Engineering fast domain switching for spintronic technologies

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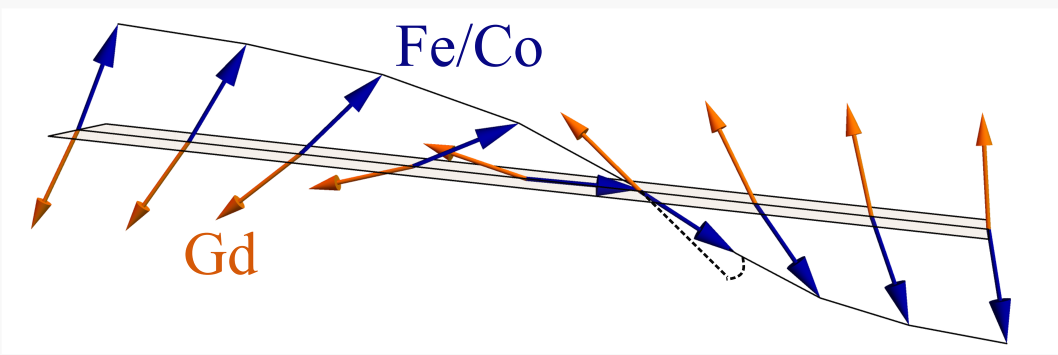
Ferrimagnetic domain wall



- Domain walls: information carriers for future spintronic devices [1];
- Ultrafast dynamics:
  – Relativistic effects close to magnon velocity [7].
  – Near spin angular momentum compensation point, $v_{\mathrm{DW}} > 1$ km/s [6];
- Efficient electrical control [5];

Relativistic domain wall theory

- The domain wall width Δ contracts according to a Lorentz-like relation:

$$\Delta = \Delta_0 \sqrt{1 - \left(\frac{v_{\mathrm{DW}}}{v_{\mathrm{g,max}}}\right)^2} \qquad (1)$$

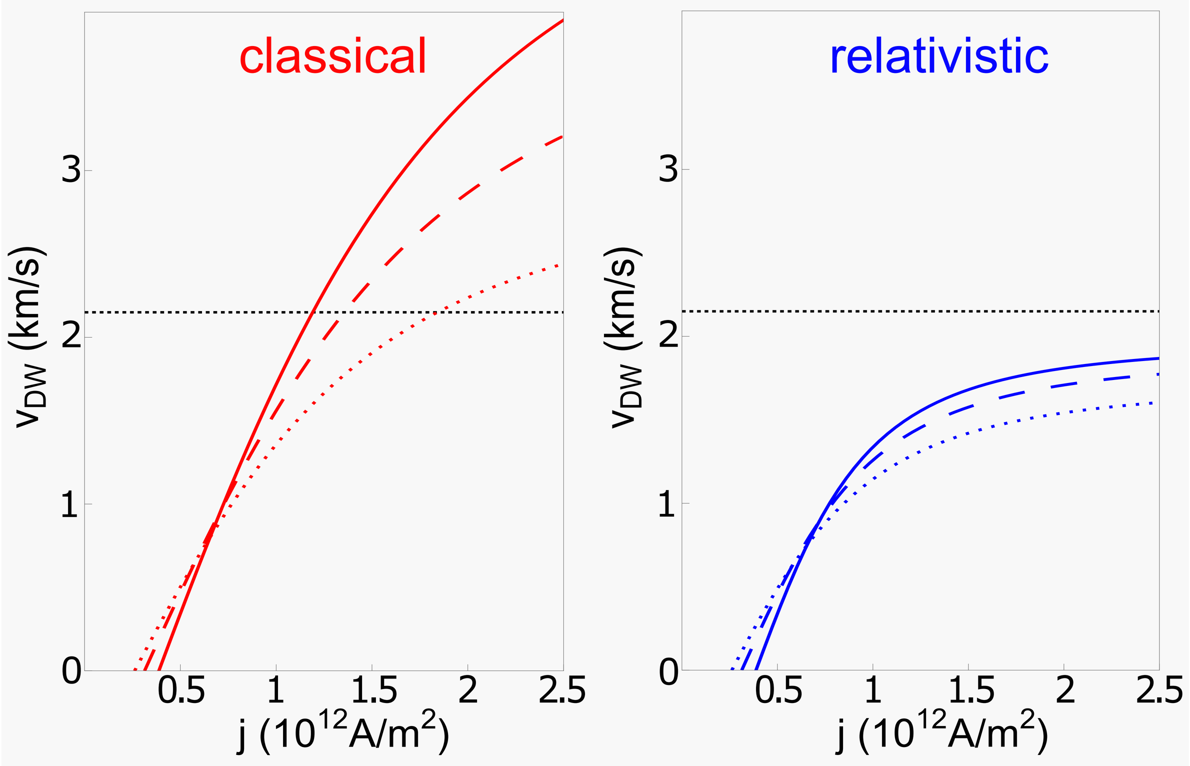
- Maximum propagation speed: magnon velocity $v_{\mathrm{g,max}}$ ↔ speed of light in special relativity;
- The domain wall velocity:

