Velocity of Transverse Doman Wall Motion Along Thin, Narrow Strips

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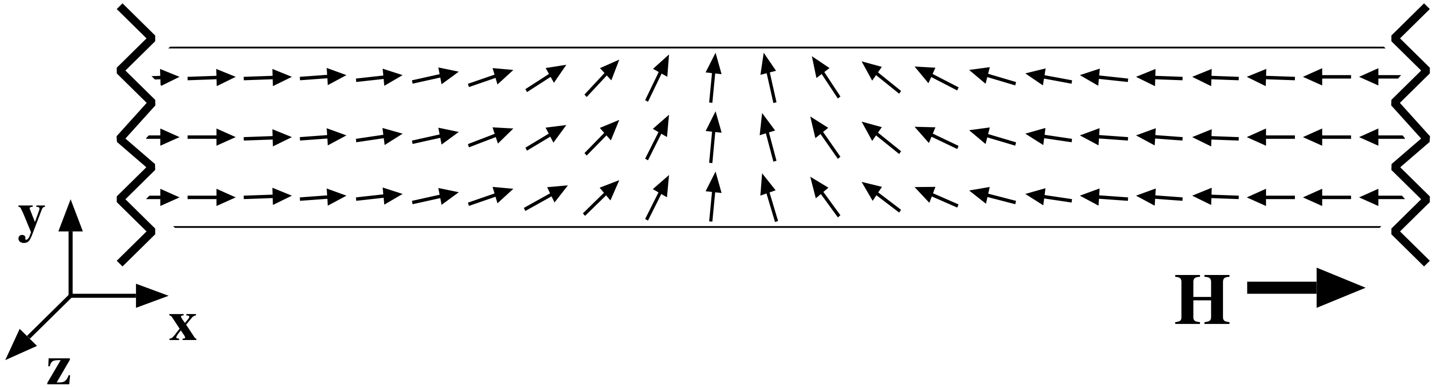
Abstract

Micromagnetic simulation of domain wall motion in thin, narrow strips leads to a simplified analytical model. The model accurately predicts the same domain wall velocity as full micromagnetic calculations, including dependence on strip width, thickness, and magnitude of applied field pulse. Domain wall momentum and retrograde domain wall motion are both observed and explained by the analytical model.

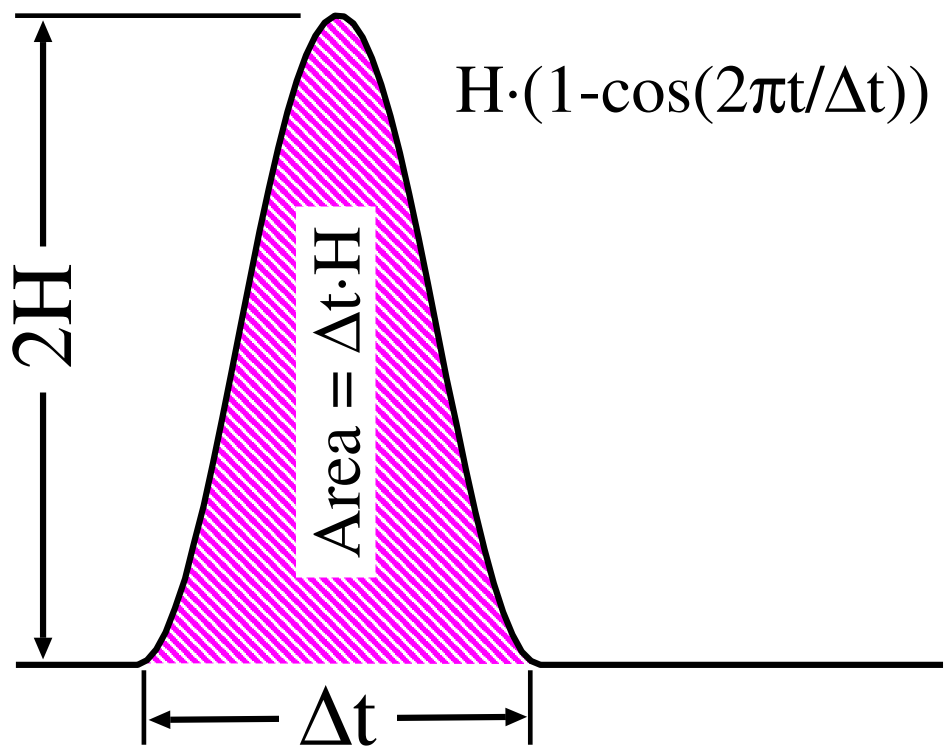
Transverse Domain Wall



- Thickness $T = 5$ nm; Width W: 5 - 35 nm.
- $A = 13$ pJ/m; $M_S = 800$ kA/m; $K = 0$.
- LL dynamics ($\gamma = -221$ kHz/(A/m); $\alpha \geq 0$):

