Lithographic fabrication of clean iron nanostructures by electron-beam induced deposition in ultra-high vacuum

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The generation of nanostructures with arbitrary shapes and well defined chemical composition is still a challenge and targets the core of the fast-growing field of nanotechnology. One approach is the technique of electron-beam induced deposition (EBID) in which a highly focused electron-beam from an SEM or TEM is used to locally crack e.g. metal containing precursor molecules, resulting in the deposition of the non-volatile fragments.
Up to now, virtually all EBID experiments were performed in high vacuum (HV) environments with the corresponding rather ill defined conditions, resulting in typical metal contents of the deposits of only 15 % to 60 %. In the present work we study the EBID process in an ultra-high vacuum (UHV) environment to guarantee well defined experimental conditions. In Fig. 1 two examples of EBID structures generated with our system are shown, the width of the lines is partly below 15 nm, which represents the lower limit we can achieve in our system using the "conventional" EBID process. Surprisingly the EBID deposits from the precursor molecule iron pentacarbonyl, $Fe(CO)_5$ on Si(001) fabricated at room temperature yield discontinuous structures consisting of individual dots with a size significantly smaller than 10 nm (see Figure 2 a). The iron content of these dots is estimated to be >95%[1]. Before the onset of the growth of the dot structures the existence of a continuous prerequisite layer with reduced purity was found. A explanation for the formation of the clusters is a high tensile stress relative to the initial layer (probably due to lattice mismatch), which leads to a preference for the formation of small clusters due to an overall energy minimization. This hypothesis was confirmed by experiments performed at 200 K in which the EBID structures are continuous due to the reduced mobility of the involved species (see Figure 2 b). The findings of the present study represent a new route towards the lithographic fabrication of (a) clean nanostructures of arbitrary shape and (b) pure metallic nanodots at defined positions with a size below 10 nm.
Supported by the DFG through grant MA 4246/1-1 and by COST Action D41.

1 Lukasczyk T., Schirmer M., Steinrück H.-P. and Marbach H., 2008, *Small*, **4**, 6, 841–846.

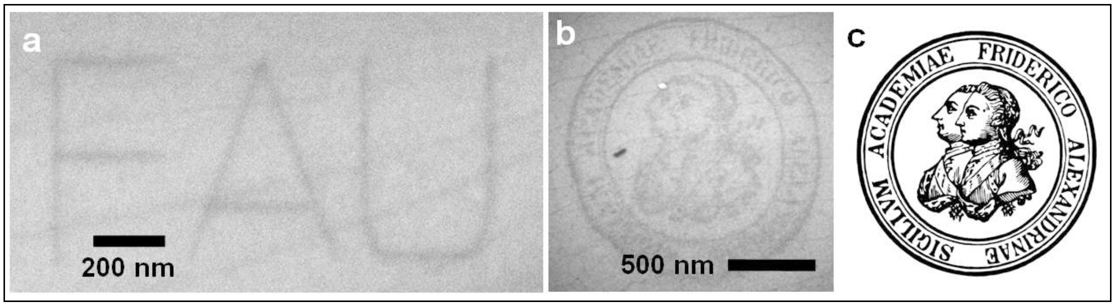

Fig. 1: SEM images of two nanostructures generated by EBID. (a) "FAU" pattern on Si(111), obtained with ethene as precursor and the sample at room temperature. (b) Seal structure on Si(111) of the master shown in (c), obtained with trimethyl-methylcyclopentadienyl-platinum as precursor and the sample at room temperature.

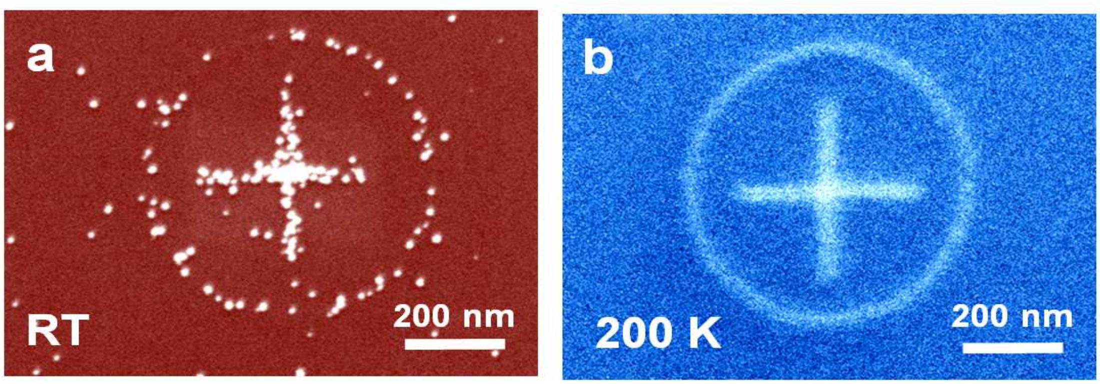

Fig. 2: SEM images acquired at RT of two nanostructures (circle and cross) generated by EBID at RT (a) and at 200 K (b).