The Influence of Substrate Temperature during Focused Electron Beam Induced Deposition (FEBID)

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Introduction

For highest precision and reliability, local precursor coverage is of highest importance, as it determines the incremental growth rate. Recently, it was found that the local beam heating massively influences the local coverage due to reduced residence times of the precursor, which explains previously observed stability problems for larger 3D structures [1] . Based on this motivation, we here turn around the situation and lower the substrate temperature to study the implications on stability and precision. While FEBID at cryogenic temperatures using liquid nitrogen was studied before[2], we here focus on temperatures from room temperature down to 0 °C, which provides a certain level of applicability compared to a much more complicated cryo-setup.

Setup of Peltier Stage

We designed, fabricated a variable temperature stage using a Peltier element (Fig. 1). The focus of the stage design was put on the modularity so that in terms of malfunction of the components the exchange is comparably simple. A 30 x 30 mm² Peltier element was used, which allows to cool substrates with a maximum size of 25 x 15 mm. A Pt-1000 was fixed on the surface of the Peltier element and a NTC on the upper module of the bimodular heat sink, which both served as input for the Peltier control unit. To complete the temperature mapping of the stage, an additional NTC sensor and a Pt-1000 were mounted on the lower module of the heat sink and directly attached on the silicon wafer, respectively.