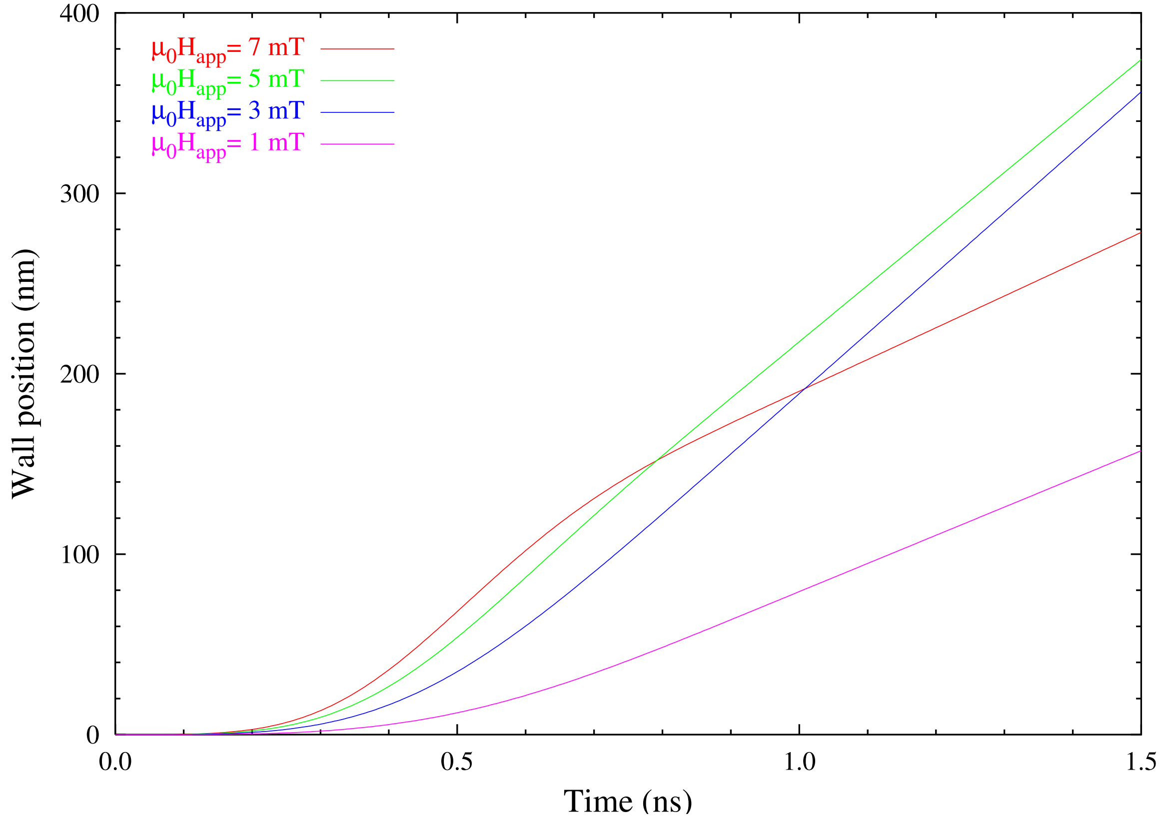
$$\frac{dm}{dt} = \frac{\gamma}{1+\alpha^2} m \times H_{\text{eff}} - \frac{\alpha\gamma}{1+\alpha^2} m \times H_{\text{eff}} \times m \tag{1}$$

