Hybrid materials by ALD/MLD: Integrating organic, inorganic, and structural design across different dimensionalities

Gabriela Ambrožić,[1,2] Iva Šarić,[1,2] Robert Peter,[1,2] Maria Kolympadi Marković,[1,2] Ivana Jelovica Badovinac,[1,2] Ivna Kavre Piltaver, Mato Knez[3,4]

[1]*University of Rijeka, Faculty of Physics, Radmile Matejčić 2, 51000 Rijeka, Croatia*

[2]*University of Rijeka, Centre for Micro- and Nanosciences and Technologies, Radmile Matejčić 2, 51000 Rijeka, Croatia*

[3]*CIC nanoGUNE, 20018 San Sebastian, Spain*

[4]*IKERBASQUE, Basque Foundation for Science, 48013 Bilbao, Spain*

Atomic layer deposition (ALD) and molecular layer deposition (MLD) offer a versatile platform for synthesizing hybrid materials from the gas phase, allowing precise control over composition, thickness, and surface chemistry. In this work, we present strategies for fabricating hybrid materials on nanoparticulate systems, flat surfaces, and three-dimensional architectures.

We demonstrate the use of MLD for targeted organic surface functionalization of inorganic materials through selective gas-phase click reactions.[1,2] ALD-deposited metal oxide thin films, such as Al_2O_3, can also serve as surface-activated substrates for solution-based organic modifications, imparting additional surface wetting properties or introducing specific functionalities, for example, in biosensor applications.[3] ALD has also been applied to complex and porous polymer fibers; conformal ALD-deposited Al_2O_3 and ZnO bilayers on cellulose impart antibacterial properties to the functional hybrid material.[4] Cellulose is also used as a sacrificial substrate for preparing three-dimensional ZnO structures with enhanced photocatalytic properties, demonstrating the advantages of ALD in building hierarchical architectures.[5]

These examples illustrate how ALD and MLD are effective approaches for designing hybrid materials, enabling the integration of organic functionality, inorganic stability, and structural complexity in substrate materials.

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[3] G. Ambrožić et al. *J. Colloid Interface Sci.* 2020, **560**, 303.

[4] S. Mežnarić et al. *J. Environ. Chem. Eng.* 2022, **10**, 108095.

[5] R. Radičić et al., *Catalysts* 2026, **16**, 17.