Nanoobjects microscopy

Micro- and nanomagnetic measurements in magnetic force microscopy

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The report presents various physical and computational aspects of the magnetic force microscopy (MFM) application for quantitative estimates of magnetization for micro and nano-magnetic objects and their ensembles. Even if we ignore the presence of concomitant forces (additional to magnetostatic forces) between the probe and the surface, the MFM data interpretation and calibration of a measuring system is a non-trivial task. This is due to the fact that all directly measured parameters, such as the frequency, phase or amplitude of a magnetized tip oscillations over surface are proportional to the gradient of magnetic force $\partial F_Z^M / \partial z$. If the magnetosensitive element of the probe behaves like a magnetic dipole (which is usually takes place), the second derivative of a magnetic field induction along vertical coordinate $\partial B_Z^2 / \partial z^2$ could be directly measured, but not a lateral distribution of induction $B_Z(\mathrm{x},\mathrm{y})$. It is shown that having already this information it is possible to judge qualitatively the relative changes in the magnetization and the size of objects, in particular to visualize interdomain walls, to identify vertical and horizontal domains, etc. The procedure for the calibration of measuring system and methods for quantification of local magnetizations for certain types of micro-magnetic systems will be discussed. For this purpose, high-precision numerical modeling (not using method of finite elements) of magnetic and force fields generated by arbitrary configuration of micromagnets is used. Quantitative estimates of the spatial resolution of the technique are given in the analysis of dense ensembles of magnetic microparticles as well as for particularly isolated domains and stripe domains.