Applied Field Pulse



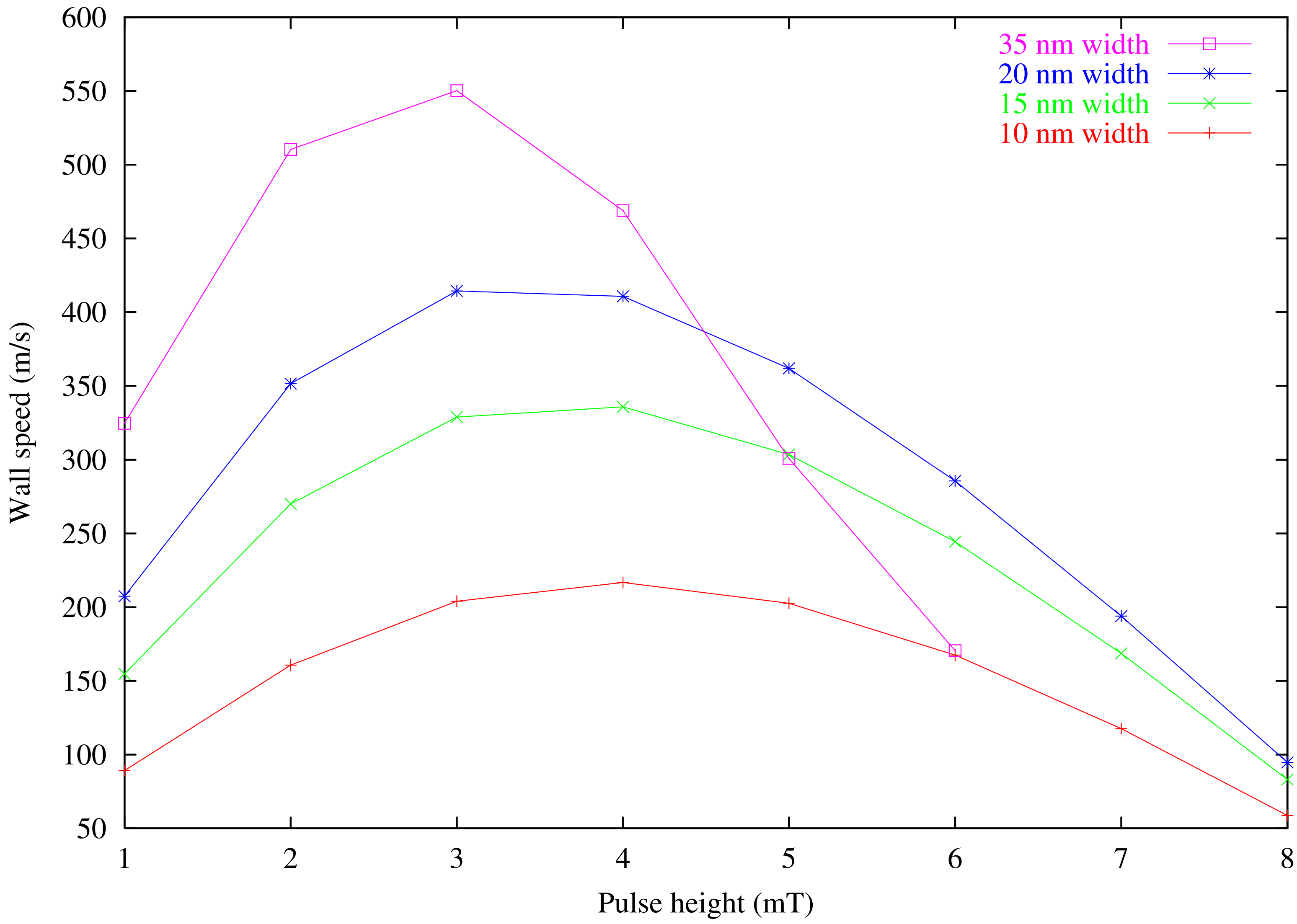
- $\Delta t = 1$ ns.

Pulse-Driven Wall Motion ($\alpha = 0$, $W = 15$nm)



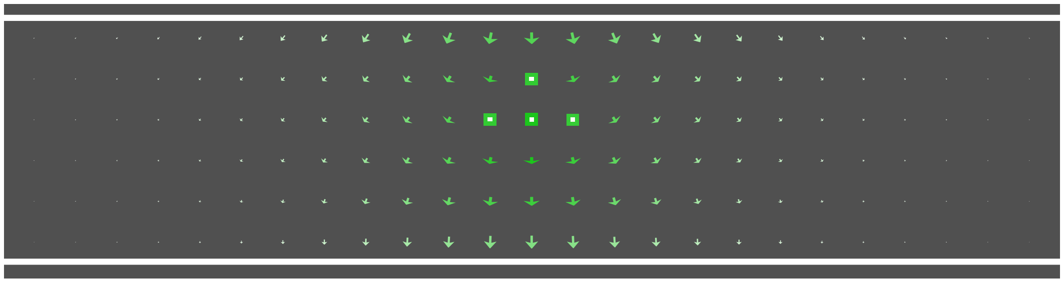
- Wall momentum: motion continues after pulse.
- $\alpha = 0$: velocity remains constant.
- $\alpha > 0$: velocity varies, can increase (!), eventually decays to zero.

