



Reactivity of Low-Energy Electrons and Ions with Molecular Clusters Relevant to Nano-Manufacturing

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Molecular clusters serve as a model system for studying molecular mechanisms relevant to condensates using vacuum- restricted methods. This is particularly important for processes induced by low-energy projectiles, such as sub-MeV ions or sub-100 eV electrons. These penetrate only the surface layers of the bulk material, which is beneficial for additive nano-manufacturing. While the ions at such low energies are directly used in ion beam manufacturing, the electrons are produced in large amounts as a secondary species that form in the substrate and deposit, affecting the deposit's shape and composition.[1]

The presentation will provide an overview of our recent cluster studies, including electron [2] and ion [3] collisions with iron pentacarbonyl, a prime example of an additive manufacturing precursor, and electron collisions with methyl methacrylate [4], whose polymer form is an industry photoresist of choice in high-resolution EUV and electron lithography.

When isolated iron pentacarbonyl interacts with ions, it decays by releasing fast CO ligands and producing slow Fe ions. [5] In clusters [3], the situation changes dramatically because all fragments are ejected against the large cluster, so the Fe-Containing fragment ions also acquire significant energies. This can be compared to the ejection of fragments from the surface, demonstrating that, particularly for heavier ion projectiles, material sputtering will play an important role. Such observation is in good agreement with the recent surface study of Abdel- Rahman et al. [6].

Isolated MMA efficiently decays upon attachment of low- energy electrons. When incorporated in clusters, a significant part of the molecules stabilizes as the parent anion, which can be related to the trapping of electrons in the substrate. As a consequence, the fragmentation channels that remain open in clusters are observed over a much wider energy range than detected for isolated molecules. Such behavior can be assigned to scavenging processes in clusters and consequently can lead to a much higher contribution of electron- induced processes in bulk than expected based on gas-phase data.

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References

- [1] D.H. Fairbrother et al. "Focused electron beam-induced processing" in *Low-Energy Electrons: Fundamentals and Applications*, O. Ingólfsson (Ed.), Pan Stanford (2019)
- [2] J. Lengyel, et al. *J. Phys. Chem. C* 120, 7397 (2016)
- [3] L. Sala et al *Phys. Scr.* 100, 025402 (2025)
- [4] T. Luxford, et al. *J. Phys. Chem. A* 127, 12, 2731 (2023)
- [5] S. Indrajith et al. *J. Phys. Chem. C* 123, 10639 (2019)
- [6] M.K. Abdel-Rahman et al., *J. Phys. Chem. C* 128, 7723 (2024)

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