Spatially controlled formation of nanostructures for magnetic and electronic applications

Helmholtz Zentrum Dresden Rossendorf, Institute for Ion Beam Physics and Materials Research [1]

°Gregor Hlawacek[1]

E-mail: g.hlawacek@hzdr.de

Gas field ion source (GFIS) based focused ion beam techniques historically also known as Helium Ion Microscopy (HIM) is recognized for its high resolution imaging and nanofabrication capabilities[1]. Over the last decade the tool has been utilized in many different ways. Applications include classical semiconductor materials, magnetic materials, 2D materials, nuclear materials but also biological materials. In this presentation I want to highlight the potential and limitations of gas field ion sources based (GFIS) noble gas beams for new magnetic and electronic device concepts. In an first example I want to present results of low fluence ion beam structuring of alloys with interesting magnetic properties such as FeAl. This material undergoes a phase transition upon ion irradiation that converts the initially paramagnetic material into a ferromagnetic one. Using the highly localized irradiation possible in the helium ion microscope and low fluencies of only 1-5 Ne per nm we can locally change the properties and this create arbitrary shaped nano magnets. The fundamental properties of these electron spin controlling structures with critical dimensions as small as 20 nm can be studied by TEM holography or scanning transmission x-ray microscopy.

Other device concepts require the control of currents at the single electron level. In the second part of the talk I will present first results of the realization of a CMOS compatible single electron transistor (SET) that works at room temperature (RT). We employ a focused GFIS Ne beam to locally mix silicon into a thin silicon dioxide layer. During a subsequent thermal treatment a single silicon cluster with a diameter of only 2-3nm forms in the oxide. The cluster is separated from the surrounding silicon by only 2nm providing optimum tunnel distances for RT SET operation. This process is based on the small size of collision cascade in the HIM. A more CMOS compatible restriction of the mixed volume can be achieved by using broad beam irradiation and nano pillars. The first is a well established technique in semiconductor fabrication and latter can be mass fabricated using advanced lithography. In the so achieved restricted mixed volume a single cluster forms during the subsequent annealing.

Both examples highlight the flexibility of the GFIS technique and its potential for the rapid prototyping of new device concepts based on ion beam techniques.

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[1] Gregor Hlawacek and Armin Gölzhäuser, editors. Helium Ion Microscopy. Springer International Publishing, Cham, 2016.