Pulse-Driven Domain Wall Velocity ($\alpha = 0$)

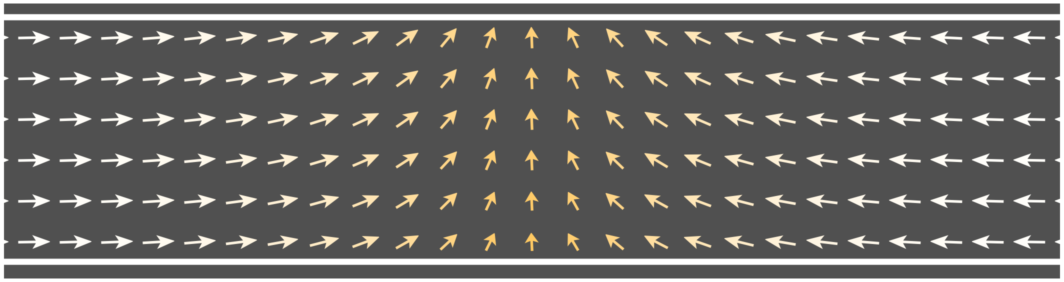


Domain Wall Motion Snapshot

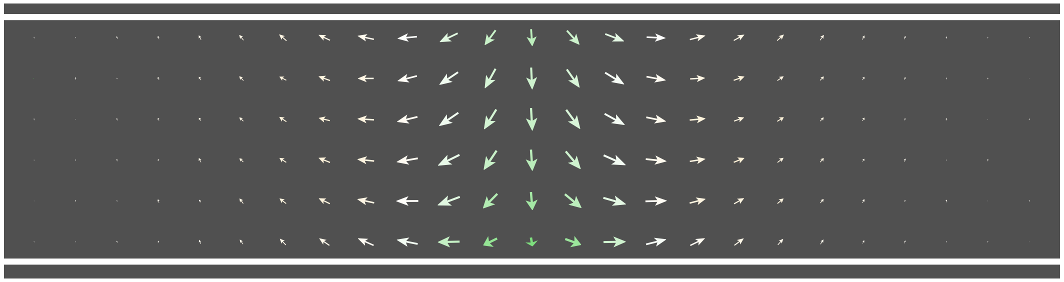
Magnetostatic field: (Green arrows into plane: $-z$)



