

Direct-Write Deposition Utilizing a Focused Electron Beam

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Local deposition of material can be induced by a focused electron beam delivering materials with a high purity and a clear interface to the substrate. Based on a commercial variable-pressure scanning electron microscope custom-tailored equipment was developed that allows introducing precursor gases through a nozzle system directly to the spot of deposition. For the deposition of material tetraethylorthosilicate (TEOS) was chosen, yielding a silicon oxide based material. The deposition process was investigated and optimized for high deposition rates. Variation of acceleration voltage and dwell time was performed, by depositing the material with a univariate parameter change. A higher deposition rate was obtained for lower electron energies. This result suggests a deposition mechanism based on the interaction with secondary electrons. Also effects of dwell time were discussed.

Introduction

The locally confined direct-write deposition is a new, maskless nanostructuring technique that is capable of fabricating 3-D structures within a single process step. The conventional fabrication of nanostructured devices with cutting-edge optical lithography requires the use of cost-intensive phase-shift masks and the processing time for several process steps including blanket deposition of the material, lithographic structuring and etch-back to obtain the desired structures. For prototyping a novel approach using direct-write deposition has been acknowledged as a promising alternative. The energy of a focused particle beam is used to locally induce a chemical vapor deposition. No mask is required and the structures can be deposited within a single process step. A frequently used approach is the deposition of a focused ion beam (FIB) [1], [2]. However, the ion contamination originating from the ion source and the atomic mixing of deposited material put a serious constraint on this method. An alternative technique could be the focused electron beam induced deposition. This technology delivers materials with a higher purity and a clear interface to the substrate.

In this article, tetraethoxysilane (TEOS) was used as a precursor for electron beam insulator deposition. The effects of several process parameters were studied. The variation of parameters was performed by depositing arrays of material with a univariate parameter change. The aim of the present work is to investigate the deposition process and to optimize the deposition parameters.

Experimental

Experiments have been performed using a variable-pressure scanning electron microscope LEO 1530 VP with a sophisticated gas inlet system. With a nozzle system the gas was introduced directly to the focus point of the electron beam. The energy of the electrons could be adjusted via the acceleration voltage in a range from 0.1 to 30 kV. The scanning operation of the electron beam could be controlled with a RAITH ELPHY PLUS pattern generator. The pattern generator allowed varying the pixel spacing of the

scan array, the dwell time of the beam on a single spot, and the number of scan repetitions.

For the deposition of material, tetraethylorthosilicate (TEOS) was chosen as exemplary precursor. The vapor pressure of TEOS is about 2 mbar at 20 °C and is sufficient for an accurate control of the gas flux via a dosing valve of the gas injection system. The acceleration voltage was varied in arrange from 5 to 30 kV. The maximum beam current was 3 to 4.3 nA (depending on the acceleration voltage), results of the use of the 120 μm aperture. In order to investigate the deposition process 50 x 20 μm SiO_x pads were deposited. The height of the deposition was determined by a DEKTAK profilometer. The surface morphology of the deposited material patches was investigated by atomic force microscopy in tapping mode.

Results and Discussion

For the deposition of silicon oxide a focused electron beam was used. The electron beam was scanned in a rectangular area.

First experiments should demonstrate that depositions of silicon oxide are feasible with the used set-up. Figure 1 shows an AFM-image of a deposited 6 x 6 μm area of silicon oxide. For this deposition an acceleration voltage of 5 kV, a pixel spacing of 46 nm, and a dwell time of 0.5 μs were adjusted.

