Electron Beam lithography as a versatile nanostructuring technique

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Electron beam lithography is a very versatile technique to produce nearly arbitrary structures in the range of about ten nanometers up to micrometers. The basic process steps are illustrated in Fig. 1: An electron sensitive resist (PMMA) is spun onto a clean substrate (usually Si or GaAs, but every substrate with a minimum conductivity is useable.) and afterwards tempered for a few minutes at a temperature of about 150° C. A second resist layer can also be prepared on the first one, giving the advantage to optimize the resist properties. The substrate is placed into a scanning electron microscope, where the electron beam exposes the resist layer locally (chart b). The chemical properties of the exposed resist are changed. A special developer can remove these exposed areas (chart c). The substrate is then placed into an evaporation chamber and the desired material is evaporated using e. g. an electron beam gun or by thermal evaporation (chart d). The last step is the so called “lift off” where the resist is removed and the desired metal structures remain on the substrate (chart e). Since the electron beam has only a size of about 2 nm structures down to around 10 nm are possible to produce depending on the form of the structures and the material these structures are build of.

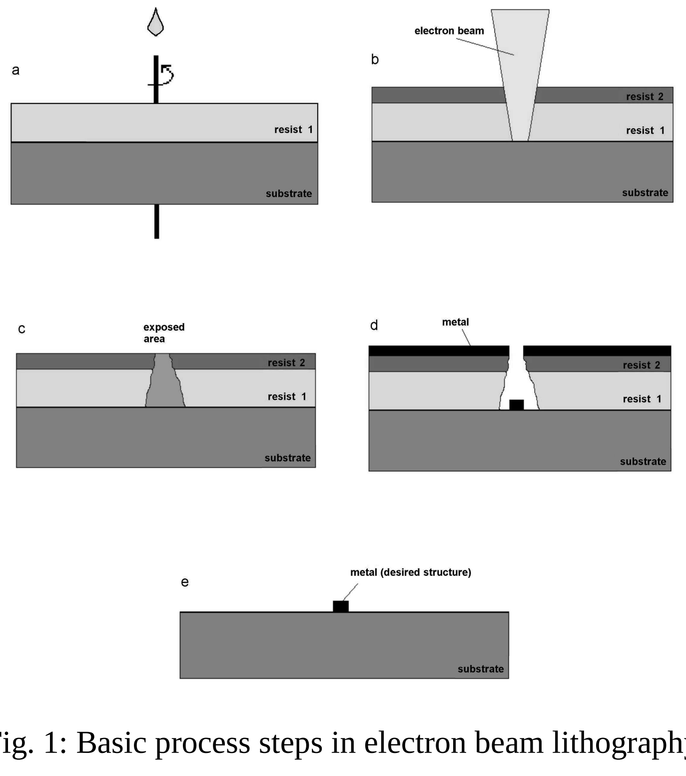

Fig. 1: Basic process steps in electron beam lithography

To give an idea what is meant by versatile technique we show a few SEM pictures of different structures prepared with the EBL – unit in Duisburg. Fig. 2 shows a dot lattice consisting of gold-dots with a diameter of ~35 nm and a spacing of ~100 nm on silicon in a field of 1,5 µm * 1,4 µm. This is only a part of the whole writefield area with a side length of 200µm * 200 µm. In such a field there are about 4 million dots. This structure was used as a test structure to produce dense magnetic dot arrays on large sample areas. Optimizing the

EBL-process we succeeded to produce an area of around 4 square millimetres consisting of 200 million magnetic dots with high uniformity (The standard deviation in diameter and spacing is about 5%). The magnetic moment of such a sample is high enough to perform SQUID – measurements for the magnetic characterization of the dots.

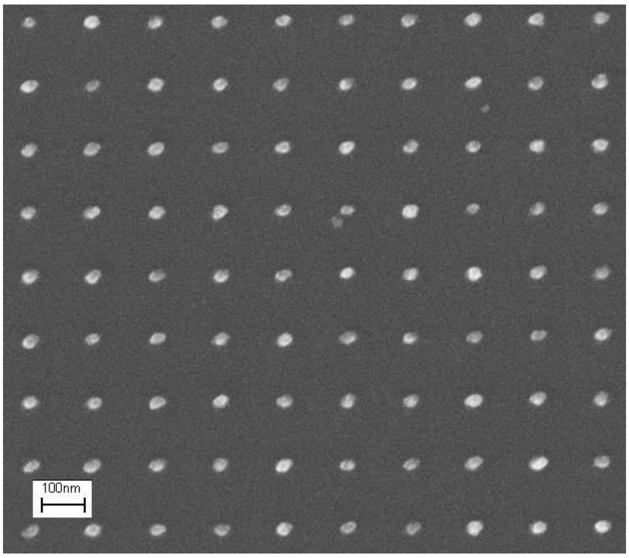

Fig. 2: Gold-dots with a diameter of ~35 nm and a spacing of ~100 nm on a silicon substrate.

A more "complicated" structure is shown in Fig. 3. The heart like structures are made of 25 nm gold, prepared on a quartz substrate covered with indium-tin-oxide (ITO). These golden hearts were prepared in collaboration with Stiftung CAESAR (Bonn) for electro-optical measurements. The challenge was to prepare a field with a size of at least 200 µm side lengths. Problems arise due to the rough surface of the ITO-layer and the sometimes not perfect conductance of this layer. Therefore the EBL-parameters had to be carefully adjusted (using the old "try and error" method) to the substrate.

