Technology Offer

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Non-collinear spin-valve

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Abstract

A classical spin valve (SV) is a device in which the electrical resistance depends on the relative position of the magnetic moments of two ferromagnetic (FM) layers: with parallel (P) and antiparallel (AP) ordering, the SV resistance is minimum and maximum, respectively. Nowadays SVs are actively used in magnetic sensors, hard disk read heads and magnetic random-access memory. Thus, the SV, analogous to a transistor in conventional electronics, is a binary (digital) device. Here we offer a new technology that allows fixing the direction of the moments of M1 and M2 at any arbitrary non-collinear alignment between AP and P states, which makes it possible to create a non-binary spin valve. Such a multiple state resistor can be used, for example, as a multi-state memory cell, or a synapse in an artificial neural network.

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The design is based on the SV scheme shown in Fig. 1, with two FM layers (F1, F2) with different types of magnetic anisotropy (uniaxial and unidirectional), and a non-magnetic spacer N2. The FM layer F1 is deposited on the substrate SU with an optional non-magnetic buffer layer N1. The F1 layer has an easy magnetic axis due to uniaxial magnetic anisotropy, which can be induced by the choice of substrate, the growth conditions, or by the shape anisotropy of the device. The FM layer F2 forms an exchange bias pair with the antiferromagnet AF. The Néel temperature T_N of the AF is chosen to be smaller than the Curie temperature T_m of the FM layers. The EB effect occurs between the neighboring AF and F2 layers at $T<T_N$. It induces a unidirectional anisotropy (UD) in the F2 layer, such that the direction of M2 can only be altered by a strong field larger than the exchange bias field H_{EB}. The latter is in the order of tens of Oe to several kOe, depending on the layer materials. At $T>T_N$ the exchange bias and the unidirectional anisotropy disappear, such that M2 can align parallel to a small field H_{CL}. The direction of the UD axis is defined by the magnetization vector **M2** during cooling below T_N, which in turn is defined by the field $\mathbf{H_{CL}}$ applied during cooling.

Defining or writing the NC magnetization state with angle $\Delta\alpha$ requires the following steps: (i) The AF layer is heated above T_N to remove EB. (ii) A small field H_{CL} is applied at an angle $\Delta\alpha$ with respect to the easy axis EA of F1. (iii) The system is cooled below T_N with H_{CL} applied. M2 will stay parallel to H_{CL} during cooling, and the direction of UD will be defined by M2. (iv) H_{CL} is removed. M2 is now stabilized by the exchange bias, and stays in the direction previously defined by H_{CL}. In this latter step after removing H_{CL}, M1 aligns along the easy axis EA, such that in this remnant state ($T<T_N$, $H=0$) the angle between M1 and M2 corresponds to the requested $\Delta\alpha$. The angle $\Delta\alpha$ affects the electrical resistance of the layer system, such that the

readout of the state is performed by measuring the resistance of the device, either in current-in-plane or current-perpendicular-to-plane mode.

In summary, the above-mentioned procedure allows to create a non-volatile device with a well-defined degree of non-collinearity. Another way to alter $\Delta\alpha$, albeit volatile, is to apply a magnetic field H, which is smaller than H_{eb} of F2 layer. This will rotate the direction of **M1** from EA towards **H**, while the direction of **M2** will still be pinned along the $\mathbf{H_{CL}}$. In particular, this small field H can also be used to invert (rotate by 180°) the direction of F1 with respect to the EA, such that in the field free remnant state **M1** can be aligned both parallel and antiparallel to EA. The advantage of this method is that the non-collinear angle $\Delta\alpha$ between **M1** and **M2** can be set at arbitrary values between -90° and 90° in a reproducible and accurate way. The angle $\Delta\alpha$ is changed by, for example, heating above T_N, followed by cooling in the field with the required orientation. Another advantage of the method is a wide range of materials for the F1(2), N1(2) and AF layers, which allows the system to be used in various applications. By choosing an AF layer with proper T_N, the operation temperature of the device is adapted to specific applications. For example, by choosing $IrMn_3$ with T_N>300K as AF layer allows for preparation of devices working at room temperature. By choosing superconductors for the N1 and/or N2 layers, superconducting NC spin valves or triplet Josephson junctions with variable and arbitrary $\Delta\alpha$ can be designed.

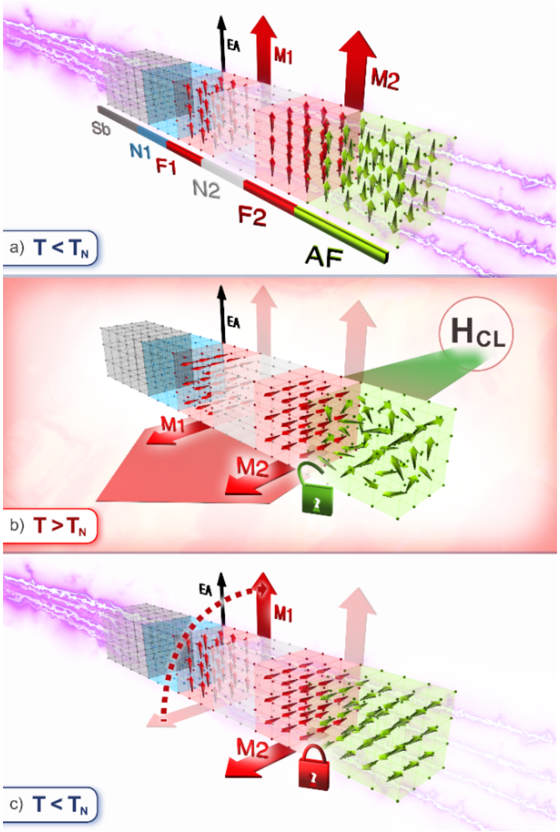

Fig. 1. Scheme (a) and principle of operation of the non-collinear spin-valve. The ferromagnetic layer F1 deposited on the substrate Sb with an optional buffer layer N1 has uniaxial anisotropy with the direction of the easy axis shown by the black arrow with caption EA. The ferromagnetic layer F2 and the antiferromagnetic layer AF form an exchange bias pair. (b) Above the Néel temperature T_N of the AF layer an external magnetic field H_{CL} is applied at an angle $\Delta\alpha$ with respect to EA. The system then is cooled below T_N in the magnetic field H_{CL}. After release of the magnetic field to zero, the magnetization vector **M1** of the layer F1 will turn towards the direction of EA while the magnetization **M2** of the layer F2 will stay along the direction of $\mathbf{H_{CL}}$ due to the exchange bias. (c) Thus, the remnant state will be characterized by the non-collinear alignment of **M1** and **M2** with the angle $\Delta\alpha$.
The figure is courtesy of Reiner Müller; FRM II/TUM

Advantages

- Possibility to create a non-volatile SV with adjustable resistance in the range between R_{min} and R_{max} corresponding to the parallel and antiparallel state respectively.
- Wide range of materials for the F1(2), N1(2) and AF layers, which allows the system to be used in various applications both at low and at room temperatures.
- Compatibility with existing technologies for the preparation of spintronic devices.

Patent Information

Patent filed.