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Crystallization dynamics in metals, polymers, and ceramics: bridging theory and experiment in materials science

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Plenary: Crystallization is a fundamental process in natural phenomena (e.g., snow and mineral formation) and engineered applications, such as metal solidification and glass-ceramic production. Understanding the crystallization dynamics is crucial for controlling material microstructure and properties, whether the goal is to promote or prevent crystal formation. While crystallization is the antithesis of vitrification, controlled nano or micro-crystallization enables the creation of valuable polycrystalline materials, including special metallic alloys and glass-ceramics. This dual role in materials science makes "crystallization" one of the most frequently cited concepts in the field. This presentation focuses on recent advancements in understanding the early stages of crystallization, particularly crystal nucleation in supercooled liquids. We will examine the progress made over the past seven decades, supplemented by short videos to illustrate key concepts. The Classical Nucleation Theory (CNT), which has been the primary tool for analyzing crystallization dynamics for over 70 years, has shown limitations. Experimental data reveals significant discrepancies between CNT predictions and measured nucleation rates across various substances, including metallic, organic, and oxide materials. However, recent molecular dynamics simulations using simplified models (e.g., Lennard-Jones, BaS, ZnSe, Ge, Ni, and H2O) have provided validation for CNT, offering new insights into this complex yet fundamental process.