$$v_{\mathrm{DW}} = \frac{v_{\mathrm{g,max}}}{\sqrt{1 + \left(\frac{v_{\mathrm{g,max}}}{v_{\mathrm{cl}}}\right)^2}} \qquad (2)$$

- The classical steady-state domain wall motion:

$$v_{\mathrm{cl}} = \frac{\Delta \gamma_{\mathrm{eff}} \tilde{H}_{\mathrm{pin}}}{\alpha_{\mathrm{eff}} \beta} \left[1 - \beta \left[1 - \left(\frac{2\eta \tilde{H}_{\mathrm{DL}}}{\tilde{H}_{\mathrm{pin}}}\right)^2\right]\right], \qquad (3)$$

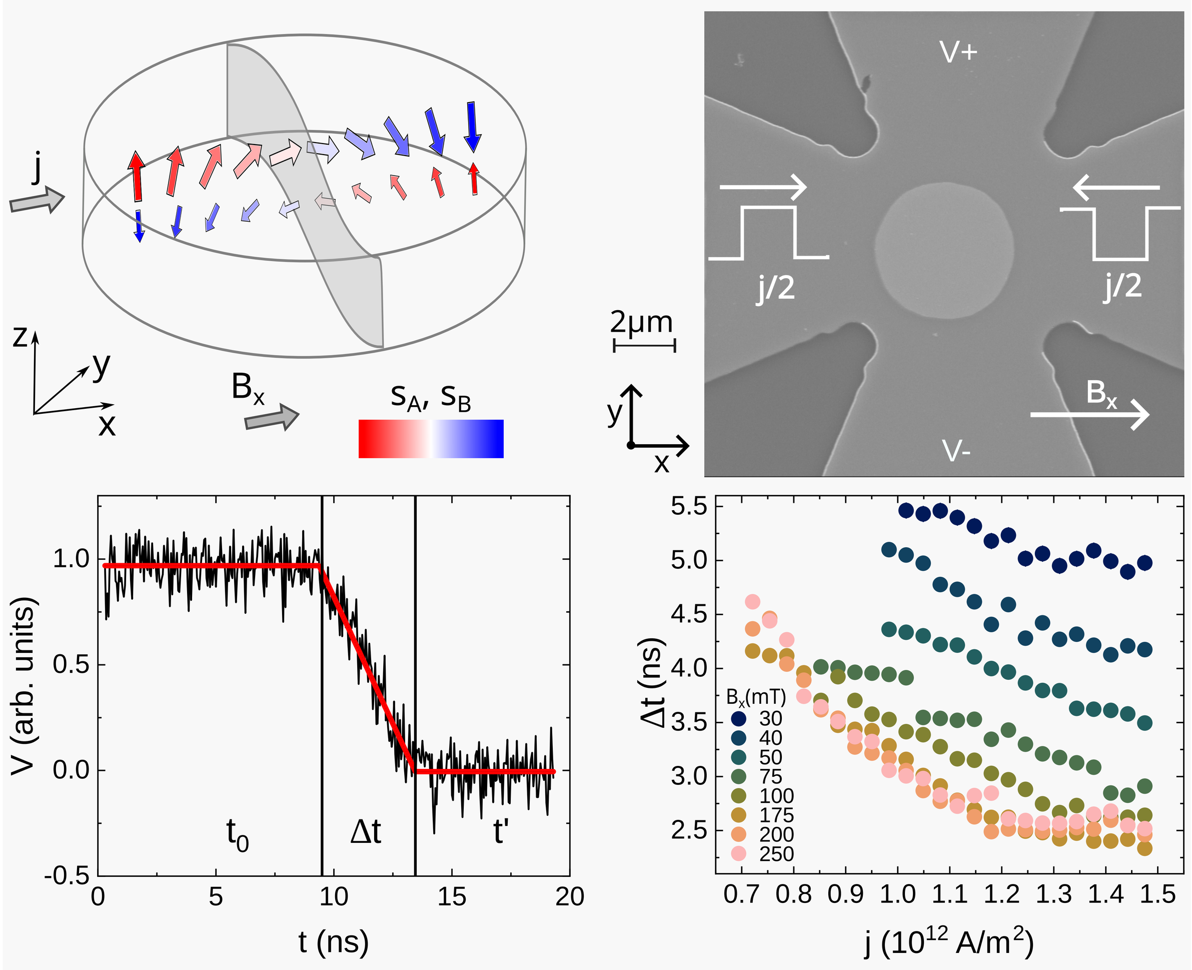
$$\beta = 1 + \left[\frac{\frac{\pi}{2}\tilde{H}_{\mathrm{DL}}}{\alpha_{\mathrm{eff}}\left(H_{\mathrm{D}} + \frac{\pi}{2} H_{\mathrm{x}}\right)}\right]^2$$



