# NON-LOCAL LATERAL SPIN VALVE ENABLED ALTERNATIVE MEMORY ARCHITECTURES

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At its inception, the non-local lateral spin valve (NSLV) was implemented solely as an experimental probe for spin dynamics in solid-state systems since it enables separation of Coulomb and pure spin-based currents [1]. However, the NLSV quickly gained traction as a potential device topology for spintronic-based magnetic field sensors [2,3]. Subsequently, the NLSV has been envisioned in various embodiments for insertion in a variety of other applications, namely, non-local spin transfer torque (NLSTT) magnetic random access memory (MRAM) and neuromorphic architectures [4,5]. Moreover, the NLSV is compatible with the majority of conventional magnetic tunnel junction (MTJ) implementations, which allows "computation-in-memory (MRAM)" using spin current as the computation variable [6].

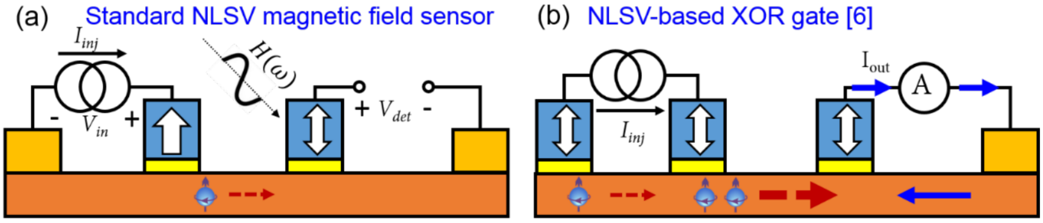

**Figure 1** (a) Cross-sectional schematics of the nonlocal lateral spin valves used as magnetic field sensor. (b). NLSV-based XOR gate where the spin current is used as the computation variable.

The NLSV operating in the non-local configuration (illustrated in Fig. 1) is comprised of a non-magnetic channel layer connecting ferromagnetic injector and detector leads. A spin-polarized current is injected in a closed-loop circuit whereby the population gradient of carriers with coherently polarized spins diffusively mediates pure spin current away from the injector region. The accumulation of polarized spins adjacent to the ferromagnetic detector gives rise to a measurable difference in electrochemical potential between the lead and channel layers.

Recent progress on 2D-material-based NLSVs has successfully enhanced spin lifetime ($\tau_s$) to tens of ns at room temperature [7]. As a result, the impact of spin accumulation/diffusion dynamics must be taken into account, especially when evaluating the NLSV performance under a temporal field (***E*** or ***H***) perturbation. At this nascent stage, little work has been reported on the frequency dependence of NLSV devices.

This work presents a charge-spin circuit model (Fig. 2a) for NLSVs that incorporates the time-dependence of spin accumulation and spin diffusion through a complex spin diffusion length [8]. Owing to the diffusive form of Boltzmann's transport equation in the spin domain [8,9], the spin diffusion length scales as $\omega^{-1/2}$, as shown in Fig. 2b. This gives rise to the transmission line characteristics of the spin channel at high frequency and shows a high-frequency roll off that is dependent on channel material properties (Fig. 3a). Depending on the application, the channel design may point to different directions. As shown in Fig. 3, to achieve higher roll-off frequency, a short $\tau_s$, but large diffusion constant ($D$), is preferred. However, to achieve large voltage output efficiency, higher $D$ and $\tau_s$ are both preferred. Therefore, the charge-spin circuit model is necessary to provide design guidance for NLSVs for a variety applications such as magnetic read heads in recording systems or computation elements in solid state memory.

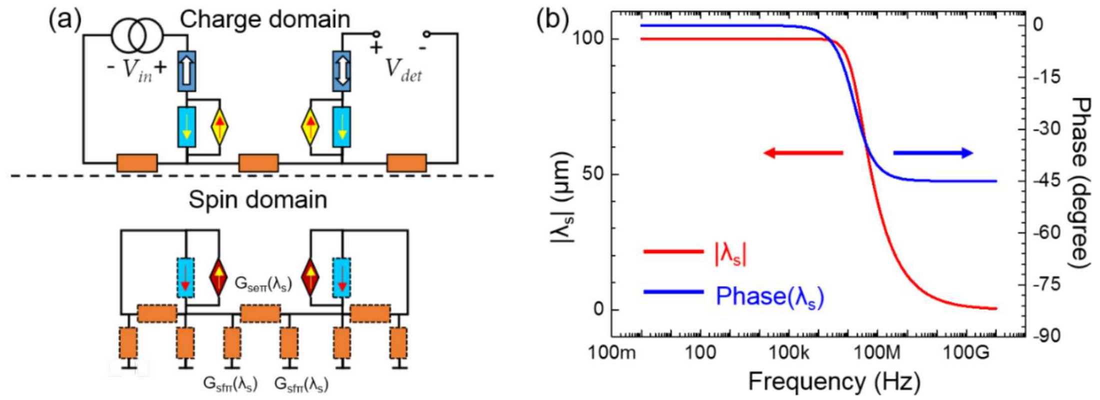

**Figure 2.** (a) Coupled charge-spin circuit model for NLSV devices (b) Frequency dependence of the magnitude and phase of the spin diffusion length ($D = 10^4\ \mathrm{cm}^2/\mathrm{s}, \tau_s = 10\ \mathrm{ns}$)

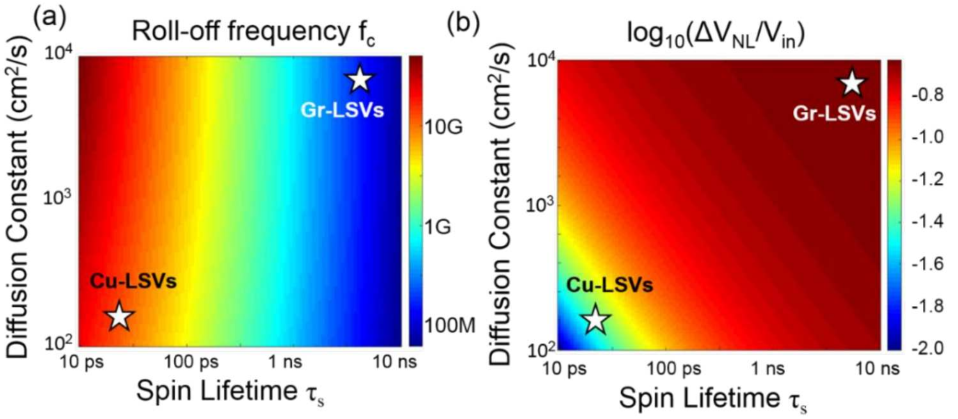

**Figure 3.** (a) 3dB roll-off frequency (under E-field perturbation) and (b) DC voltage output efficiency of NLSV devices with respect to the channel diffusion constant and spin lifetime.

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