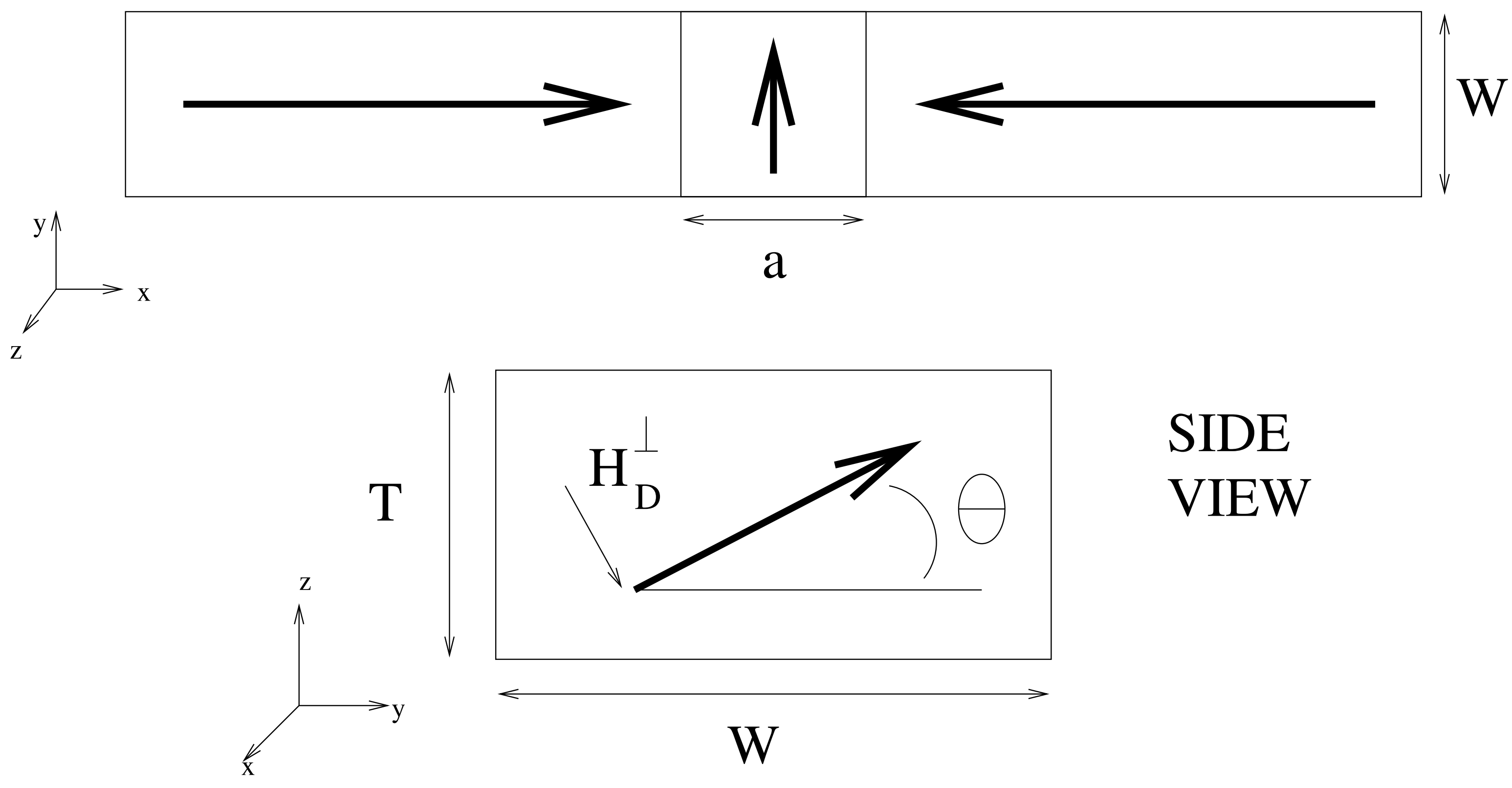
Magnetization: (Orange arrows out of plane: $+z$)



Exchange field:



Three Spin Model



Domain Wall Width

- Derived from balancing exchange and demag energy.

$$a = 1.15\pi\sqrt{\frac{A}{K_m}}. \tag{2}$$

$$K_m = \frac{\mu_0 M_S^2}{2}\{f(\frac{W}{T})\cos^2\theta + f(\frac{T}{W})\sin^2\theta\} \tag{3}$$

$$f(\sigma) = 1 - \frac{2}{\pi}\tan^{-1}(\sigma) + \frac{1}{2\sigma\pi}\log(1+\sigma^2) - \frac{\sigma}{2\pi}\log(1+\sigma^{-2}) \tag{4}$$

Theory: Equations of Motion

- Changing tilt angle θ of wall out of plane.

$$\frac{d\theta}{dt} = |\gamma|(H_{\rm app} - \alpha H_D^{\perp}). \tag{5}$$

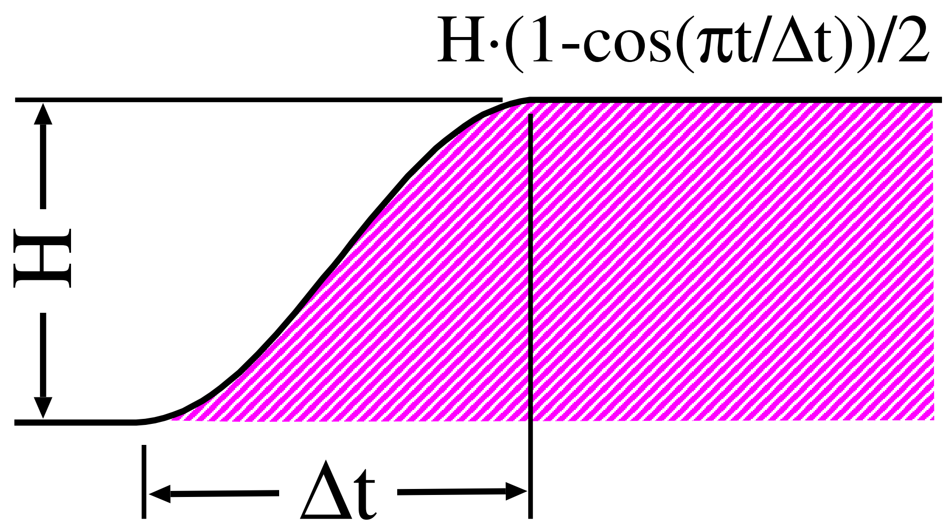
- Demag field due to tilt. (N_y, N_z: demag factors of wall region)

