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MAGNETIC FORCE MICROSCOPY APPLIED IN MAGNETIC DATA STORAGE TECHNOLOGY

Microstructured thin-film elements with critical dimensions of 1 7m or less play an increasingly important role in magnetic components for information technology applications. Devices that are directly based on such microstructures are key components in magnetoelectronics for storage and sensor applications as well as modern concepts which are likely to substitute today's hard disk drives. Basic research on magnetic materials as well as industrial applications creates an increasing demand for high-resolution magnetic imaging methods. One such method is magnetic force microscopy (MFM). In spite of considerable achievements, MFM also has some serious shortcomings, which have not been overcome to date. Under normal circumstances, the method yields only qualitative information about the magnetic object and it is difficult to improve the resolution to values below 100 nm. In this paper, we will report on advanced MFM probe preparation, based on electron beam methods, and discuss the possibilities for batch fabrication of such advanced MFM tips. We show that the advanced probes allow high-resolution imaging of fine magnetic structures within thin-film permalloy elements without perturbing them. Additionally, we present high-frequency MFM measurements on a hard disk write head.

*Appl. Phys. A. 7**6**, 879-884 (2003)*

M.R. Koblischka, U. Hartmann and T. Sulzbach
IMPROVEMENTS OF THE LATERAL RESOLUTION OF THE MFM TECHNIQUE

We report on the preparation of high-resolution magnetic force microscopy (MFM) tips using the electron beam deposition method for MFM measurements on soft magnetic samples. Electron beam lithography using a scanning electron microscope was used to define small particles of magnetic material at the very end of a commercial scanning microscope tip to achieve maximum lateral resolution with low magnetic moment. Several approaches were tried out and demonstrated on permalloy thin films. The achieved resolution (down to 20 nm) is clearly proven by the fact that more details of the magnetic structure can be observed. However, it turned out that no standard exists in order to reliably determine the resolution of the MFM measurements; the development of such a standard will be a very important new task.

*Proc. E-MRS Spring Meeting, Strasbourg, 2002, France; Thin Solid Films **428**, 93 (2003)*

H. Zhang, D. Mautes, and U. Hartmann
A STUDY OF CHARGE QUANTIZATION ON LIGAND-STABILIZED AU55 CLUSTER MONOLAYERS

Low-temperature ultrahigh-vacuum scanning tunnelling microscopy and spectroscopy was employed to analyse the electronic transport through the ligand-stabilized metal cluster Au55[P(C6H5)3]12Cl6, prepared as a monolayer on Au(111) substrates. The current-voltage behaviour is governed by charge-quantization phenomena expected for a nanometre-sized metallic particle. The related electric capacitances of the involved tunnelling junctions have been determined from accompanying current-distance measurements. Resonant tunnelling through states of the ligands can be ruled out as a relevant process in electronic transport through the clusters.

New Journ. Phys. ***5****, 30.1 (2003)*

H. Zhang, G. Schmid, and U. Hartmann
REDUCED METALLIC PROPERTIES OF SMALL LIGAND-STABILIZED METALL CLUSTERS

Low-temperature ultrahigh-vacuum scanning tunneling microscopy was employed to analyze the electronic behavior of Au_{55} clusters stabilized by $[P(C_6H_5)_3]_{12}Cl_6$ ligands. At 7 K, the actual arrangement of the C_6H_5 rings of the ligand molecules could be imaged. Spectroscopic data reveal discrete energy levels with an average spacing of 170 meV that can be attributed to the Au_{55} core. Additionally, characteristic charge-quantization phenomena were observed. Energy and charge quantization both support the view that the clusters consist of a metallic core extending slightly beyond the first close-packed shell of Au atoms.

Nano Lett. ***3****, 305 (2003)*

M. Reinstädtler, U. Rabe, V. Scherer, U. Hartmann, A. Goldade, B. Bushan, and W. Arnold
ON THE NANOSCALE MEASUREMENT OF FRICTION USING ATOMIC FORCE MICROSCOPE CANTILEVER TORSIONAL RESONANCES

We studied friction and stick-slip phenomena on bare and lubricated silicon samples by measuring the torsional contact resonances of atomic force microscope cantilevers. A piezoelectric transducer placed below the sample generates in-plane sample surface vibrations which excite torsional vibrations of the cantilever. The resonance frequencies of the vibrating beam depend on the tip-sample forces. At low lateral surface amplitudes the cantilever behaves like a linear oscillator with viscous damping. Above a critical surface amplitude, typically 0.2 nm, the amplitude maximum of the resonance curves does not increase any more and the shape of the resonance curves changes, indicating the onset of sliding friction. The critical amplitude increases with increasing static cantilever load. For a bare silicon sample it is higher than for the lubricated silicon. Microslip known from macroscopic contacts causes energy dissipation in the atomic force microscope tip-contact before sliding friction sets in.

Appl. Phys. Lett. ***82****, 2604 (2003)*

M. R. Koblischka and U. Hartmann
RECENT ADVANCES IN MAGNETIC FORCE MICROSCOPY

During the past ten years magnetic force microscopy (MFM) has become probably the most powerful generalpurpose method for magnetic imaging. MFM can be applied under various environmental conditions and requires only little sample preparation. Basic research on magnetic materials as well as the mentioned industrial applications creates an increasing demand for high-resolution magnetic imaging methods. This contribution will review some new concepts which have been realized in the field of advanced probe preparation, based on electron beam methods in order to improve the spatial resolution beyond 100 nm. It is shown that the advanced probes allow high-resolution imaging of magnetic fine structures within thin film permalloy elements exhibiting a complicated cooperative magnetization reversal process. These investigations are of importance for various concepts underlying modern magnetic data storage developments. Furthermore, we present some developments of MFM to suit the needs of the magnetic recording industry.

*Proc. SPM, Cantilever Sensors, and Nanostructures Conf., Tokyo, Japan, 2001; Ultramicroscopy **79**, 103 (2003)*

M. R. Koblischka, U. Hartmann and T. Sulzbach
RESOLVING MAGNETIC NANOSTRUCTURES IN THE 10NM RANGE USING MFM AT AMBIENT CONDITIONS

Following the demand of the magnetic data storage industry, the magnetic structures in hard disk heads are continuously shrinking. This requires a powerful tool to investigate the magnetic properties of these elements in the range of about 10 nm. To achieve this goal, we prepared MFM tips using the electron-beam deposition (EBD) contamination technique, where carbon caps and needles are grown onto the micromachined Si cantilevers. For batch production of MFM tips, however, this technique is not suited well, so we employ the focussed ionbeam (FIB) technique to produce MFM tips with a high aspect ratio similar to those tips with carbon needles. We show that the use of these tips not only improves the lateral resolution, but also considerably reduces the disturbation effects of the weak magnetic structures due to the magnetic tips.

*Mat. Sci. Eng. C **23**, 747 (2003)*

M. Oberringer, M. Jennewein, K. Schmitz, S. Motsch, A. Seekamp, T. Pohlemann, H. Bohn, J. Ißle, and U. Hartmann
INFLAMMATION RESEARCH USING FLUORESCENCE AND ATOMIC FORCE MICROSCOPY
*Imaging and Microscopy **4**, 44 (2003)*