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Investigation of Regular Arrangements of Ferromagnetic MnAs Nanoclusters for New Planar Magnetoelectronic Devices

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1. Introduction

Compared to standard electronic devices, which consist of doped semiconductor materials, magnetoelectronic devices offer extended functionalities, e.g. the non-volatility of stored information in magnetic random access memories [1]. In addition, magnetoelectronic devices consist of metals, making them more robust and miniaturizable than doped semiconductors. Today magnetoelectronic devices such as read-heads for hard disks or magnetic sensors are based on the giant magnetoresistance (GMR) effect [2, 3] or tunnelling magnetoresistance (TMR) effect [4] and are composed in their simplest form of two magnetic layers which are separated either by a diamagnetic metal (GMR-device) or an insulating layer (TMR-device). However, the device geometry of these layered structures, where the current is mostly applied perpendicular to the layer plane, is not ideally suited for integrating these devices into larger planar structures and complicates device miniaturization, which is essential for further optimization of fabrication costs.

A promising alternative may be the so-called granular ferromagnetic-paramagnetic hybrid structures. The hybrids consist of ferromagnetic nanoclusters, which are embedded in a paramagnetic matrix, and show magnetoresistance effects similar to the GMR- and TMR-effect [5, 6]. However, conventionally synthesized hybrids usually exhibit a random cluster distribution, which strongly influences their properties.

With the growth of MnAs nanoclusters on (111)B-substrates by selective-area metal-organic vapor phase epitaxy on pre-patterned substrates the problem of randomness can be overcome. This method allows one to control precisely the cluster position on the substrate, their size as well as the cluster shape [7, 8] and thus offers the possibility to grow different nanocluster arrangements, which may act as novel planar magnetoelectronic devices.

2. Experimental procedure

We present the growth of different regular arrangements of MnAs nanoclusters consisting of hexagon-shaped as well as elongated nanoclusters by selective-area metal-organic vapor phase epitaxy (SA-MOVPE). The fabrication process for the controlled positioning of the MnAs clusters comprises several steps. First, a SiO_2-layer is deposited on the (111)B-GaAs substrate by plasma enhanced chemical vapour deposition (PE-CVD). This layer is then structured by electron beam lithography followed by reactive ion etching with carbon tetrafluoride (CF_4) to create initial openings in the SiO_2 at points, where the MnAs clusters are to grow in the MOVPE process. In the actual growth process first an AlGaAs buffer layer is grown at 800°C. The MnAs clusters are grown afterwards at 825°C. The shape of the MnAs clusters is determined by the shape of the openings in the SiO_2. Because of the faster growth rates of the nanoclusters on a-plane facets the orientation of the openings are chosen parallel to the [1-10] crystal directions of the substrate or equivalent directions arising from it by rotation of 120° about the [111] direction.

First prototypes of novel planar magnetoelectronic devices were fabricated in two different ways. SEM images of the prepared nanocluster arrangements as well as a schematic illustration of the cluster orientation with respect to the crystal orientation of the substrate are presented in figure 1. In one case, the distance between the initial openings was reduced to 40 nm in order to achieve a merging of the nanoclusters during the growth. As shown theoretically by Heiliger et. al. [9] the prepared cluster arrangements are supposed to show a 360° symmetry of the magnetoresistance for a rotation of the external magnetic field in the sample plane. In the other case, the distance between the initial openings was 200 nm. In a second structuring process gold was deposited in the gaps between the nanoclusters as diamagnetic layer in order to connect the nanoclusters and to fabricate GMR-like devices. The gold layer has a thickness of about 100 nm. Prior to the gold layer a 10 nm thin Ti layer was deposited in order to guarantee a good adhesion of the gold layer on the substrate.

Electric contacts for measuring the transport through the nanocluster arrangements were also prepared during this second structuring process. A schematic illustration of the prepared structures is presented in figure 2.

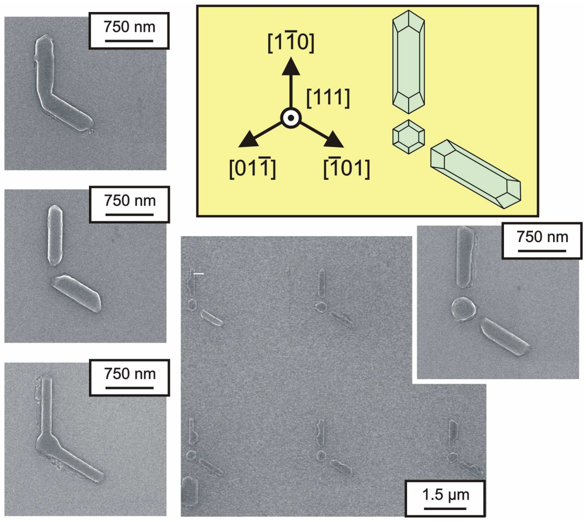

Figure 1: Scanning electron microscopy images of the four different arrangements prepared after the growth of the MnAs nanocluster. Top-right: Schematic illustration of the nanoclusters' orientation on the (111)B substrate.

