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Technology Offer

Non-collinear Spin Valve for Multi-State Memory and Neuromorphic Devices

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Abstract

This invention introduces a non-collinear spin valve (NC-SV) architecture capable of storing and reading arbitrary angles between magnetization vectors of two ferromagnetic layers. Unlike conventional spin valves that exhibit binary resistance states corresponding to parallel or antiparallel magnetization alignments, the NC-SV enables multiple stable configurations, allowing for analog or multi-level operation. By utilizing layers with different magnetic anisotropies and a temperature-dependent exchange bias effect, the system enables precise and non-volatile control of the relative magnetization direction. This tunability makes the device highly suitable for emerging applications such as multi-state memory cells, analog computing elements, and synaptic weights in neuromorphic systems. The platform is compatible with a wide range of material systems and can operate at both cryogenic and room temperatures.

Background

Traditional spin valves are foundational components in magnetic sensors, hard drives, and MRAM, relying on digital switching between two collinear magnetization states. However, these binary systems are limited in addressing emerging computational demands such as neuromorphic architectures or analog signal processing. Existing technologies lack efficient mechanisms to reproducibly stabilize intermediate magnetic states. This invention addresses this gap by introducing a robust method for fixing the angle between magnetization directions in a non-collinear manner, thereby enabling a continuum of resistance states. Such capability greatly expands the functional scope of spintronic devices, supporting multi-bit memory and analog processing within standard device footprints.

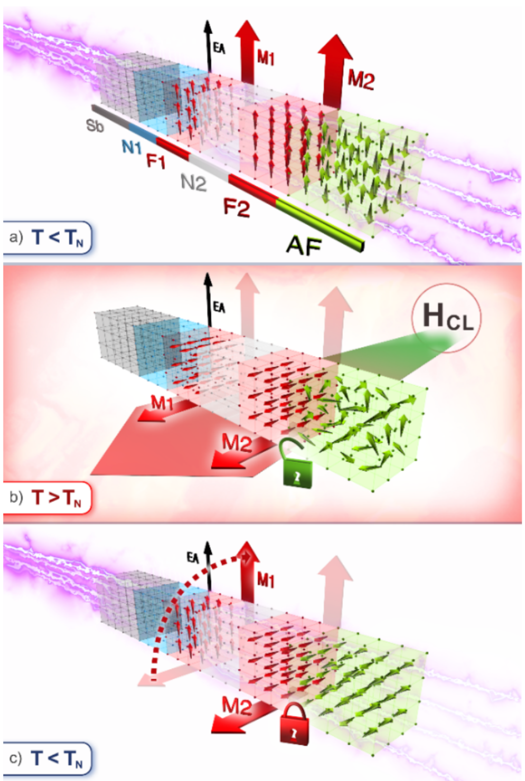

Figure 1: Schematic representation and operating principle of the non-collinear spin valve.
(a) The device comprises two ferromagnetic layers (F1, F2) separated by a non-magnetic spacer. F1, deposited on a substrate (Sb) with an optional buffer layer (N1), exhibits uniaxial magnetic anisotropy, with its easy axis (EA) indicated by a black arrow. F2 is exchange-coupled to an adjacent antiferromagnetic layer (AF), forming a pair with unidirectional anisotropy.
(b) To define a non-collinear state, the system is heated above the Néel temperature (T_N) of the AF and subjected to a magnetic field (H_{CL}) at angle $\Delta\alpha$ relative to EA.
(c) Upon cooling below T_N in the presence of H_{CL} and subsequent field removal, M1 aligns along EA, while M2 remains fixed along H_{CL}, resulting in a stable, remanent non-collinear magnetization configuration characterized by angle $\Delta\alpha$.

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The proposed spin valve architecture comprises two ferromagnetic (FM) layers, F1 and F2, separated by a non-magnetic spacer layer (N2). The FM layer F1 is deposited on a substrate, optionally incorporating a non-magnetic buffer layer (N1), and exhibits uniaxial magnetic anisotropy, which defines its easy axis (EA). This anisotropy can be tailored through substrate selection, film deposition parameters, or lithographically defined shape effects. The second FM layer, F2, is coupled to an adjacent antiferromagnetic (AF) layer, forming an exchange-biased pair. The AF layer is selected such that its Néel temperature (T_N) is below the Curie temperatures of both FM layers. When the system is heated above T_N and cooled in a weak magnetic field (H_{CL}) applied at a chosen angle $\Delta\alpha$ relative to EA, the magnetization direction M2 of F2 aligns with H_{CL} and is locked via exchange bias upon cooling. Simultaneously, M1 in F1 relaxes along EA, resulting in a non-collinear remanent magnetization configuration. The angle $\Delta\alpha$ between M1 and M2 determines the spin valve resistance, enabling a continuous tuning between the resistance states of the conventional parallel (P) and antiparallel (AP) configurations. This mechanism is non-volatile, thermally stable, and reprogrammable, and supports analog resistance control, making it highly suitable for applications in multi-level spintronic memory and neuromorphic computing.

Advantages

- **Multi-state functionality:** Enables adjustable resistance levels through precise control of magnetization angles, supporting analog or multi-bit data storage.
- **Non-volatile operation:** Magnetic states are retained without power via exchange bias, ensuring stable and energy-efficient memory.
- **Broad material compatibility:** Suitable for various ferromagnetic, antiferromagnetic, and non-magnetic materials, including room-temperature systems.
- **Low energy configuration:** Requires only small magnetic fields and moderate heating for state setting, reducing energy consumption.
- **Scalable and integrable:** Compatible with standard spintronic fabrication techniques for integration into memory and logic circuits.

Potential applications

- Multi-level magnetic memory (beyond binary MRAM).
- Synaptic elements in neuromorphic computing architectures.
- Reconfigurable analog logic elements.
- Magnetic field sensors with enhanced resolution.
- Superconducting spintronics and triplet Josephson junctions.

Patent Information

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