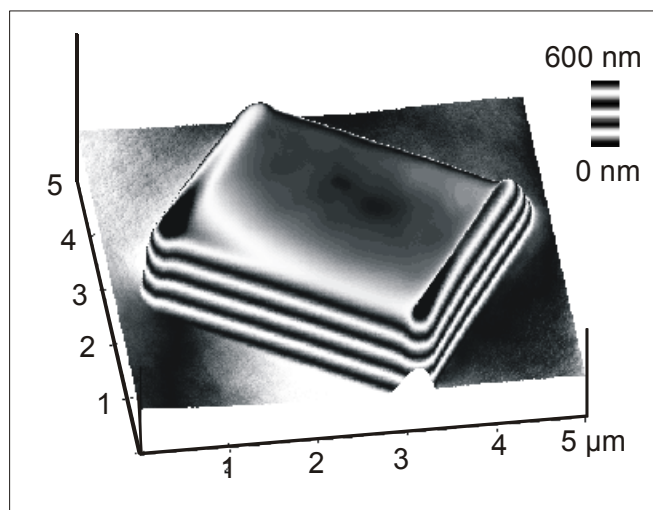


Fig. 1: AFM – image of a silicon oxide deposition on a 6x6 μm area

In the AFM-image (Fig. 1) a 6 x 6 μm deposition is seen. The deposited field has a total height of about 630 nm. The thicker material at the rim results from the longer dwell time at the left and right edge of the scan pattern, which is generated by the pattern generator. In the area between the rims the roughness of the surface is very low. This is of special interest in combination with optical applications. These findings prove that an electron beam may be used as a local probe for the deposition of well-defined structures. Investigations of the correlation between acceleration voltages and deposition thickness were performed with acceleration voltages from 30 kV down to 5 kV. All other process parameters were kept constant. The thickness of the deposited material was measured with a Dektak profilometer.

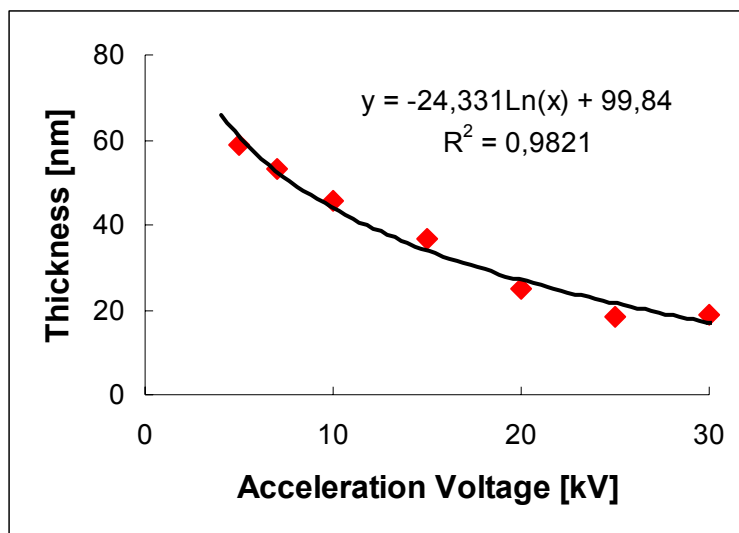


Fig. 2: Deposited thickness to acceleration voltage

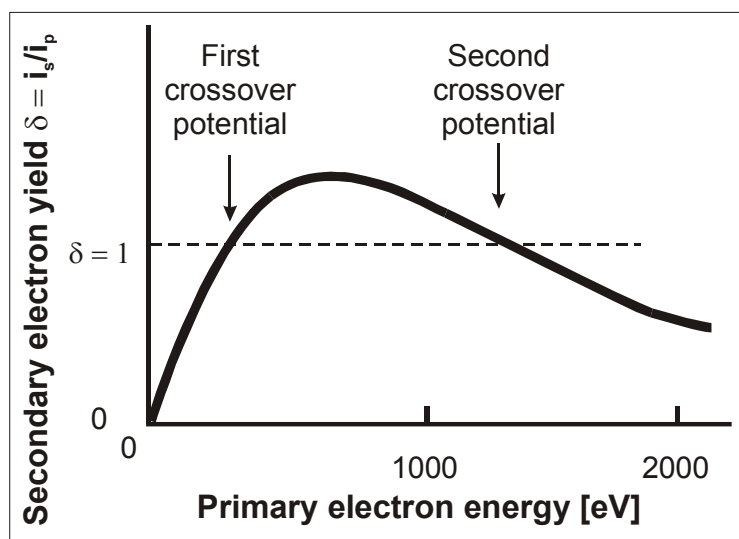


Fig. 3: Secondary electron yield correlated depending on the acceleration voltage from Hearle [4]

The dependence of the deposited thickness against the acceleration voltage is illustrated in Fig. 2. The graph indicates that the deposition rate increases at lower beam energies. This result correlates with the hypothesis that the deposition reaction is potentially induced by interaction of the adsorbed precursor with the secondary electrons [3], [4]. The yield of the secondary electrons (SE) depends on the energy of the primary electrons as it is illustrated in Fig. 3. Towards lower beam energies down to 600 V the penetration depth of electrons is reduced and the secondary electrons yield increases. The problem with low primary electron energy is the loss of beam stability.

