Switching Optimization of an Electrically Read- and Writable Magnetic Logic Gate

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INTRODUCTION

The continuously growing demand for bigger bulk memory at decreasing prices pushes scaling efforts and leads to the introduction of new device types and materials. Spin based technologies are auspicious due to their fast switching, high endurance, and non-volatility. They additionally permit the use of spin as a degree of freedom to join information storage and processing in a single device, thus enabling a fully non-volatile information processing system. Recently, a fully electrical read-write device out of a ferromagnetic semiconductor has been shown [1]. It was also contemplated to extend this device to a logic XOR gate, which offers the combination of memory storage and logical operations within a single unit. We proposed a way to extend the functional capabilities of the logic gate to further logic functions and carried out a simulation study showing that the switching of the gate is feasible for horizontal as well as diagonal current flow [2] (see Fig. 1). We also found that it is much harder to reset the structure with a diagonal current flow as reliably and fast as for a horizontal current flow, due to the impediment at the constriction connecting the two disks (see Fig. 4). Therefore, we propose an alternative switching path which avoids the passage of the constriction (cf. Fig. 1, Fig. 2, and Fig. 3).

METHODS

Analogously to [2] we assume disk radii of 30, 40, and $80\,\mathrm{nm}$, a fixed constriction length and width of $15\,\mathrm{nm}$, a saturation magnetization M_S of $32\,\mathrm{kA/m}$, a cubic anisotropy with the easy axis oriented parallel to the leads and a cubic anisotropy constant K_C of $2\,\mathrm{kJ/m^3}$ for the $(Ga,Mn)As$ film (cf. [3], [4]). Furthermore, to improve the accuracy of the results, all data points shown are an average over several simulations (in the range of $\pm 5\%$ of the corresponding current density) and the error bars depicted in Fig. 5 and Fig. 6 state the respective standard deviation $\pm\sigma$.

RESULTS/DISCUSSION

Comparison between Fig. 5 and Fig. 6 reveals that for an alternative current flow path the switching occurs for a broader range of current densities. At the same time the switching speed has also increased, provided the current densities for the diagonal and alternative flow paths are the same. In general, for higher currents the switching occurs faster. Deviations from this rule are due to the formation of nontrivial spin texture excitations or vortices which delay relaxation of the total magnetization towards its equilibrium orientation. The alternative current flow path also leads to an increase of the switching probability to 65% as compared to 43% for the case of diagonal current flow.

CONCLUSION

The proposed alternative current flow path enables higher switching speed as well as higher switching probabilities.

ACKNOWLEDGMENT

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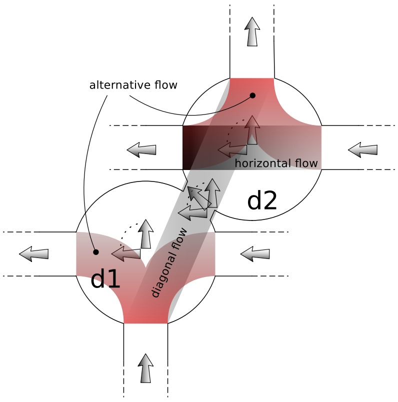

Fig. 1. The magnetization in the leads is fixed and oriented along 180° for the horizontal leads and along 90° for the vertical leads. The disks $d1$ and $d2$ can be set back to their initial magnetization state either by applying a current diagonally passing the constriction or by applying the alternative current path avoiding the constriction. Horizontal current paths were used in [2] to switch $d1$ and $d2$ independently.

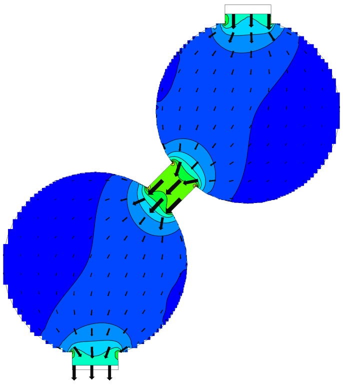

Fig. 2. Current density profile for two 40 nm disks and diagonal flow path.

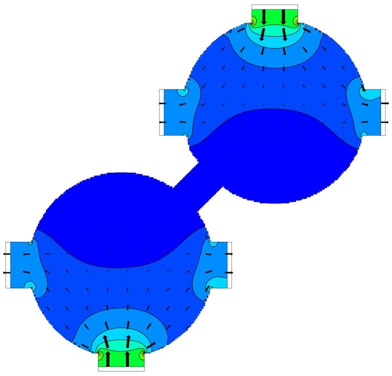

Fig. 3. Current density profile for two 40 nm disks and alternative flow path.

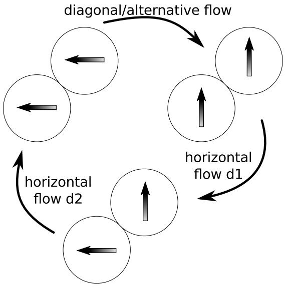

Fig. 4. The different initial and ending states and the corresponding current paths needed for transition between these states are depicted. The cycle begins with both disks exhibiting a magnetization along 90° and applying a horizontal current flow through disk $d1$ to reach the state, where the magnetization in $d1$ is flipped to 180°, while in disk $d2$ the magnetization is still oriented along 90°. From there a horizontal current flow is applied through $d2$ to orient the disk in the same direction as $d1$). In order to reset the two disks to their initial state a diagonal (alternative) flow path through (avoiding) the constriction is applied.

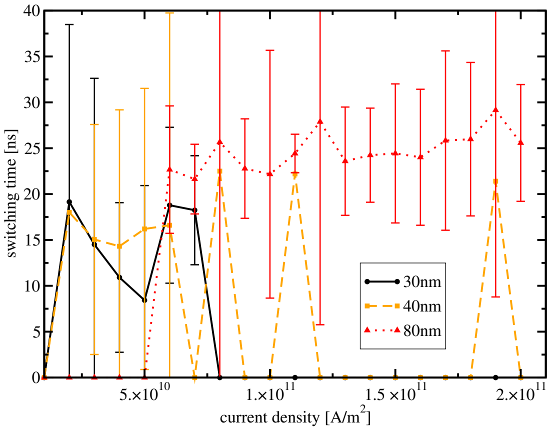

Fig. 5. Switching times for diagonal flow at 30, 40, and 80 nm.

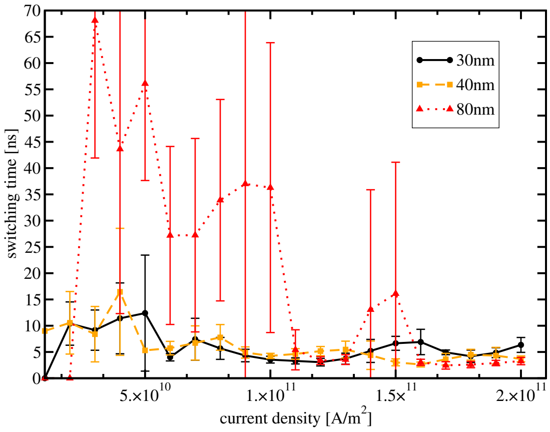

Fig. 6. Switching times for alternative flow at 30, 40, and 80 nm.