Reprogrammable Hybrid Magnonic Materials for Neuromorphic Computing Based on Spin-Wave Coupling to Single-Molecule Magnets

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Conventional CMOS-based computing architectures face fundamental limitations in energy efficiency and scalability, motivating the exploration of alternative paradigms such as wave-based information processing [1]. Spin-wave (magnonic) computing is particularly attractive due to its intrinsically low energy dissipation and ability to support rich interference phenomena, enabling dense, all-to-all connectivity that naturally maps onto artificial neural network architectures [2]. However, achieving strong, tunable, and reconfigurable control of spin-wave propagation at the nanoscale remains a key challenge.

Here, we propose and numerically demonstrate a reprogrammable hybrid magnonic platform tailored for neuromorphic computing applications. The system consists of a low-damping yttrium iron garnet (YIG) thin film functionalized with an ordered array of Mn_{12}-based single-molecule magnets. Micromagnetic simulations, supported by finite-element modeling and coupled-mode theory, reveal resonant coupling between propagating spin waves and molecular magnetic moments, resulting in controllable anticrossing gaps in the spin-wave transmission spectrum. The coupling strength and spectral position of these gaps can be continuously tuned via external magnetic fields or molecular patterning.

Importantly, we demonstrate intrinsic reprogrammability through the formation of antiferromagnetically aligned molecular clusters, enabling dynamic modulation of spin-wave pathways and interaction strengths. Such a control of magnonic signal flow may introduce a new degree of freedom for implementing adaptive, multi-functional neural networks. Our results therefore, establish a scalable route toward energy-efficient, reconfigurable magnonic neural hardware by bridging low-loss spin-wave transport with molecular-level magnetism.

References:

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