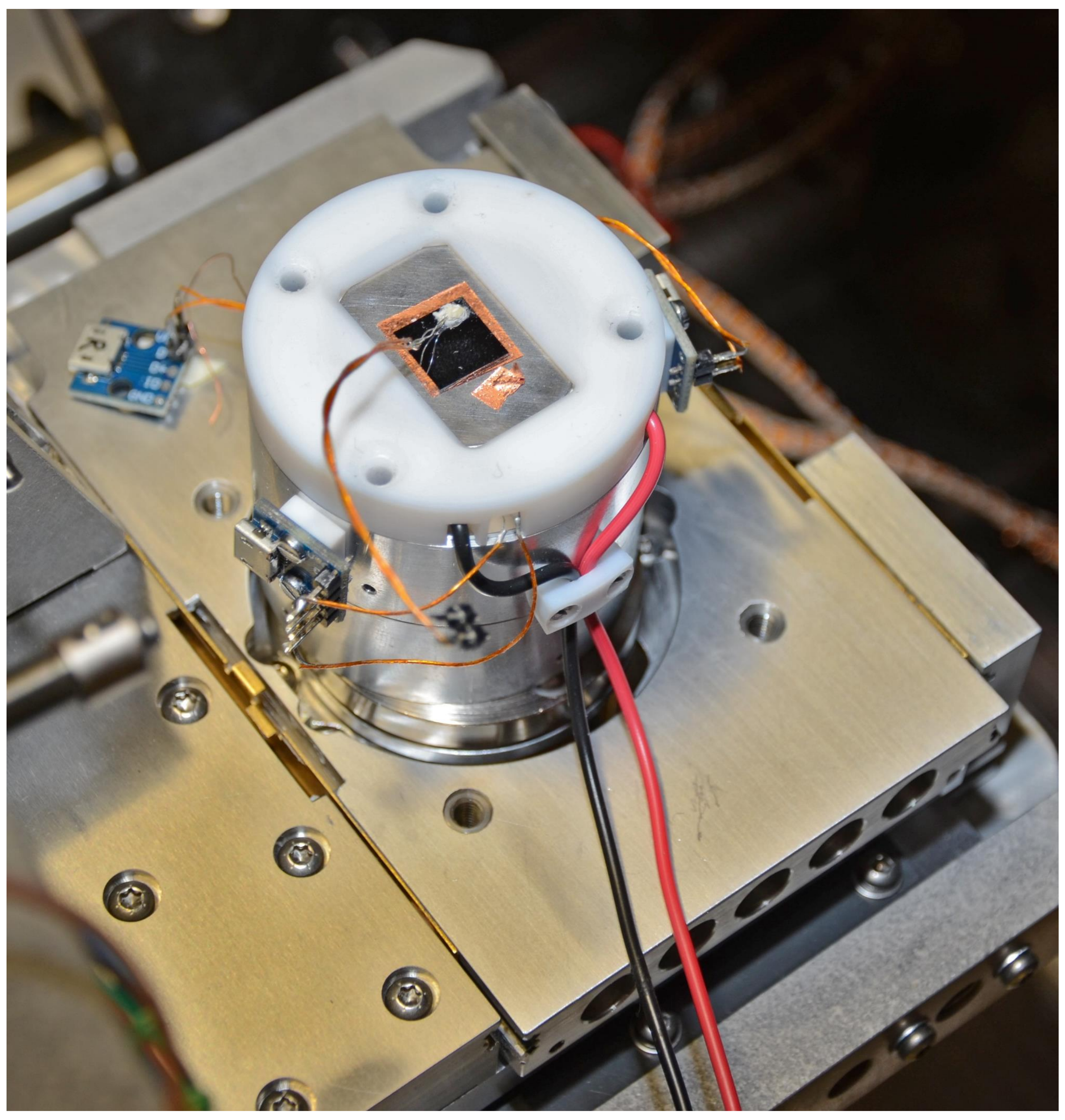

Figure 1: Peltier Stage integrated in FIB-SEM Quanta 3D

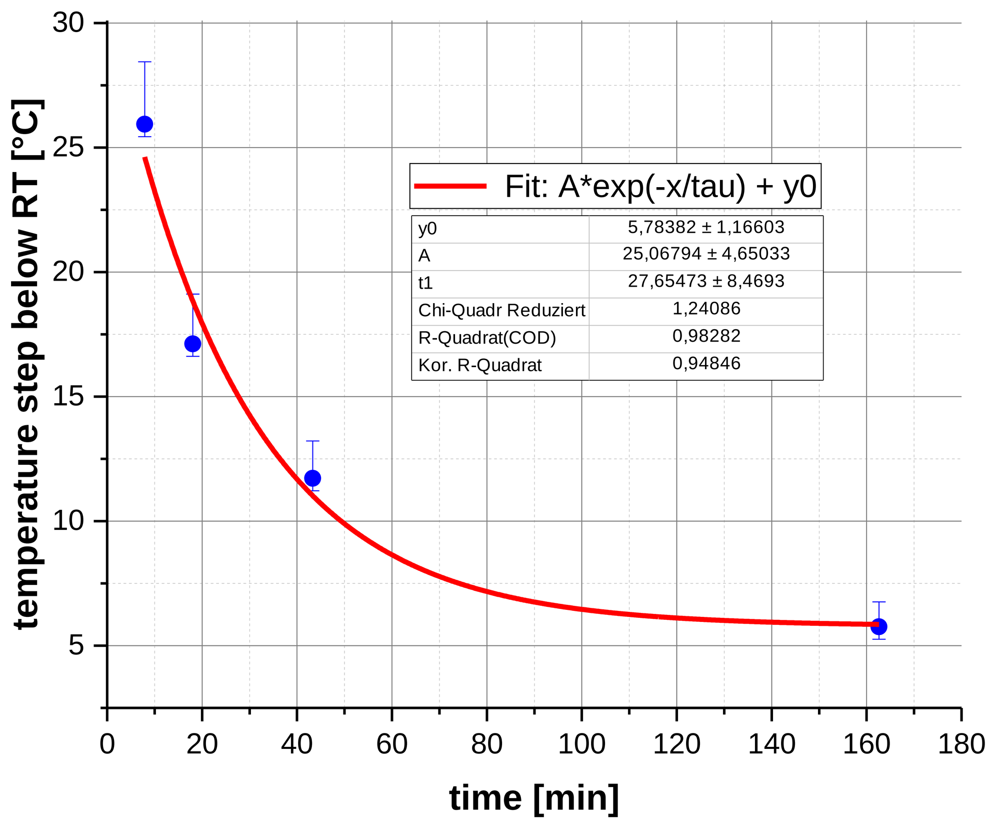

Figure 2: Temperature steps below RT in dependence of its stabilization time

The control unit of the Peltier element allows full temperature control with variable heating/cooling rates up to 3 K/s. The stage was tested and optimized in terms of control engineering (PIDT1) for cooling steps from room temperature (RT) down to -5°C, as well as for heating steps from RT up to 45 °C. The timescale on which certain temperature steps below RT can be stabilized is shown in (Fig. 2) for cooling rates of 1 K/s.

Experiments with Substrate Temperature Controlled FEBID (STEC-FEBID)