$$H_D^{\perp} = M_S(N_z - N_y)\cos\theta\sin\theta, \tag{6}$$

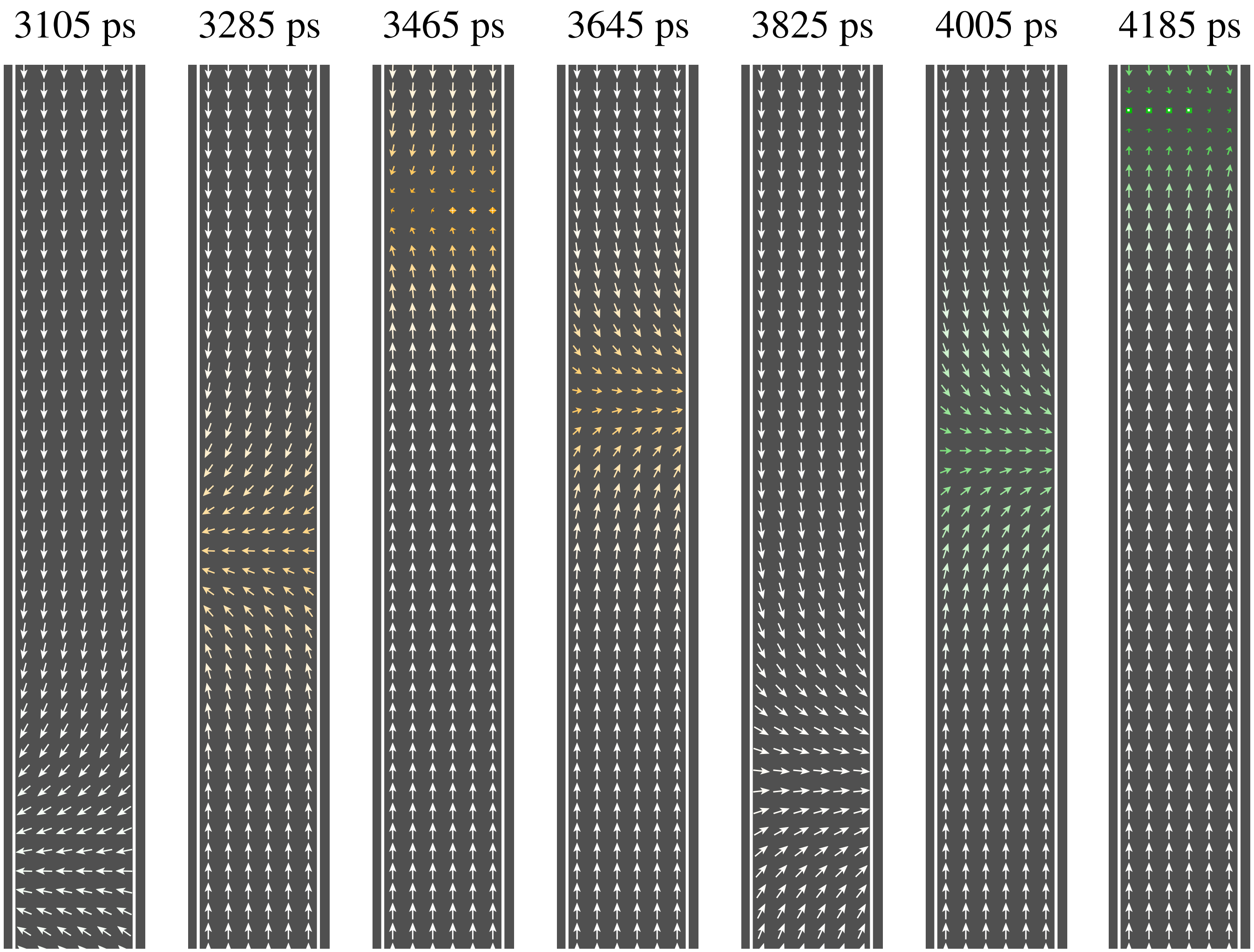
- Wall velocity: precess about demag + damp toward applied.