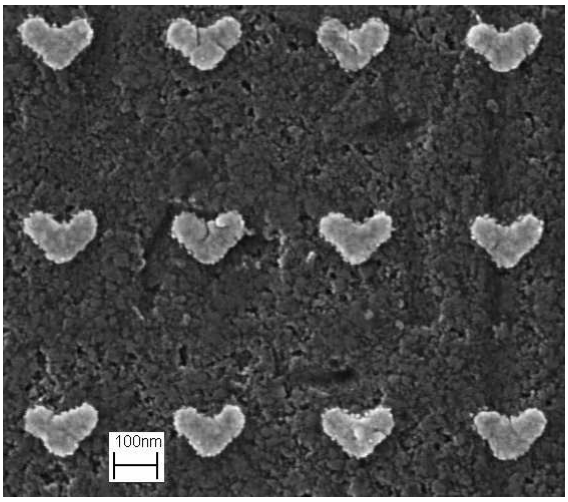

Fig. 3: Golden hearts on a quartz substrate covered with a 150 nm layer of ITO (indium tin oxide)

Also challenging is the preparation of nanowires if they become very small (around 20nm), or if they have minimal spacing. Fig. 4 shows a SEM-picture of an array of gold nanowires with 50 nm thickness and a width of around 100 nm prepared on a silicon substrate. The spacing between two wires is also around 100 nm. In the inset the dimensions of the whole array are sketched. Each wire is 50 µm long and the whole array has a length of 100 µm. Every second wire is shifted by 5 µm forming a so called interdigital system. With a second EBL-step it is possible to contact the alternating rows of this array for applying a voltage between the wires. This system can be used as a gas sensor, when depositing special nanoparticles between the wires; an application with is currently under investigation.

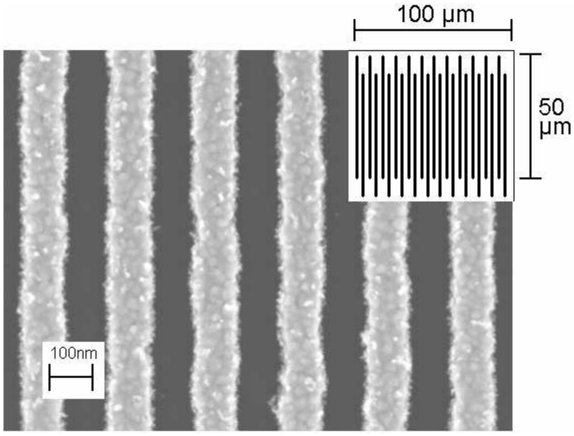

Fig. 4: An Array of gold nanowires with a width and spacing of ~100 nm. The wires are 50 µm long and the whole array has a length of 100 µm.

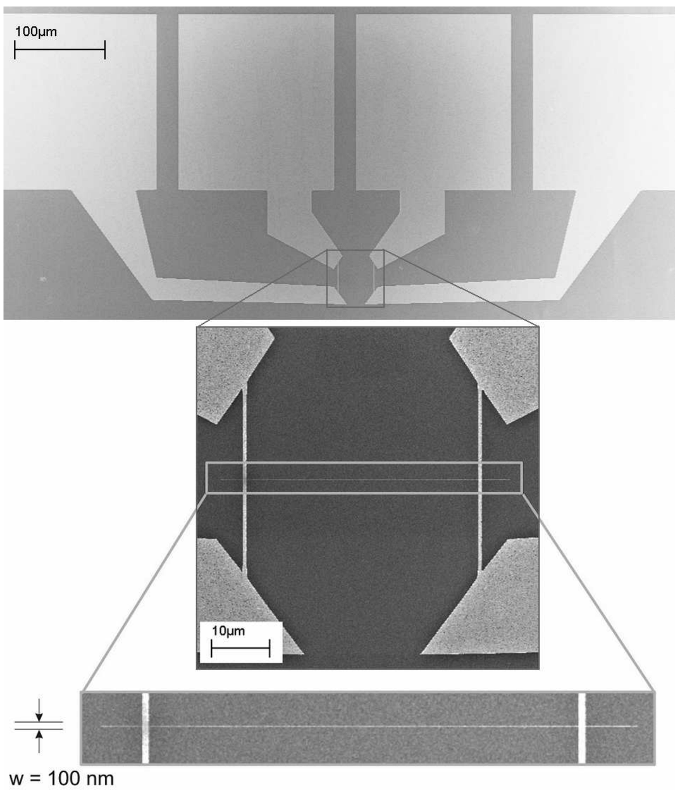

Fig. 5: Contacted nanowire prepared with a two step EBL process.

Another example which shows the possibilities in the production of hybrid nanostructures is shown in Fig. 5. Here one can see a contacted magnetic nanowire on a silicon substrate. In the upper part of the SEM-picture the rectangular gold contact pads are visible. Zooming into the contact area of the structure leads to the middle part of Fig. 5 where the smaller contact wires and also the nanowire is visible. In the lower part of the picture the 100 nm wide nanowire is clearly visible.

This structure was produced using a two step EBL-process. The advantage of this process is the use of different materials for the nanowire and the contact structure. In this case the wire is made of a 30 nm thick layer of cobalt for magnetic measurements. The whole contact structure is made of gold with a height of around 100 nm to give the necessary stability for the bonding process and also to minimize the resistance of the contact structure.

For further information on EBL see for example: Strukturelle und magnetische Eigenschaften nanostrukturierter Systeme, (Structural and magnetic properties of nanostructured systems) Burkhard Stahlmecke, Diploma thesis, Gerhard Mercator Universität Duisburg, August 2002. This thesis is available as a .pdf document on the document server of the university library in Duisburg.

This article also appears in the second issue of the SFB 616 newsletter.