Implementation of an hysteresis model in VHDL-AMS for compact modeling of spintronic devices
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Why an hysteresis model?
Spin dependent electronic devices such as giant magnetoresistance or magnetic tunnel junctions have promising properties for circuit design. Memory cells, transistors as well as magnetic sensors using the spin dependent electronic properties of (anti)ferromagnetic materials have already been demonstrated. The more, the manufacturing techniques of these devices are CMOS compatible and have been recently integrated into standard 0.18µm CMOS chips. However, the lack of compact model of such devices is a truly limiting factor for the design of integrated spintronic circuits.

To accurately model spintronic devices, one needs an hysteresis model to describe the behavior of the magnetic layers. Such a model should ideally include the following features:
- Magnetization vector (2D or 3D)
- Shape effect (demagnetizing field)
- Dynamics (magnetic moment movement, temperature,...)

MTJ model
A magnetic tunnel junction is basically made of two ferromagnetic layers separated by a thin insulating layer. When a voltage is applied, electrons are forced to pass thru the oxide by tunnel effect. The conductance of the junction depends on the relative orientation of both magnetizations of the ferromagnetic layers.

A MTJ compact model has been written in VHDL-AMS thanks to two coupled hysteresis models (one SW model for each ferromagnetic layer + magnetic coupling between layers). The junction is simply modeled thanks to a capacitor and a conductor in parallel. The capacitance is constant while the conductance depends on the scalar product of the magnetic moment of the ferromagnetic layers.

Simulation of a magnetometer
This simple magnetic tunnel junction model has been developed for the design of a two-axis magnetometer using a single magnetic tunnel junction [3]. Here, the simulation of the front-end circuit of this magnetometer is shown.

The MTJ is subjected to an ac magnetic field (triangle and square curves). When magnetic reversals occur the conductance of the junction changes. The induced voltage pulses (magenta curve) are amplified and converted into a bit stream (orange curve).

Stoner-Wohlfarth model
The Stoner-Wohlfarth model [1] allows to determine the equilibrium position of a magnetic moment subjected to a magnetic field. It takes account for the longitudinal and transversal components of the magnetic field. The SW model is thus two or three dimensional.

This model is based on a graphical method which is not well suited for software implementation. The tangent to the SW astroid must be evaluated and more than one solution may be found: the history of the magnetization vector must be considered. The effect of the demagnetizing field is modeled thanks to the factor k which depends on the shape of the modeled magnetic layer.

VHDL-AMS implementation
A dichotomous method is used to evaluate the tangent to the SW astroid. Since the astroid is symmetric, this function is written only for the upper right quadrant. The sign of the Y component is chosen identical to the sign of H_y (vertical symmetry) and a boolean signal which is inverted each time h goes over the SW curve is used to model the hysteresis effect (memory + horizontal symmetry).

Simulation
The simulation results obtained with this hysteresis model written in VHDL-AMS are in perfect agreement with the Stoner-Wohlfarth model. The hysteresis loop is perfectly square when the transversal field is null and the hysteresis totally disappears when this field is larger than k times H_k.

References