Thermally assisted focused electron beam induced deposition

G. Hochleitner, M. Hörtlackner, P. Rödiger, H.D. Wanzenböck, E. Bertagnolli
Vienna University of Technology
Institute for Solid State Electronics
A-1040 Vienna, Austria

D. Fischer, W. Bühler
Carl Zeiss NTS
D-73447 Oberkochen, Germany

This presentation presents a novel approach of a thermally assisted focused electron beam induced deposition (FEBID) process. This method extends the capability of FEBID by applying a previously unused autocatalytic effect. Focused beam induced processing has the capability of producing real three-dimensional structures at nanometer scale without the need for masks or photoresist. Complex nanostructures could be produced and characterized during the last years and are summarized in detail by Utke et al. [1]. The technique is based on the locally confined decomposition of a precursor molecule with a focused particle beam. The precursor is usually supplied through a gas injection system and decomposes by either a focused ion beam (FIB) or a focused electron beam (FEB). Processing with the FIB leads to higher deposition rates and when using metal containing precursors the metal content of the deposit is often higher than with FEBID [2]. With the thermally assisted approach these properties have been made available also for FEBID. Furthermore no implantation of source ions (e.g. Ga+ ions) and no amorphization occur with FEBID.

We implemented and analyzed an autocatalytic growth process [3] in a FEB system for the first time leading to deposition rates comparable with rates of FIB induced deposition or even higher. By heating the substrate slightly below the thermal decomposition temperature of the precursor, selected precursors start to grow rapidly only on regions activated with the electron beam (Fig. 1). The influence of a parameter set including substrate temperature, beam energy, beam current, cycle time, dwell time, writing direction, deposition time, precursor pressure and additive gas for iron-pentacarbonyl as precursor will be presented.

To gain a better understanding of the process the thermal behavior of iron-pentacarbonyl on silicon substrate at temperatures above room temperature was investigated. Therefore a thermal programmed desorption setup containing a tube furnace and a residual gas analyzer (RGA) was attached to the system vacuum chamber of the scanning electron microscope.

The geometries of the deposited structures were compared with electron distributions in substrates calculated with Monte-Carlo simulations. A correlation between the deposition size and the distribution of SE2 (secondary electrons caused by the back scattered electrons) was ascertained (Fig. 2). New insights on beam heating effects are presented and an estimation of the temperature rise in deposited tips will be given. Besides $Fe(CO)_5$ other precursors were investigated and similar autocatalytic growth behaviors were identified.

The benefits of this method are (i) the very high deposition rates at the micrometer scale (Fig. 3), (ii) a very high metal content in the deposited structure, which exceeded 60at% with the $Fe(CO)_5$ precursor and (iii) that no ions are implanted into the substrate. The application as protective layer was demonstrated and successful examples will be given. This new enhanced technique for electron beam induced deposition extends the application range and another area of parameters which should be tested for EBID.

[1] Utke, I., Hoffmann, P., Melngailis, J., Gas-assisted focused electron beam and ion beam processing and fabrication, 2008 *Journal of Vacuum Science and Technology B: Microelectronics and Nanometer Structures* 26 (4), pp. 1197-1276

[2] Botman, A., Mulders, J.J.L., Hagen, C.W., Creating pure nanostructures from electron-beam-induced deposition using purification techniques: a technology perspective, Aug. 2009, *Nanotechnology* 20, 372001

[3] Kunz, R.R., Mayer, T.M., Catalytic growth rate enhancement of electron beam deposited iron films, Apr. 1987, *Applied Physics Letters* 50 (15), pp. 962-964

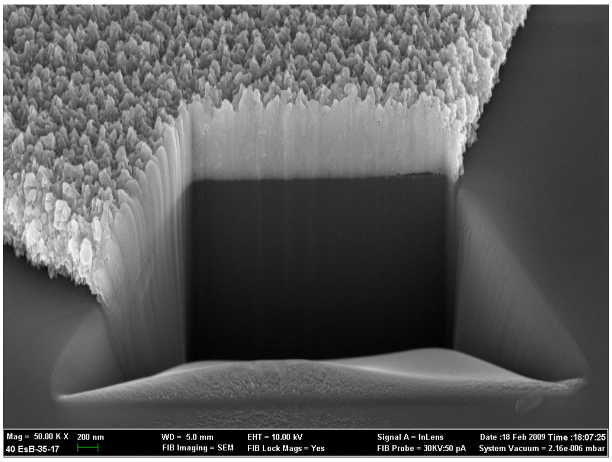

Fig. 1. Cross-section of thermally assisted FEBID structure with $Fe(CO)_5$ as precursor

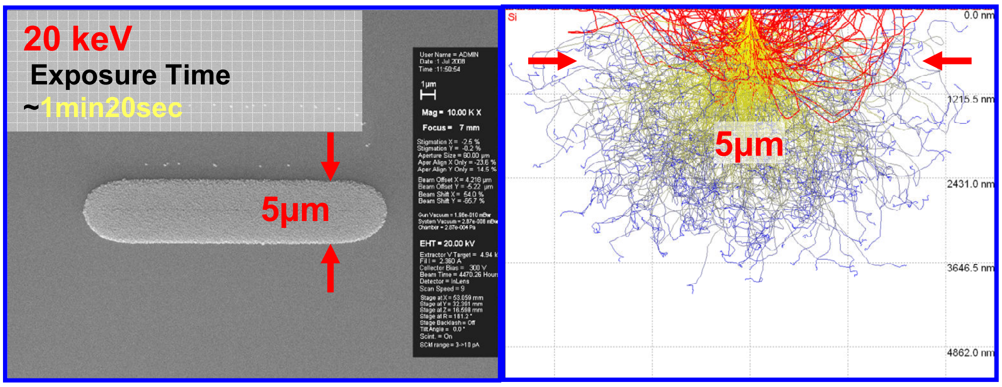

Fig. 2. (Left) deposited structure on a 25x5µm² area, deposited in line deposition mode at 20kV acceleration voltage. (Right) Monte-Carlo simulated electron distribution in silicon substrate at 20kV acceleration voltage. The structure width is comparable with the width of the distribution of the BE, SE2.

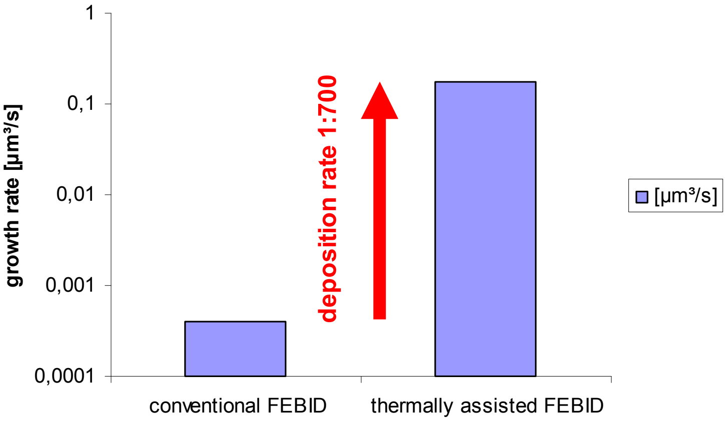

Fig. 3. Growth rate of depositions with conventional FEBID and with thermally assisted FEBID using $Fe(CO)_5$ as precursor