Preface: the life and accomplishments of Alex Chernov

In the last two decades, crystal growth science has experienced explosive expansion. The primary driver has been the vast range of natural and engineered materials whose understanding and optimization require in-depth knowledge of how molecules cooperate to erect perfect three dimensional translationally-symmetric arrays—the miracle that we call crystallization. These huge fundamental and applied advances were possible only because we, the current generation of researchers, stand on the shoulders of our giant forefathers. Alex Chernov is among the tallest of the crystal growth giants.

This volume of *Journal of Crystal Growth* comprises 40 papers dedicated to Alex Chernov. The range of studied materials represents the breadth of the field in our times and stretches from protein crystals, biominerals and other natural materials, including ice, through organic semiconductors, inorganic optical elements and pharmaceuticals, all the way to zeolites and other silicates used as catalysts and light emitting devices. We selected the covered topics to reflect Alex's broad interests and the impacts that he leaves on all areas of crystal growth: thermodynamics of crystallization, nucleation, molecular mechanisms (or elementary processes, in Chernov-speak) of growth, solute and impurity transport, modifier effects, and agglomeration. The methods employed in these papers mirror the advanced approaches that are now available to crystal growers and enabled the recent blast of results: direct-space and scattering optics and x-rays, time-resolved *in situ* scanning probe and confocal microscopies, reduced gravity aboard spacecrafts and planes, abetted by analytical theory and all-atom, coarse-grained, and Monte Carlo simulations.

Alexander Alexandrovich Chernov, Alex to English speakers, grew up in Moscow, then the capital of the USSR, in a family of medical doctors. He graduated from Moscow State University with a degree in physics. Alex completed his PhD in the group of Lev Landau, considered the last universal theoretical physicist. Alex's direct supervisor was Ilya Lifshitz, another great theorist famous to the crystal growth community for the Lifshitz and Slyozov theory of Ostwald ripening. During these years, Alex passed several of the Theoretical Minimum exams, a notoriously hard set of tests, despite the misleading label, which were designed by Landau to cover the knowledge base of a future theoretical physicist. The years in the Landau group sculpted Alex's thinking. He firmly believed that a good theorist may foresee the outcomes of a properly staged experiment and his experimentalist collaborators, among who are the three of us, were driven to apply great effort to meet his expectations.

Alex's dissertation served as the basis of a review article in *Uspekhi Fizicheskikh Nauk*, the Soviet equivalent of *Reviews of Modern Physics*. It represents a tour-de-force over several issues of crystal growth, which resonate throughout his subsequent career. Alex was the first to address these topics or pushed the state-of-the art further than his predecessors had:

equilibrium crystal shapes, kinetic laws for crystal growth from vapor, solution, and melt, impurity effects on step motion, impurity incorporation into crystals, and step-step interactions and step bunching. Analyzing these phenomena, Alex came up with two of his most important discoveries. The first one was the representation of crystal growth as a chemical reaction between a solute molecule and a kink, during which old bonds, such as those with the solvent, break and new ones set in. As with any other chemical reaction, the kink-solute collisions are impeded by an activation barrier, which combines with spatial and temporal factors to define the step kinetic coefficient, an analogue to a rate constant in chemical kinetics. In the subsequent years, the step kinetic coefficient has been modeled and modified by theorists, measured and interpreted by experimentalists, and has persisted as one of the most fundamental concepts of crystal growth.

The second discovery in Alex's dissertation was the realization that the shape of a macroscopic crystal is determined by the anisotropy of its growth rate and not the anisotropy of the surface free energy. The surface free energies of the individual crystal faces govern, according to the venerable Gibbs-Curie-Wulf rule, the shape of crystals comparable in size to the crystal nucleus, but not much larger. The Chernov rule guides the prediction and interpretation of crystal shapes in areas that extend from pharmaceutical production to catalyst synthesis.

Chernov started work as a junior scientist in the Institute of Crystallography of the USSR Academy of Sciences and rose to the position of Head of the Institute's Division of Physics of Crystallization and Real Crystal Structure and Professor at his alma mater, Moscow State University. His achievements during these years were spectacular. Alex applied the tools of theoretical physics to crystal growth problems and in this way elucidated numerous previously elusive phenomena. He showed how crystals preserve their shapes during growth from the ubiquitous non-uniform concentration fields. Alex introduced the concept of kinetic roughening and highlighted the step dynamics and the combination of parameters that govern the loss of smooth interfaces at high supersaturations. His model of how step bunching couples to solution flow was later adapted to the interaction of steps and electric fields in semiconductor growth. Among Alex's other firsts are the theories of inclusion migration in crystals; of kinetic phase transitions; of the kinetic coefficient for growth from a melt; of formation of inclusions and dislocations in growing crystals; of surface melting; and of non-equilibrium trapping of impurities by statistical selection.

Between 1992 and 1995, