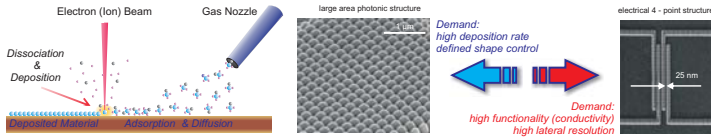


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Introduction & Basic Principle^[1]



- EBID and IBID are versatile direct write methods to deposit functional materials (conductive, insulating, magnetic, sensing, ...) on the nanoscale
- The techniques utilize gaseous precursor which adsorb on the surface and dissociate during an interaction with electrons / ions into volatile and non-volatile products
- Compared to ions, electrons are practically free from sputtering effects and unwanted material implantation, provide very low thermal stress and allow for higher lateral resolution capabilities
- Drawbacks of EBID can be
 - low deposition rates (time and drift critical)
 - high carbon contents (suppressing the intended functionality such as electrical conductivity)
 - electron trajectory related proximity effects (reducing spatial resolution capabilities)
- Several counterstrategies have been developed which compensate for many drawbacks, briefly summarized on this poster (mainly carried out with $(CH_3)_2CH_2C_2H_4Pt$ precursor on SiO_2)

Efficiency Tuning by Alternative Patterning Strategy^[2]

- The main problem is depletion and replenishment of the precursor coverage during (dwell time) and in between (refresh time) electron pulses
- A single pulse depletes also the precursor coverage in the proximity of the beam by diffusion
- Thus, consecutive closely spaced patterning points start with increasingly reduced precursor densities which strongly decreases the growth rates
- The introduction of an interlacing strategy eliminates proximity depletion
 - 1st step: large point pitch to decouple diffusive effects (d)
 - 2nd step: shift of the pattern by very small distances (d)
- Process time and surface roughness are not affected
- Fully optimized patterns can improve the efficiency by more than 200%

Controlling the Chemistry via Process Parameters

- Two different regimes can occur during parameter variation:
 - Reaction rate limited (RRL) is defined by a lack of electrons w.r.t. precursor molecules. The increased carbon contents originates from **incompletely dissociated molecules**
 - Diffusion enhanced (DE) is defined by an excess of electrons which can lead to electron induced **polymerization of precursor fragments / chamber residues** as origin of increased carbon contents
- The ideal balance is complicated to establish because of:
 - changing morphology, leading to
 - different coverage rates due to varying diffusion
- Extreme regimes, however, can be easily established!

Functionality Improvement by e-Beam Curing^[3]

- Since the maximum Pt content can not be established easily (see left) a new, two-step strategy is introduced:
 - Step 1: on-purpose incorporation of incompletely dissociated precursor molecules (RRL regime; MTL is much less efficient!)
 - Step 2: postgrowth e-beam exposure to finish dissociation
- Temporal evolution reveal two regimes (top left)
 - Regime 1: fast improvement due to efficient molecule dissociation
 - Regime 2: slow improvement due to graphitization of the carbon matrix by the increasing number of available electrons
- Curing in regime 1 leads to increasing Pt grains (1.7 to 2.2 nm) without agglomeration (see TEM BF and TEM EELS results)
- By this, the tunneling probability through the insulating carbon matrix is increased leading to resistivity decays of more than 3 orders of magnitude with a curing rate better than $1.5 \mu m^2 / min$ (footprint)

Understanding and Minimization of Proximity Deposition

- Correlated AFM - KFM measurements reveal unwanted proximity deposition on partly large scales with different chemistry
- As representative example, 30 keV deposit reveal
 - Edge tilt / broadening**: fully functional (see below)
 - Outer halo**: related to $BSE_{SUBSTRATE}$, non-functional due to incompletely dissociated molecules (see KFM and C-AFM)
 - Transition region**: partly conductive
- Edge tilt / broadening is caused by $BSE_{DEPOSIT}$ and represents a fundamental limitation (function of E_{elec} , substrate and deposit chemistry, deposit height)
- Intermediate energies reveal an additional plateau of the outer halo
- This represents a pattern reflection outside the deposit and is the result of patterning footprint, substrate chemistry and beam energy
- The comparison of edge, outer, and transition effects allows for the derivation of design rules for Pt deposits in the sub-100 nm regime
- Very high energy provides highest lateral resolution (defined by its conductive edge halo) with a thin, large scale halo (non-conductive)
- Very low energies are slightly broader (defined by its conductive outer halo) but much more efficient during deposition
- Intermediate energies should be completely avoided

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