Optimization of nozzle-based gas injection systems for focused electron- and ion-beam induced processing

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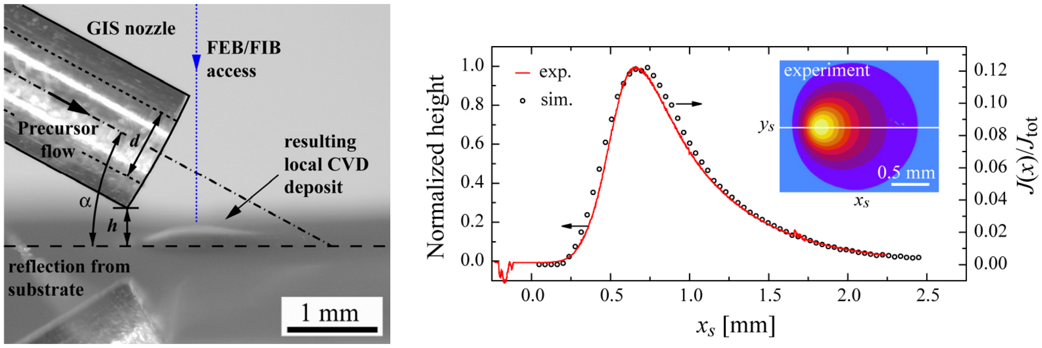
For direct-write nanostructuring techniques using focused electron- and ion-beams (FEBs and FIBs) it is crucial to identify the rate-limiting process to understand experimental results, such as the processing rate and resolution[1] and the deposit material composition[2]. One of the fundamental limitations to this objective is the lacking knowledge of the locally supplied precursor molecule flux in most reported studies.

In the conventionally used nozzle-based gas injection system (GIS) (Fig. 1 (a)) the molecule flux distribution which reaches the substrate is determined by the nozzle dimensions, its position relative to the substrate and the prevailing gas flow regime. We report on the experimental investigation of the impinging flux patterns on the substrate using a dedicated CVD reactor. The flux distribution is reproduced by the mass transport limited growth rate of the impinging precursor on the heated substrate (Fig. 1 (b)).[3] Two alternative nozzle designs (Fig. 2) increase the accessible flux to the FEB/FIB up to 6 times for the same molecule throughput injected into the vacuum chamber.

Optimization of the local precursor supply by nozzle-based gas injection systems was further investigated based on Monte Carlo simulations of the rarefied gas flow. The ideal position and incidence of the tube nozzle relative to the substrate and the FEB/FIB as well as flux shadowing effects (Fig. 3) are identified.

The results from these investigations provide accurate data of the impinging precursor flux to the processing area in contrast to previous studies[4,5]. The achieved optimization of the precursor supply leads to an increased processing rate *and* resolution while the pressure load for the vacuum system is minimized.

[1] I. Utke, V. Friedli, M. Purrucker, and J. Michler, *J. Vac. Sci. Technol. B*, 25(6): 2219, 2007
[2] I. Utke, V. Friedli, J. Michler, T. Bret, X. Multone, and P. Hoffmann, *Appl. Phys. Lett.*, 88(3): 031906, 2006
[3] I. Utke, V. Friedli, S. Amorosi, J. Michler, and P. Hoffmann, *Microelectron. Eng.*, 83(4-9): 1499, 2006
[4] K. T. Kohlmann, M. Thiemann, and W. H. Brunger, *Microelectron. Eng.*, 13(1-4): 279, 1991
[5] M. Komuro, N. Watanabe, and H. Hiroshima, *Jpn. J. Appl. Phys. 1*, 29(10): 2288, 1990



(a) (b)

Fig. 1: (a) Microscope image of the of the tube nozzle-based gas injection system (GIS) configuration in side-view. The silicon substrate is mounted on a heating stage to thermally decompose all impinging molecules on the surface. (b) Deposit height profiles determined by optical profilometry (solid lines) deposited from $Co_2(CO)_8$ at 200°C substrate temperature with a tube nozzle (d=400µm, α=33°, h=190µm). Superposed are Monte Carlo simulations of the normalized impinging flux $J(x)$ in transient flow conditions. The inset shows the deposit topography in top-view.

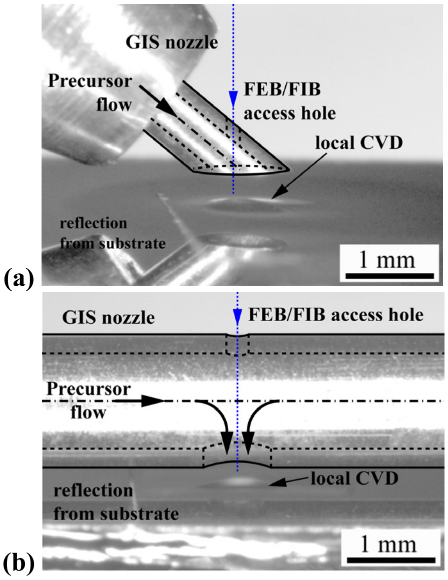


Fig. 2: Thermal decomposition experiments from the precursor $Co_2(CO)_8$ for two alternative GIS nozzle geometries. Microscope images show the nozzle-substrate configuration in side-view. For clarity, the geometry is pointed out by an overlay. (a) Angled tube nozzle. (b) Horizontal nozzle.

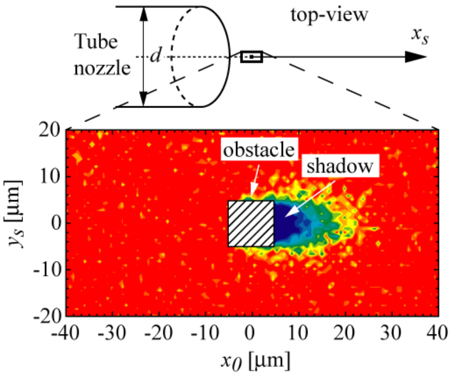


Fig. 3: Simulated isoflux contours of the molecular impinging flux on the substrate (in top-view) around a cubic obstacle (shaded box) of 20 µm height and 10x10µm^2 area for a tube nozzle (d=400µm, h=100µm, α=33°).