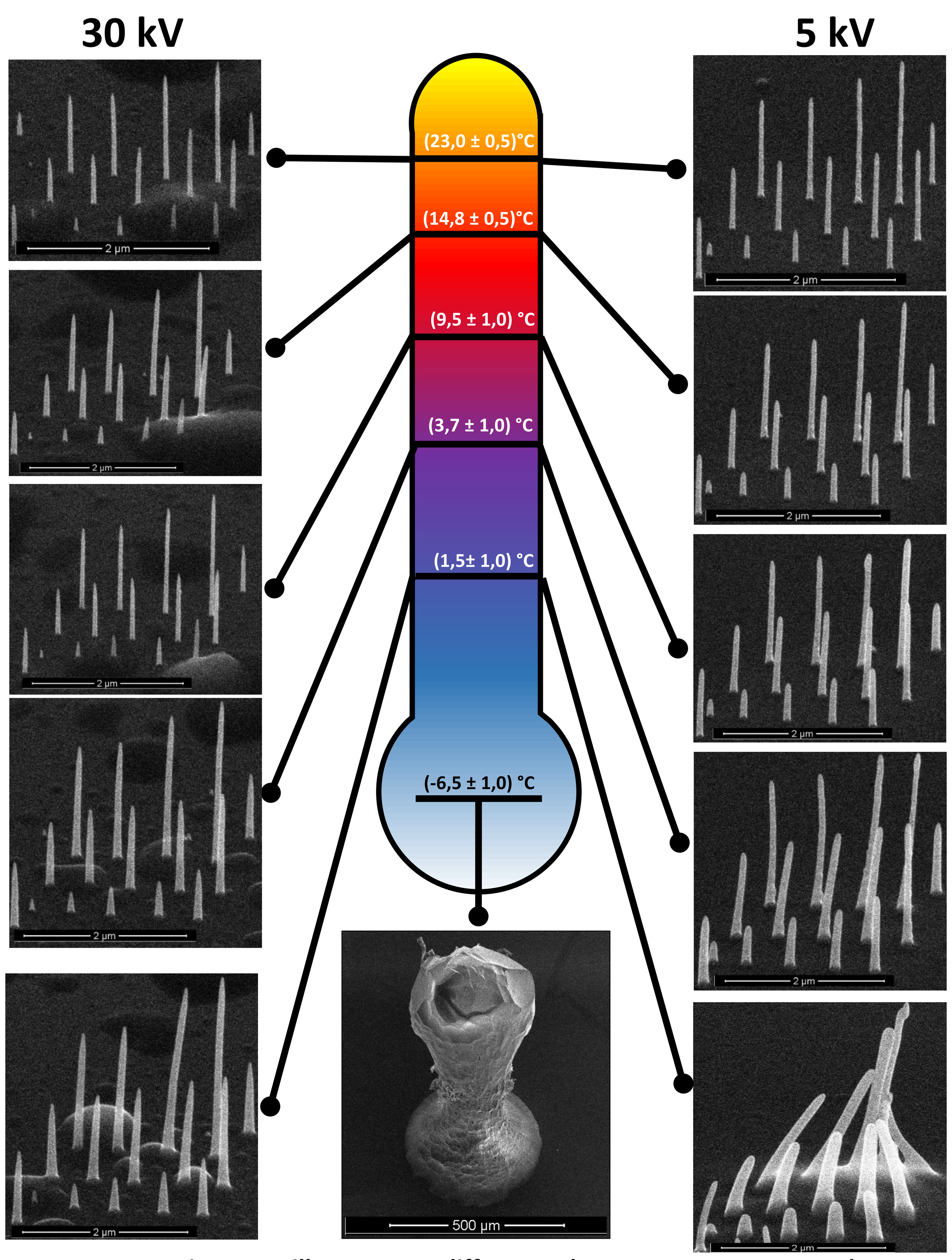

Figure 3: Pillar arrays at different substrate Temperatures and acceleration voltage

Quasi-1D-pillars were fabricated at 30 kV and 5 kV at substrate temperatures from RT down to 1.5 °C (Fig. 3). Below 1.5 °C the precursor solidifies on the substrate, resulting in an amorphous cone-like structure.

