# Manipulating Topological Spin Textures in Spin-Valve Type Nanopillars

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*Primary CNF Tools Used: Heidelberg mask writer DWL 2000, GCA 5x stepper, JEOL e-beam lithography, even and odd evaporators, AJA ion mill, AJA sputtering, DISCO dicing saw*

## Abstract:

**We study the properties of topological spin textures at nanoscale dimensions. We fabricate spin-valve nanopillars composed of a thin-film $B_{20}$ FeGe below copper and $Ni_{80}Fe_{20}$ (permalloy) layers. Bypassing a current through these nanopillars, we explore magnetic field-dependent resistance to understand the non-trivial spin texture formed in the nanopillars, and at high current, manipulate the spin texture using spin-transfer torques. Our fabrication and characterization study of these structures is aimed at realizing future power-efficient memory devices.**

## Summary of Research:

Transition metal germanides (TMGs) have a non-centrosymmetric crystal structure, which creates a non-vanishing asymmetric exchange energy in addition to the common symmetric exchange in ferromagnets [1-3]. In an external magnetic field, asymmetric exchange can stabilize chiral and topological spin textures, including magnetic skyrmions and helices. These spin textures are functionally a magnetic quasi-particle in which information can be stored and manipulated with a very low energy as compared to other magnetic storage modalities.

The potential application in energy-efficient storage and logic applications makes understanding the nanoscale spin dynamics in these TMGs crucial. Studying their nanoscale spin dynamics requires the fabrication of spin valve nanopillars made of TMGs, transition metals, and ferromagnetic multilayers and with a characteristic diameter of 100 nm. The nanoscale diameter is necessary to creating large current densities and is promising for high-density magnetic storage applications. A schematic cartoon of a nanopillar is shown in Figure 1. The TMG is iron germanium (FeGe) in this case.

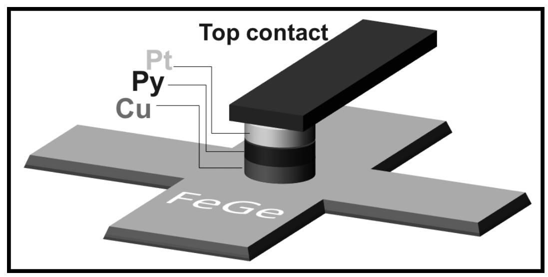


*Figure 1: A cartoon picture of the nanopillar. The bottom FeGe layer is a chiral magnet that can stabilize magnetic skyrmions. The permalloy layer is a well-understood ferromagnetic layer that can generate spin current when a charge current passes through the nanopillar. The Cu layer works as spin-transport layer while decoupling the magnetic moments of permalloy and FeGe.*

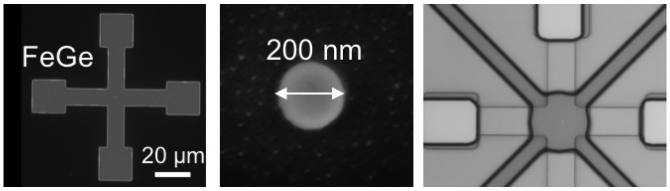


*Figure 2: Micrographs of some of the steps during the nanopillar fabrication. The left and middle SEM micrographs are the bottom FeGe layer and a 200-nm-diameter pillar. The right optical micrograph is the final contact pads before deposition.*

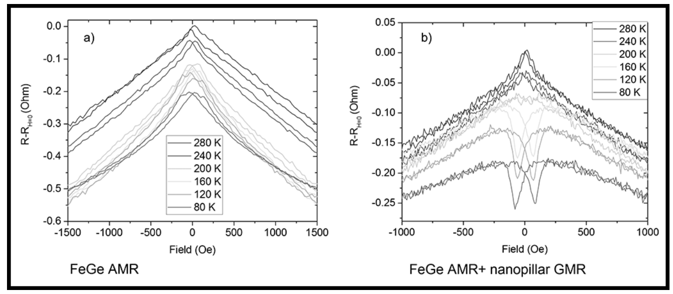


*Figure 3: Magnetoresistance measurements of a nanopillar at varied temperatures. a) shows the resistance of the bottom FeGe layer only, which is a typical AMR that is less sensitive to the sample temperature. The right graph b), however, shows the combination of the FeGe AMR and the nanopillar GMR, which shows strong temperature dependence.*

We grow FeGe on a Si <111> substrate with MBE before transferring the wafer into a sputtering system where we deposit copper, permalloy, and platinum layers under ultrahigh vacuum. Then, we fabricate magnetic nanopillars devices with multiple optical and electron-beam lithography steps, some of which are shown in Figure 2. The left and the middle images are scanning electron micrographs of the bottom FeGe layer and a 200-nm-diameter pillar, respectively. The right image is an optical micrograph of the final contact-pads before their deposition.

Our structure has complicated spin configurations due to the chiral magnetism of the FeGe layer. We study the magnetoresistance (MR) properties of the nanopillars to understand their equilibrium magnetization configurations. For example, FeGe has temperature-and field-dependent phases, including paramagnetic, spin-helix, magnetic skyrmion, and field polarized states. Moreover, the permalloy layer can stabilize magnetic vortices and multi-domain magnetic textures. By making such nanopillars, we enable interactions between these magnetic textures. We vary the sample temperature and magnetic field orientation as we measure the resistance of the nanopillar, which should reflect the magnetic configuration of the individual nanopillar.

In Figure 3, we show field-dependent MR curves at different temperatures. The left graph, Figure 3a, shows the anisotropic MR (AMR) of the bottom FeGe layer, which is isolated by measuring between bottom contacts. We observe a slight change of anisotropic MR as a function of temperature. On the other hand, Figure 3b shows both the AMR of FeGe and the giant MR (GMR) of the pillar, which is measured between the nanopillar top and bottom contacts. At high temperatures (the purple curve), FeGe is in the paramagnetic phase; therefore, we do not observe a GMR response of the FeGe/permalloy spin valve. However, at low temperatures (the red and orange curves), the GMR response is strong. As the permalloy layer switches at around 100 Oe, the total MR varies substantially.

Our experiment shows an interesting but non-trivial magnetoresistance behavior. To understanding it better, our next effort will be micromagnetic modeling.

In summary, we fabricate spin valve nanopillars and study their MR to understand topological spin textures in confined geometries. Our preliminary measurements show a strong GMR effect. Further modeling will shed light on these complicated spin configurations.

## References:

[1] Nagaosa, et al., Nature Nanotechnology 8, 899 (2013).
[2] Turgut, et al., Physical Review B 95, 134416 (2017).
[3] Turgut, et al., Journal of Applied Physics 122, 183902 (2017).