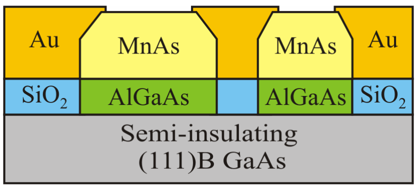

Figure 2: Schematic illustration of the structures prepared.

3. Magnetic properties of the nanoclusters

Hexagon-shaped nanoclusters show a hard magnetic axis oriented along the c-axis, which is parallel to the [111] direction of the substrate, i.e. the magnetization is oriented in the sample plane. In in-plane geometry, they exhibit a weak hexagonal anisotropy due to the cluster shape and the hexagonal crystal structure [10, 11]. In order to determine the magnetization orientation of the elongated nanoclusters magnetic force microscopy (MFM) measurements were performed. Prior to the MFM measurements the samples were exposed to an external magnetic field of 0.35 T in order to align the magnetization of the nanoclusters. The actual measurements were carried out without an external magnetic field. The MFM images, which are presented in figure 3, clearly show a magnetization orientation of the elongated nanoclusters parallel to the cluster main axis. Thus, the asymmetric shape of the nanoclusters forces the magnetization to align along the main axis of elongation. The magnetic anisotropy of the nanoclusters can therefore be influenced by the shape of the nanoclusters, making the clusters ideal components for magnetoelectronic devices.

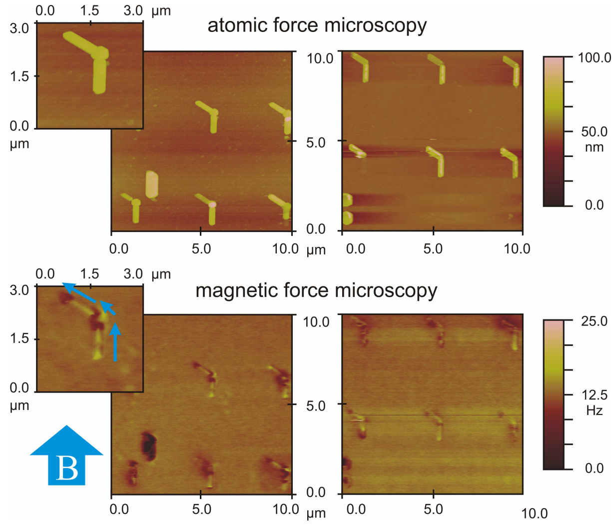

Figure 3: AFM (top) and MFM (bottom) images of two different cluster arrangements prepared. The magnetic anisotropy is influenced by the shape of the ferromagnetic MnAs clusters leading to a magnetization orientation along the cluster main axis.

4. Summary

In summary, we presented the fabrication of first prototypes of novel magnetoelectronic devices by SA-MOVPE. The devices consist of elongated and hexagon-shaped MnAs nanoclusters. MFM images show, that the in-plane magnetic anisotropy can be influenced by the cluster shape, making the nanoclusters ideal components for magnetoelectronic devices.

[1] G.A. Prinz, Science **282** (1998) 1660
[2] P. Grünberg, R. Schreiber, Y. Pang, M. B. Brodsky, H. Sowers, Phys. Rev. Lett. **57** (1986) 2442
[3] M.N. Baibich, J.M. Broto, A. Fert, F.N. Van Dau, F. Petroff, P. Etienne, G. Creuzet, A. Friederich, J. Chazelas, Phys. Rev. Lett., **61** (1988) 2472
[4] M. Julliere, Phys. Lett. A **54** (1975) 225
[5] A. E. Berkowitz, J. R. Mitchell, M. J. Carey, A. P. Young, S. Zhang, F. E. Spada, F. T. Parker, A. Hutten, G. Thomas, Phys. Rev. Lett. **68** (1992) 3745
[6] W. Heimbrodt, P. J. Klar, S. Ye, M. Lampalzer, C. Michel, S. D. Baranovskii, P. Thomas, W. Stolz, J. Supercond. **18** (2005) 315
[7] T. Wakatsuki, S. Hara, S. Ito, D. Kawamura, T. Fukui, Jpn. J. Appl. Phys. **48** (2009) 04C137
[8] S. Ito, S. Hara, T. Wakatsuki, T. Fukui, Appl. Phys. Lett. **94** (2009) 243117
[9] C. Heiliger, M. Czerner, P.J. Klar, S. Hara, IEEE Transactions on magnetics **46** (2010) 1702
[10] S. Hara, T. Fukui, Appl. Phys. Lett. **89** (2006) 113111
[11] M.T. Elm, C. Michel, J. Stehr, D.M. Hofmann, P.J. Klar, S. Ito, S. Hara, H.-A. Krug von Nidda, J. Appl. Phys. **107** (2010) 013701