Magnetic carbon: A new application for ion microbeams

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Recent studies show that magnetic ordering in carbon based materials like highly oriented pyrolithic graphite (HOPG) [1] and amorphous carbon films can be induced by high energy proton irradiation. For this purpose, the samples were irradiated with protons at the ion nanoprobe LIPSION using a 2 MeV broad beam (diameter: 0.8 mm) and a 2.25 MeV microbeam (diameters used: 1-3 µm). The fluences ranged from about $6\times10^{6}/\mu m^{2}$ to $4.7\times10^{11}/\mu m^{2}$ resulting in total beam charges of a few 0.1 nC up to 600 µC depending on the size of the irradiated area. Before and after each irradiation step the samples were investigated using magnetic force microscopy (MFM) and/or a superconducting quantum interference device (SQUID) with reciprocating sample option (RSO) with a sensitivity of $<10^{-7}$ emu. The magnetic moment of the samples was found to be several 10^{-6} emu at 300 K after subtraction of the diamagnetic background and increases with increasing fluence at low total fluences. However, the studies show that annealing effects during irradiation have to be taken carefully into consideration. The magnetic ordering was found to be stable at room temperature. Since the content of potentially ferromagnetic impurities in the samples was determined using PIXE simultaneously during each irradiation step it could be proven that the observed magnetic signals are not due to impurities, but of intrinsic origin.

We report on recent results, technical developments like a dedicated beam scanning system and future plans of proton beam writing of magnetic microstructures in carbon at the ion beam laboratory LIPSION.

[1] P. Esquinazi, D. Spemann, R. Höhne, A. Setzer, K.-H. Han, and T. Butz, *Phys. Rev. Lett.* **91**(22), 227201 (2003).