



Precursor development for charged particle deposition: Case studies based on Nb and Ta

Nicolas P. Jochmann^a, Fabrizio Porрати^a, M. Huth^a and Sven Barth^{*a}

^a *Goethe University Frankfurt, Germany*

Direct-write nanofabrication techniques are of particular interest to the semiconductor industry as well as fundamental research, as they enable the maskless fabrication of free-form three-dimensional nanostructures on any surface. The portfolio of applications for materials prepared by focused electron/ion beam induced deposition (FEBID/FIBID) includes electronics, magnetics, magnonics, photonics, optics, etc., making this technique a powerful tool for transdisciplinary research. Access to more diverse materials with desirable compositions requires the development of new precursors with desired properties that make them suitable for the FEBID and FIBID processes.[1]

Here, we present recent advances in precursor design targeting organometallic complexes of Group 5 transition metals. The specific ligand systems are designed to enable the deposition of binary materials such as nitrides and carbides. The key challenge is often the combination of a sufficiently high vapor pressure of the precursor with adequate stability in both the condensed and gaseous phases, while at the same time ensuring efficient decomposition upon interaction with charged particles. Developing molecular design principles is therefore essential for the preparation of novel nanomaterials and is closely guided by the underlying chemistry of molecular fragmentation induced by charged particle interaction. Metal nitride deposits are targeted using nitrogen-rich ligands such as amides, hydrazines, or azides, whereas carbide deposits exploit direct metal–carbon bonds in alkylated metal centers or carbonyls. FEBID relies on pre-defined chemical bonds within the precursor molecules that are intended to be retained in the final material, such as the strong metal–nitrogen double bonds found in imido motifs. In contrast, FIBID typically exhibits complex fragmentation and recombination behavior, arising from several concurrent processes such as sputtering, implantation, and fragmentation via both momentum transfer and secondary electron interaction. Thus, the ion-induced deposition is considerably more complex.[2]

To date, the direct writing of a binary metal/non-metal material from a single-source precursor has not been reported for FEBID. Here, we demonstrate the deposition of functional materials from niobium single-source precursors, paving the way for studies of nanostructures with applications in the fields of sensors or electrical contacts. This contribution summarizes our ongoing efforts in precursor design for FEBID and FIBID based on Group 5 metals.

Acknowledgements

We acknowledge generous financial support of these studies from the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) projects BA6595/2-2 and BA6595/5-1.

References

- [1] S. Barth, M. Huth, F. Jungwirth; *J. Mater. Chem. C* **2020**, 8, 15884.
- [2] N. P. Jochmann, A. Salvador-Porroche, and S. Barth; *Adv. Funct. Mater.* **2025**, 35, 49, e07465.