Effects of gallium focussed ion beam Milling on the magnetic properties of novel layered ferromagnetic materials

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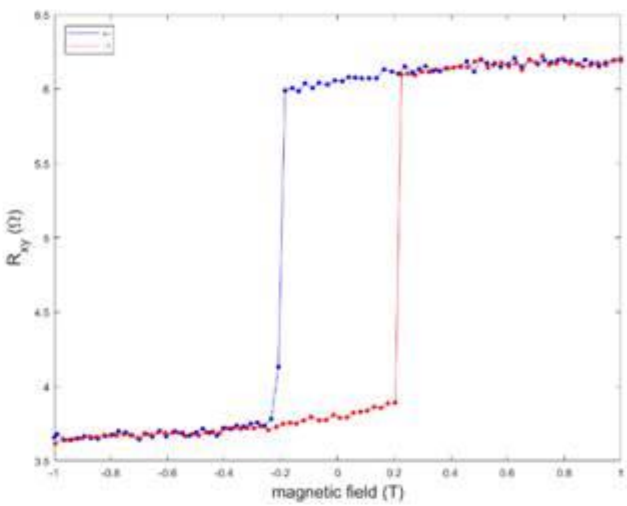
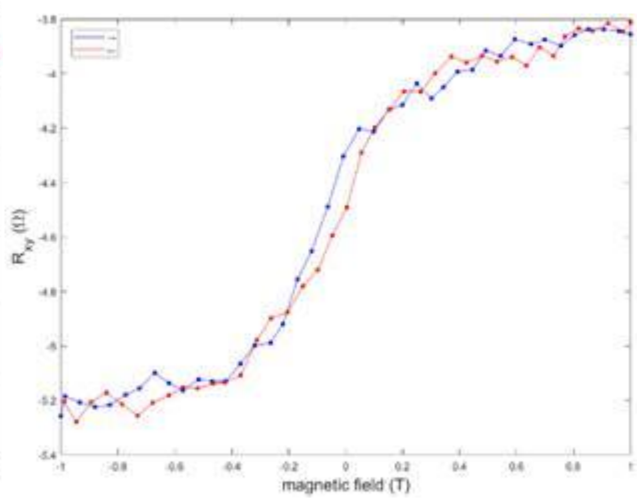
Recently there has been surge of research into topological materials and van der Waals heterostructures in the search for stable, high temperature, dissipationless electrical systems. Layered van der Waals materials similar to graphene which can be brought into their 2D state through simple mechanical exfoliation have seen special interest. It is important to understand how the techniques used in constructing test devices effect the properties of the device itself. In testing van der Waals Heterostructure devices it is important to accurately control the direction of current with respect to the resistance measurements and an etching step is almost always necessary. While the gallium focussed ion beam (Ga-FIB) is used regularly in the preparation of transmission electron microscope (TEM) samples it also provides the ability for highly accurate, selective top-down etching.

In this paper the effects of top-down etching using a Ga-FIB on novel, layered, magnetic materials is explored using the metallic ferromagnet Fe_3GeTe_2. It is found that the Ga-FIB has a significantly destructive effect on the magnetism of the material, manifesting in a lack of magnetic hysteresis in the R_{xy} measurement after the etching process. Further experiments find that this is likely due to a phase change brought on by high-temperatures and currents generated during the milling process rather than gallium implantation or chemical degradation. Using a modified etching process including either; short etching steps with cooling periods allowed between them or; a metallic contact deposited onto the Fe_3GeTe_2 flake to act as a heat-sink before the etch, the magnetic hysteresis of the Fe_3GeTe_2 can be retained throughout the Ga-FIB etching process. Further, it is found that by controlling the length of each etching step the usual square hysteresis of Fe_3GeTe_2 can be tuned to become curved, suggesting that the phase change is gradual, creating smaller magnetic domains isolated from each other within the flake.





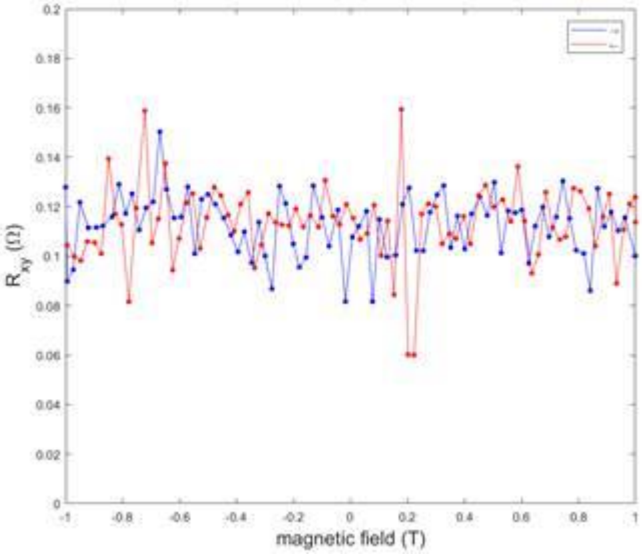


Figure 1. The magnetic hysteresis measurements of 3 Fe_3GeTe_2 flakes after different levels of Ga-FIB etching. **Top-Left:** A near-pristine Fe_3GeTe_2 showing square hysteresis. **Top-Right:** A flake that was subjected to long etching steps with short cooling breaks. The flake appears to have been split in to many magnetic domains. **Bottom:** A flake that was continuously etched using the Ga-FIB for more than 20 minutes. No magnetic hysteresis is detectable.

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