Nanometrology with operational MEMS devices

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Nanometrology quantitatively separate domain of Metrology. Nanometrology objectives are to investigate nanoscale phenomena and search for adequate reverence quantities. Both objectives are correlated and may be sufficed by application of specialized tools for nanoscale metrology – namely micro-electromechanical systems (MEMS).

Objective of works described in the thesis was to develop technology of operational MEMS devices, which function would be determined by embedded and measured nanostructure. Demand for such technology arises from the fact, that macroscopic metrology doesn't enable insight into series of quantum phenomena, to which belongs variety of tunneling effects of attractive practical applications. Nottingham effect also belongs to them, which is a thermal effect correlated with field emission.

In the work introduction of opMEMS as a universal measurement device for nanometrology is proposed. opMEMS consists of movable MEMS platform shaped specifically to connect measurement signals and separate from noise measured nanostructure embedded inside. Region, in which nanostructure is placed, is required to be of proper dimensions and include electrical contacts. It is called Region of Interest (RoI).

Whole process of development and fabrication of opMEMS was described – from objectives, through kinematic and dynamic synthesis, to MEMS fabrication technology. Methodology of measurement of opMEMS platform was described. Methods of RoI fabrication and RoI precise displacement control, which are crucial for successful application of opMEMS, were described. Deposition of nanostructures in RoI was described. All those parts were summed up as an opMEMS technology.

Application of focused electron/ion beam induced deposition (FEBID/FIBID) for synthesis of nanostructures was an integral part of opMEMS technology. FEBID/FIBID structures are typically used as an auxiliary material e.g. for fabrication of lamellae for transmission electron microscopy. FEBID/FIBID material itself, which is a composite of Pt nanocrystals in carbon matrix, presents attractive properties due to its internal structure. Described experiments shows proficiency in deposition and development of nanostructures – nanowires with diameters from 20 nm and lengths up to 2 μm. Influence of opMEMS application on disadvantageous properties of FEBID was described, primarily discontinuation of the so-called halo effect, which causes parasitic leakage currents and inhibits measurement capabilities of free-standing FEBID structures.

Usefulness of opMEMS was demonstrated through a series of measurements of FEBID nanostructures. Mechanical properties of FEBID nanowires embedded in opMEMS – including yield strength – were measured. Resistance measurements in two- and four-point configuration were performed. Resistivity of FEBID material was determined. Heavy influence of FEBID-base resistance on serial resistance of nanowires was disproved, what resolves a long-going public debate.

Most important results of measurement described in the thesis concerned Nottingham effect, which – up to this moment – was not shown experimentally. Phenomenon is correlated with the field emission and is a subtle change of heat of the field emitter due to disparity in energies of emitted and supplied electrons. Effect was observed thanks to minimizing heat capacity of the emitter by depositing it and thermistors by FEBID. Thanks to setup designed by author the measurement was performed in which coincident change of temperature and emission current was observed.

Investigation described above present a cross-section of measurement capabilities of opMEMS devices. I believe, that in further prospect opMEMS devices will find their use in nanometrological measurements all around the world thanks to their universal nature and high scale of integration between examined nanostructure and macro-scale measurement devices.

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