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Interplay Between Morphology and Transport in Nanoscale Pattern Formation

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The formation of a pattern is a ubiquitous trait of morphogenesis, in which an ordered structure with a characteristic periodicity in space emerges spontaneously out from an otherwise homogeneous medium which is driven out of equilibrium [1]. As already exemplified by the classic mechanism proposed by Alan Turing [2], a key ingredient for pattern formation is the interplay between reaction and transport mechanisms, the latter originating in diffusion processes for the type of (macroscopic) chemical and biological systems that were the context for his original proposal. Current high-resolution experimental techniques have elucidated quite similar phenomena also in the context of traditional hard (microscopic) condensed matter systems down to nanometer distances. While underscoring the economy of principles that governs the self-organization of matter, within Nanotechnology this fact may prove relevant to the production of materials with new or enhanced properties [3].

Surfaces and interfaces have an increased physical relevance at the nanoscale, due to the enhanced surface-to-volume ratio and to their role as loci for the exchange of energy and matter between a physical system and its environment, key to the system behavior under non-equilibrium (*e.g.*, growth or erosion) conditions. At such small distances, both reaction and transport processes become particularly influenced by geometrical constraints, fluctuations, and kinetics, and in principle require reanalysis if one is to obtain an understanding of the system that enables predictive power.

In his seminal definition of the term "Nanotechnology" in 1974, Norio Taniguchi already identified ion-beam irradiation (IBI) of solid targets as a promising technique for the manipulation of matter at small scales [4]. Indeed, IBI has been subsequently confirmed to enable the efficient production of self-organized patterns of *e.g.* nanoripples or nanodots on the surfaces of virtually all types of materials [5,6]; but ironically, the key processes controlling the surface behavior in time and space remain to be fully understood in these systems.

In this talk I will use IBI to exemplify the ways in which material transport and "reaction" processes interact with each other to yield formation of surface patterns at the nanoscale. Analogies with macroscopic contexts for pattern formation, such as granular systems or viscous fluids, turn out to be particularly fruitful, due to the slow time scales in which IBI systems nontrivially evolve. Similarities and differences will be explored with other (microscopic) approaches for the production of ultrathin films. Along this process, improved knowledge is being uncovered on the manifestations of diffusive phenomena in small spatially extended systems far from equilibrium.

References

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