$$v = v(\theta) = (\gamma/\pi)(H_D^{\perp} + \alpha H_{\rm app})a, \tag{7}$$

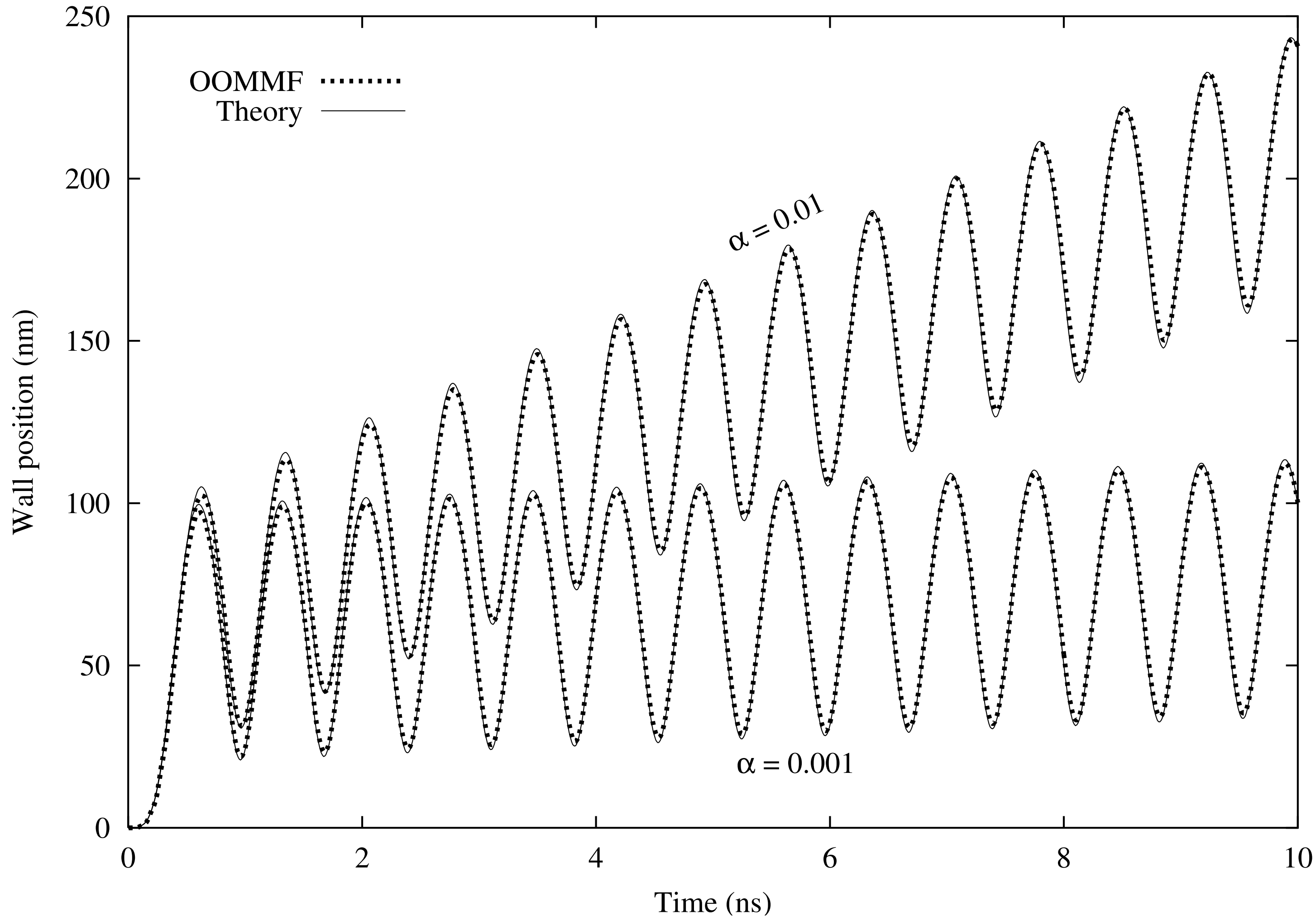
Applied Field Step



Retrograde Wall Motion ($\alpha = 0.01$)



Retrograde Wall Motion



- $\mu_0 H = 25$ mT; $W = 15$ nm; $\Delta t = 0.5$ ns.

Component Energies ($\alpha = 0.01$)