Confined Dissipative Droplet Solitons in Spin-Valve Nanowires with Perpendicular Magnetic Anisotropy

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Magnetic dissipative droplets are localized, strongly nonlinear dynamical modes excited in nanocontact spin valves with perpendicular magnetic anisotropy. These modes find potential application in nanoscale structures for magnetic storage and computation, but dissipative droplet studies have so far been limited to extended thin films. Here, numerical and asymptotic analyses are used to demonstrate the existence and properties of novel solitons in confined structures. As a nanowire's width is decreased with a nanocontact of fixed size at its center, the observed modes undergo transitions from a fully localized two-dimensional droplet into a two-dimensional droplet edge mode and then a pulsating one-dimensional droplet. These solitons are interpreted as dissipative versions of classical, conservative solitons, allowing for an analytical description of the modes and the mechanisms of bifurcation. The presented results open up new possibilities for the study of low-dimensional solitons and droplet applications in nanostructures.

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Spin transfer torque (STT) induced excitations in magnetic systems [1–3] have attracted significant attention during the past decade due to their interesting fundamental properties and potential for technological impact. STT can,magnetic layer is subjected to STT, giving rise to current-tunable dynamical modes such as propagating spin waves [9–13], localized spin-wave bullets [12–17], vortices [18–20], and dissipative droplets. [21–23] The required high current densities are usually achieved by patterning a nanocontact (NC) on top of the spin valve (NC-SV). On the other hand, STT induced by currents within a magnetically inhomogeneous sample provides the basis for current-induced domain-wall motion [24,25], as demonstrated in nanowire ferromagnetic thin films [26–28] and SVs [29,30].

For both types of STT excitations, perpendicular magnetic anisotropy (PMA) materials are of fundamental and technological interest. PMA materials support topological (Skyrmions) [31,32] and nontopolp6r22.7(i501(gi0.5(o)14.1([(39)22.7(])]TJ0.137250.121570.12549scn1.29040TD(.)Tj-23.0819-1.14

decreasing width while keeping the NC laterally centered and of fixed radius. The droplet nucleation is due to a spin-wave modulational instability [21] leading to strongly nonlinear dynamics, often requiring micromagnetic simulations to uncover their features. However, an analytical treatment is available when some simplifications are made, as will be discussed below.

The system under study is a trilayered NC-SV consisting of PMA free and fixed layers (Fig. 1). Micromagnetic simulations are performed for the free layer with the graphics-processing-unit-based tool Mumax2 [42], using a second-order Runge-Kutta solver with an adaptive step bounded between 1 fs and 1 ps [13]. The dynamics follow the Landau-Lifshitz-Gilbert-Slonczewski equation

$$\frac{d\hat{m}}{dt} = -\gamma\hat{m} \times \mu_0\vec{H}_{\mathrm{eff}} + \alpha\hat{m} \times \frac{d\hat{m}}{dt} - \gamma\mu_0 M_s\sigma(I)f(\vec{x})\epsilon\hat{m} \times \hat{m} \times \hat{M}; \qquad (1)$$

where $\gamma/2\pi = 28$ GHz/T is the gyromagnetic ratio, $\hat{m}$ and $\hat{M}$ are the normalized free and fixed layer magnetization vectors, respectively, α is the Gilbert damping, and $\sigma(I) = \hbar I P\lambda/\mu_0 M_s^2 eV(\lambda + 1)$ is the dimensionless spin torque coefficient where $\hbar$ is the reduced Planck constant, I is the spin-polarized current, P is the polarization, $\epsilon = 1/(1 + \nu\hat{m} \cdot \hat{M})$, $\nu = (\lambda - 1)/(\lambda + 1)$, λ is the spin torque asymmetry, μ_0 is the vacuum permeability, M_s is the saturation magnetization, e

$$\mathrm{FMR} = \gamma\mu_0(\mathsf{H_a} + \mathsf{H_k} - \mathsf{N_z M_s})$$

periodically changes as the domain boundary precesses. Consequently, we believe that this novel droplet opens up new possibilities for low-dimensional droplet applications and magnetic soliton research.

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