The effect of the dwell time on the deposition thickness was analyzed by fabricating an array of $50 \times 20 \mu\text{m}$ areas in a 3×6 matrix (Fig. 4) with increasing dwell times. The default value for the shortest dwell time was set at $0,375 \mu\text{s}$. Other dwell times were obtained with a multiplier ($= 1 + 2n$) resulting in a 3-, 5-, 7-, ...- fold longer dwell time.

Within the array (Fig. 4) the dose for every deposited field was different. The thickness was measured by Dektak profilometer. To compare the deposited thickness the measured values were calibrated against the exposure dose. The deposited structures in Fig. 4 are well defined with sharp edges and excellently aligned. This array demonstrates that electron beam lithography is a serious technique for maskless direct-write lithography and for prototyping in the sub μm microelectronic technology.

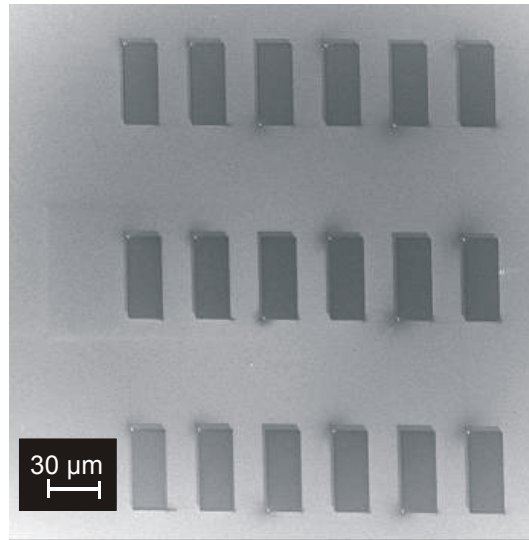


Fig. 4: Array of deposited material by electron beam induced deposition

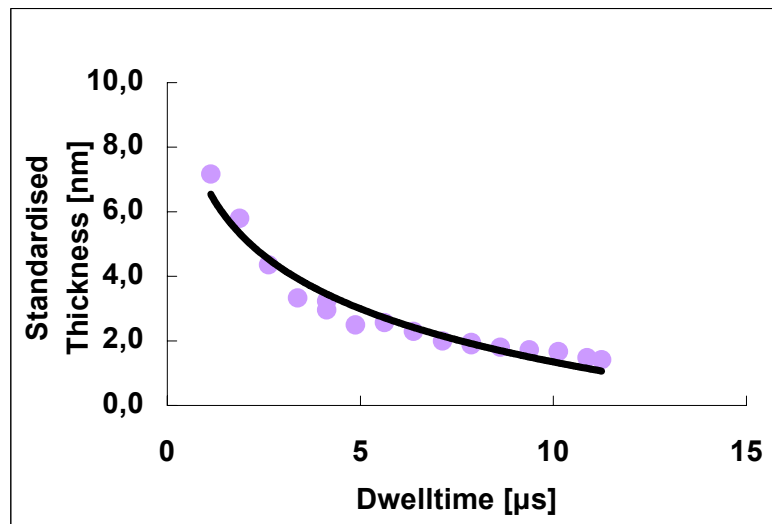


Fig. 5: Standardized thickness against dwell time

The evaluation of the dwell time influence is shown in Fig. 5. It is shown that the deposition thickness increased at lower dwell times. This indicates that the deposition reaction is faster than the surface saturation. A further decrease of the dwell time will result in a rise of the deposition rate.

Conclusions

It has been successfully demonstrated that an electron beam may be used as a local probe for the deposition of well-defined structures. This technique is an essential technology for repairing and preparing sub- μm feature sized structures. It has been shown that a higher deposition rate was obtained for lower electron energies. A deposition mechanism based on the interaction of the adsorbed precursor molecules with secondary electrons leads to the assumption. These findings are considered a solid basis for the better understanding of electron-induced surface reactions and path the way to a further process optimization of this innovative nanofabrication technique.

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