Nanomachining by focused ion beam

Thesis

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Outline

Focused Ion Beam (FIB) systems previously used to repair, and modify lithographic masks, failed microcircuitry and for rapid prototyping, became a promising tool for nanoelectronic device fabrication, too. The major advantage of a crossbeam system built up of high resolution SEM and FIB column has the ability of ion beam process (milling and deposition) monitoring during nanometer size feature shaping. To avoid the ion beam caused damages, the layers are deposited in combination with electron beam induced deposition.

Later, applications of FIB nanomachining have been found in a wide area of science and technology. The FIB was successfully used in materials science (metallurgy, ceramics, composites, polymers), geology, biology and pharmacology.

My work on focused ion and electron beam machining started in 2003, in Research Institute for Technical Physics and Materials Science (MFA) in Budapest was based on a LEO 1540 XB crossbeam system. The aim of the work was to study the physical-chemical processes of ion beam machining, the applicability of the system and the characterization of ion beam shaped nanostructures.

My work in fabrication, investigation and characterization of nanosized objects in three different scientific areas shows the wide range applicability of FIB machining. In all the three cases, FIB nanomachining as sample preparation method was the tool of achieving scientific results and contributed to the understanding of certain phenomena.

Aims

As my first topic, artificial photonic nanoarchitectures, modelling the shard of the Taiwanese beetle, Trigonophorus rothschildi varians, were shaped by FIB in order to understand the correlation of the structure and the optical properties. This work is a part of the research area of bioinspired materials intensively studied in Nanostructures Department of MFA. SEM investigations showed that the shard consists of chitin and air layers with sparse perpendicular columns. These columns were modelled by cilindrical holes drilled in a multilayer structure by FIB. The effects of columns on the optical properties were investigated by the comparative study of the biological "blueprint" and its artificial counterparts with different sizes and arrangements.

My second subject was the morphological and electrical characterization of ion and electron beam deposited tungsten layers, used as contact for various nanoobjects. The topic was motivated by another research area of the MFA Nanostructure Department, the study of carbon nanotubes. This type of deposition takes place when a metalorganic precursor gas compound introduced in the chamber decomposes because of ion or electron beam irradiation and conducting material deposits over the desired position with a few ten nanometers accuracy. In case of electrical characterization of the contacted nanoobjects, it is necessary to take into consideration the properties of the contact material, too.

My third topic was the investigation of the sputtering characteristics of Mo and ZnO thin films. FIB cutting is one of the possible ways of dividing layers into cells in thin film solar cell technology developed in MFA. This motivated my studies of ion beam sputtering of these two materials, both used in solar cells. Besides determination of technological parameters (size, processing time, turnout), the study of the changes in sputtering characteristics of the mentioned thin layers during ion irradiation was aimed.

Thesis

1.a) The structure of the shard of a beetle living in Taiwan in three different colour variants (Trigonophorus rothschildi varians) was studied by SEM investigations. The structure was defined as a multilayer with intercalated channels causing nonspecular reflection. Based on SEM results, a structural model was created, composed of a one dimensional (multilayer) and random two dimensional (channels) structure. [A2]

1.b) Artificial counterparts of the shard structure of the beetle were shaped in SiO_x /Si(Ge) multilayer. The holes milled by FIB correspond to the channels of the natural structure. The similarities of the optical properties of the natural and artificial structures were verified by spectroscopy measurements. [A2]

1.c) Varying the arrangement and periodicity of FIB milled holes, I demonstrated the correlation between hole periodicity and reflected light wavelength in case of square-shaped arrangement. No effect of the hole diameters was noticed. In case of random arrangement, only a weak correlation of the average hole distance and the wavelength was found. In general, I demonstrated that bioinspired photonic nanoarchitectures with controlled optical properties can be produced using the above mentioned method. [A2]

2.a) Studying the structural and electrical behaviour of ion beam deposited tungsten layers, it was found that their cross section is non-prismatic. The deposition rate is constant, i.e. the deposited volume is constant in time. The layers deposited by ion beam between prepatterned gold electrodes showed ohmic conductivity, their resistivity corresponds to literature data. The electrical behaviour of the layers were found to be influenced by annealing, heat treatment in vacuum caused irreversible changes. [A3, A4, A5]

2.b) Studying the morphological and electrical behaviour of electron beam deposited tungsten layers, their morphology was found to differ from ion beam deposited ones. The height of EBAD deposited layers increases by tilting the sample from normal incidence, and by lowering the primary electron energy. Both are consequences of higher secondary electron rate. For electron beam deposited layers, significantly higher resistance was observed compared to ion beam deposited ones. Besides, I found significant differences both in the resistance values and in the character of IV curves, quasi-linear and non-linear characteristics were found, too. [C28]

3.) Studying the sputtering characteristics of Mo and ZnO thin films used in solar cell technology, a technical sputtering yield of the layers prepared by the given technology valid for perpendicular milling by 30 keV Ga^+ ions was determined. I found that the milling depth depends on the ion dose. In case of Mo, a rough surface with island-like protrusions was found after ion milling regardless the layer preparation method. This can be the consequence of a significant degree of redeposition, comparable to that of sputtering. In case of ZnO, a smoother surface was observed, the redeposition effect in this case is presumably less significant. [A1]

Publications

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4. **Horváth E**, Neumann PL, Tóth AL, Vázsonyi É, Biró LP, Fürjes P, Dücső C, Electrical characterization of tungsten nanowires deposited by focused ion beam (FIB), Nanopages 1 (2) (2006) 253-260.

5. **Horváth E**, Neumann PL, Koós AA, Tóth AL, Fókuszált ionsugárral leválasztott W csíkok morfológiai és elektromos vizsgálata, MKN Konferencia Kiadvány (2007) 243-246.