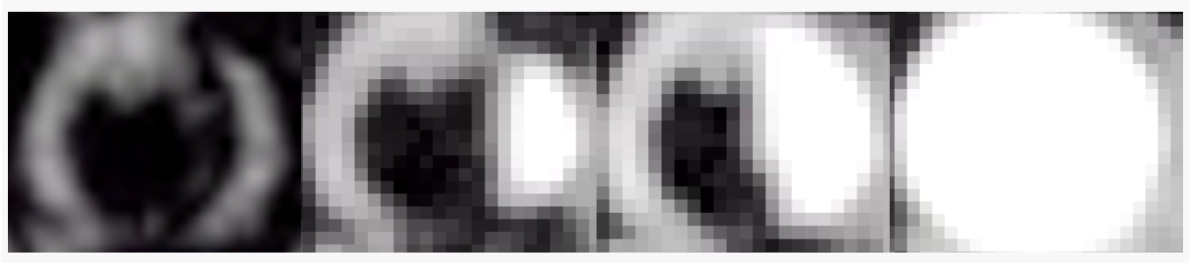
- Classical: continuous velocity increase with current and field
- Relativistic: velocity saturation towards magnon velocity $v_{\mathrm{g,max}}$

Time-resolved anomalous Hall measurements

- μm-sized dots of amorphous GdFeCo sputtered on Pt;
- Alloy compositions: $\mathrm{Gd_{30}Fe_{63}Co_7}$ and $\mathrm{Gd_{31}Fe_{62}Co_7}$;
- Domain walls driven by spin orbit torque, tracked by time-resolved anomalous Hall measurements [4];



Magneto-optical Kerr effect imaging



- Domain wall nucleation and propagation;
- Walls are straight;