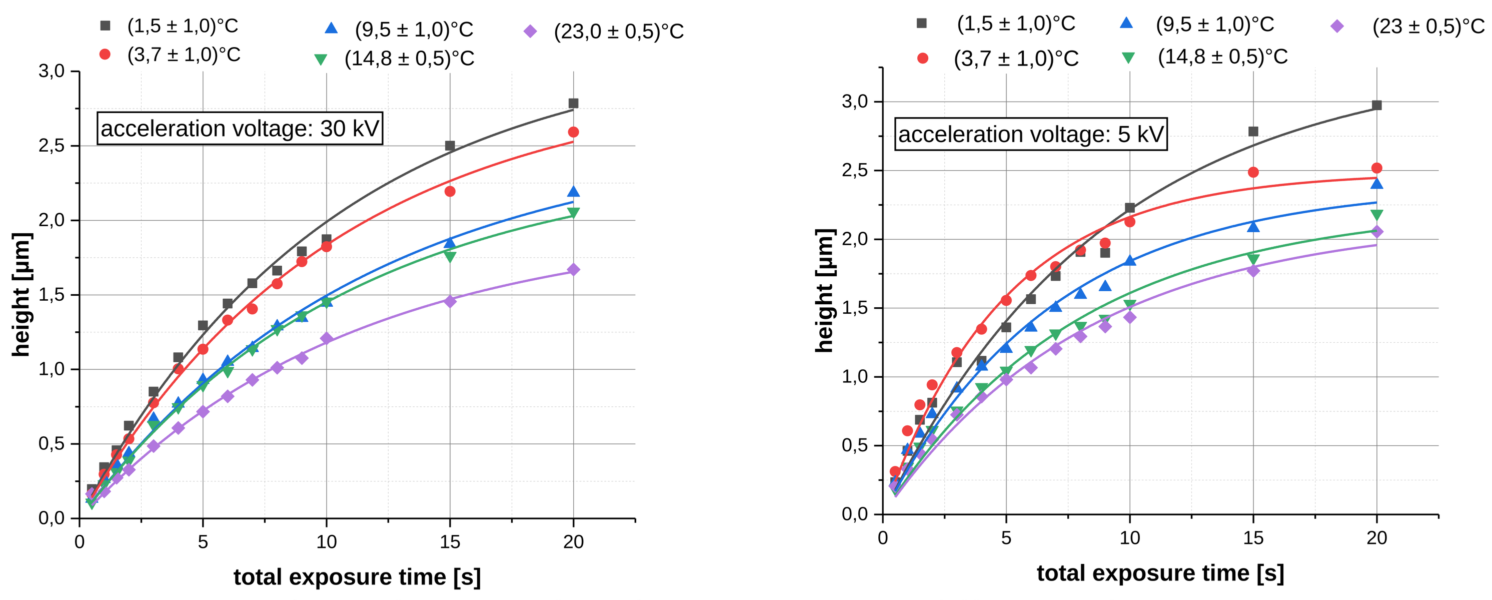

Figure 4: Heights as function of total exposure time at different substrate temperatures

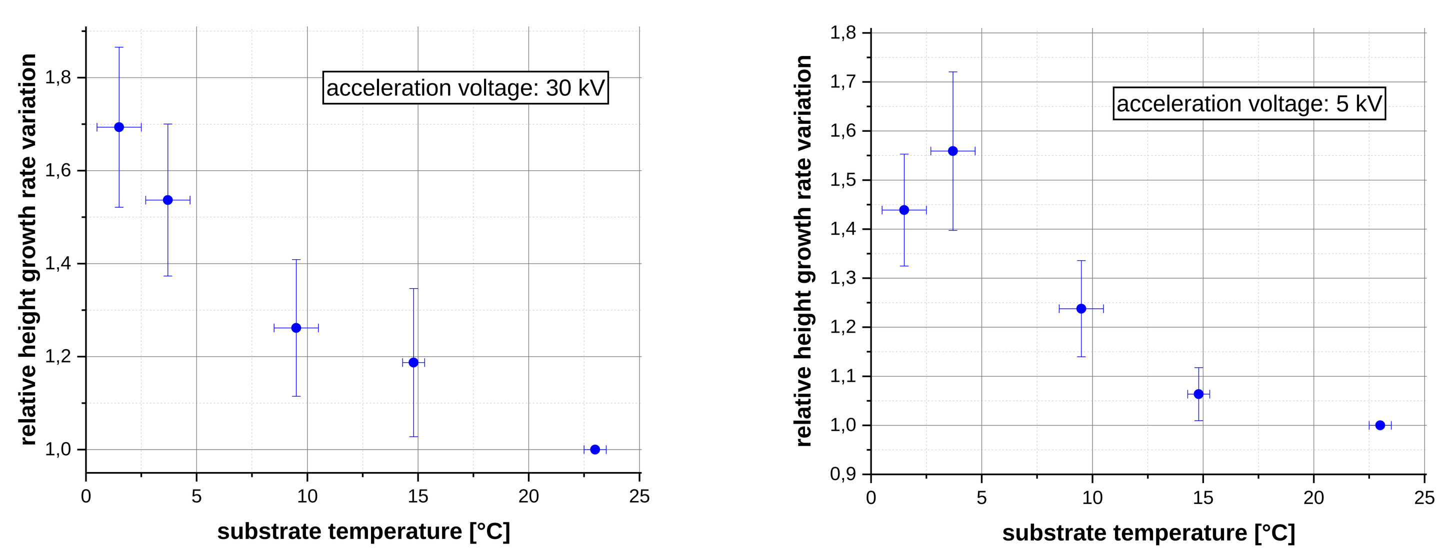

Figure 5: Relative height growth rate as a function of temperature

Conclusion

A massive growth rate increase was observed for a both primary energies when approaching 1.5 °C (Fig. 5), demonstrating the expected growth boost for lower substrate temperatures.

References

[1] Mutunga et al., ACS Nano (2019), DOI:10.1021/acsnano.8b09341
[2] Bresin et al., Nanotechnology 24 (2013), 035301-1 - 035301-7

Acknowledgements

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3 µm