves coherent spin waves at an intermediate stage, which leads the authors to claim that the DWs are driven by the spin waves. This is misleading and should be corrected (via a suitable modification of the tile and then finetuning the text) before I could recommend the paper for publication. I would also avoid dubbing the DWs “ultrafast” beside “ultrafast” optical excitation. I have not found anything wrong with the technical contents of the manuscript.

Reviewer #3

(Remarks to the Author)
In this work, Seyler et al., present comprehensive studies of the domain wall dynamics in a room-temperature antiferromagnetic (AFM) material $Sr_2Cu_3O_4Cl_2$. Using wide-field SHG imaging and pump-probe SHG spectroscopy/microscopy, they demonstrate record-high domain wall motion velocity at ~50 km/s and the domain propagation direction can be controlled by both pump laser helicity and the sign of the domain wall winding number. Meanwhile, they provide detailed experimental results to rule out other plausible interpretations such as photoinduced magnetic anisotropy, heating effect, coupling between photoinduced in-plane magnetic field and weak in-plane ferromagnetism. As a result, they propose the domain wall motion is essentially driven by coherent excitation of spin waves, which produces an in-plane rotation of Neel vector n. Finally, they carried out simulation using a 1D model. This simplified picture captures most of the key features of the domain wall motion.
This work addresses an important scientific question regarding the driving mechanism of ultrafast manipulation of domain walls. Especially, in AFM materials, coherent spin wave holds the promise of propelling domain walls to the magnon group velocity with low joule heating. The work has realized both optical excitation of coherent spin waves and the simultaneous nonlinear optics detection of domain wall dynamics. The methods are valid and the conclusions are well supported by high-quality data. I recommend publication as an article in Nature Communications.
Before publication, we would recommend that the authors to further discuss two questions:
1) What is the energy gap size of the AFM insulator $Sr_2Cu_3O_4Cl_2$? Is the gap size above or below the photon energy?
2) The simulation shows that the beam profile of the pump laser is not critical to the DW motion. Is there any experimental evidence of that?

Version 1:

Reviewer comments:

Reviewer #2

(Remarks to the Author)
The authors have successfully responded to my queries, and I am happy to recommend the manuscript for publication.

Reviewer #3

(Remarks to the Author)
I have reviewed the revised manuscript, and my questions have been addressed accordingly. I have no further questions and recommend publication as is.

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Reviewer Comments:

Reviewer #1 (Remarks to the Author):

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We are grateful to the reviewer for their positive assessment of our work and for recommending it for publication.

Reviewer #2 (Remarks to the Author):

The authors report on their study of AFM DW dynamics induced by short optical pulses. The mechanism of excitation involves coherent spin waves at an intermediate stage, which leads the authors to claim that the DWs are driven by the spin waves. This is misleading and should be corrected (via a suitable modification of the tile and then finetuning the text) before I could recommend the paper for publication. I would also avoid dubbing the DWs "ultrafast" beside "ultrafast" optical excitation. I have not found anything wrong with the technical contents of the manuscript.

We thank the reviewer for their comments. As suggested, we now avoid dubbing DWs "ultrafast". We have modified the title to "High-speed antiferromagnetic domain walls driven by coherent spin waves" and replaced "ultrafast" with "high-speed" when describing the domain walls in the text. We believe that this title accurately and concisely captures the main discovery. Our data and theoretical modelling unambiguously show that coherent spin waves are the proximate driving mechanism.

We fully agree that the causal chain (ultrafast laser pulses → coherent spin waves → domain wall motion) should be unambiguous throughout the text. We have revised the abstract to clearly state the sequence of events: "Here we experimentally realize an approach where ultrafast laser pulses generate coherent spin waves that drive AFM DWs and develop a technique to directly map the spatiotemporal DW dynamics." In addition, when comparing the timescales of DW motion and spin waves on page 5 of the main text, we now explicitly state that "These observations confirm the causal chain: the ultrafast optical pulse rapidly excites coherent spin waves, which subsequently propel the DW over a significantly longer timescale."

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In this work, Seyler et al., present comprehensive studies of the domain wall dynamics in a room-temperature antiferromagnetic (AFM) material Sr2Cu3O4Cl2. Using wide-field SHG imaging and pump-probe SHG spectroscopy/microscopy, they demonstrate record-high domain wall motion velocity at ~50 km/s and the domain propagation direction can be controlled by both pump laser helicity and the sign of the domain wall winding number. Meanwhile, they provide detailed experimental results to rule out other plausible interpretations such as photoinduced magnetic anisotropy, heating effect, coupling between photoinduced in-plane magnetic field and weak in-plane ferromagnetism. As a result, they propose the domain wall motion is essentially driven by coherent excitation of spin waves, which produces an in-plane rotation of Neel vector n. Finally, they carried out simulation using a 1D model. This simplified picture captures most of the key features of the domain wall motion.

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Before publication, we would recommend that the authors to further discuss two questions:
1) What is the energy gap size of the AFM insulator Sr2Cu3O4Cl2? Is the gap size above or below the photon energy?

We used 1.55 eV pump photon energy, which is slightly below the charge gap of 1.86 eV as measured by ellipsometry in Ref. 55.

In the revised manuscript, we now mention that the 1.55 eV pump photon energy is "below the 1.86 eV charge gap [55]" when first describing the ultrafast experiments of Fig. 2.

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2) The simulation shows that the beam profile of the pump laser is not critical to the DW motion. Is there any experimental evidence of that?

We did not perform systematic pump beam profile dependence measurements, but it would certainly be interesting to explore in future follow-up experiments.