References

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6. K. Kim et al., *Fast domain wall motion in the vicinity of the angular momentum compensation temperature of ferrimagnets*, Nature materials 16.12 (2017): 1187-1192.
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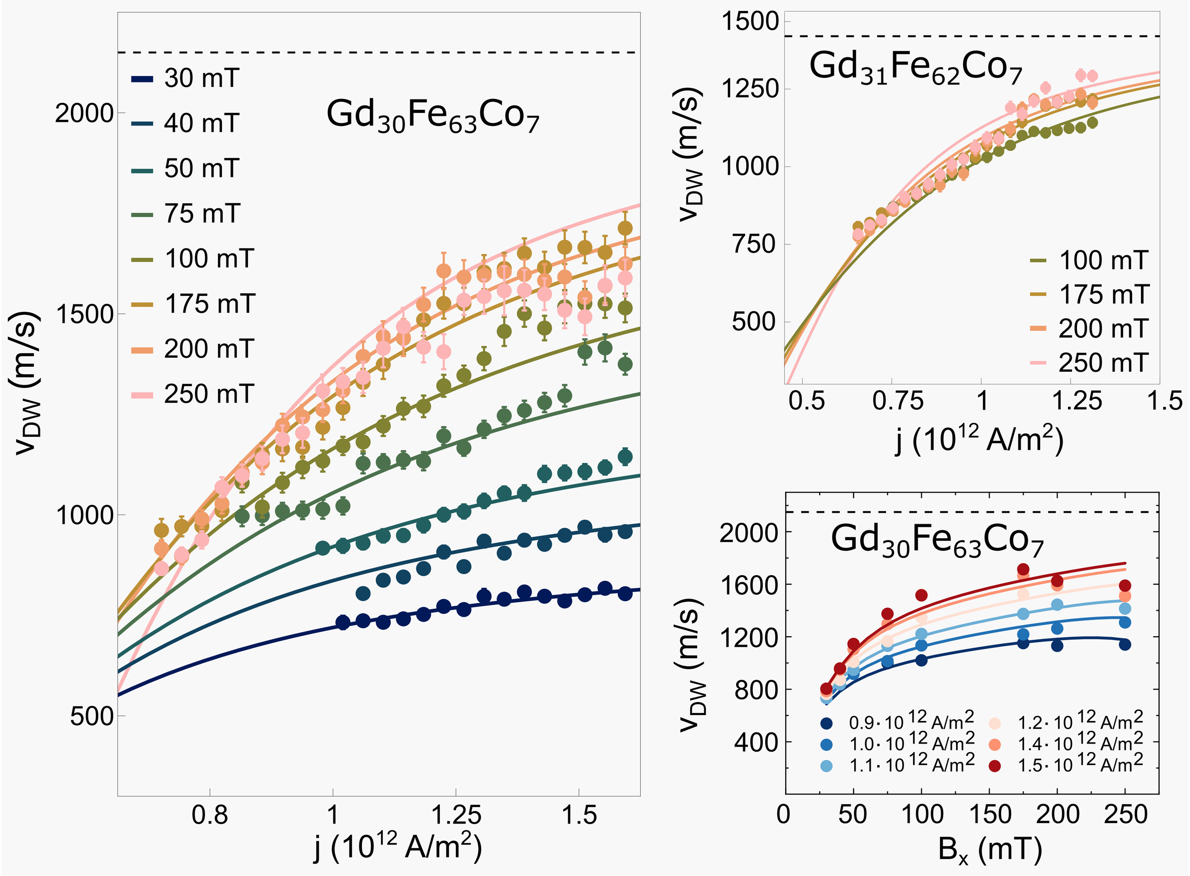
Experimental Results

- Domain wall velocity saturates above $B_x \approx 100$ mT;
- The relativistic model (solid lines) accurately reproduces the experimental data;
- Wall velocities reach ∼ 90% of magnon velocity;
- Extracted magnon velocities:
  – $\mathrm{Gd_{30}Fe_{63}Co_7}$: 2.1 km/s
  – $\mathrm{Gd_{31}Fe_{62}Co_7}$: 1.4 km/s



Parameters	$\mathrm{Gd_{30}Fe_{63}Co_7}$	$\mathrm{Gd_{31}Fe_{62}Co_7}$
A	$1.9\,\mathrm{pJ/m}$	$1.2\,\mathrm{pJ/m}$
M_{A}	$4.3\cdot10^5\,\mathrm{A/m}$	$4.1\cdot10^5\,\mathrm{A/m}$
α	0.006	0.005
H_{pin}	28 mT	29 mT
$v_{\mathrm{g,max}}$	$2.1\,\mathrm{km/s}$	$1.4\,\mathrm{km/s}$
K_{eff}	$9.2\cdot10^3\frac{\mathrm{J}}{\mathrm{m^3}}$	$10\cdot10^3\frac{\mathrm{J}}{\mathrm{m^3}}$
M_{S}	$4.3\cdot10^4\frac{\mathrm{A}}{\mathrm{m}}$	$3.8\cdot10^4\frac{\mathrm{A}}{\mathrm{m}}$
θ_{DL}	0.13	0.13

- A, M_{A}, α, H_{pin}, $v_{\mathrm{g,max}}$ are fitted to the experimental data;
- K_{eff}, M_{S} and θ_{DL} are measured;

Conclusions

- Relativistic domain wall motion observed in amorphous GdFeCo ferrimagnets;
- Domain wall velocities reach 90% of the magnon speed;
- Amorphous ferrimagnets: a scalable platform for ultrafast spintronics;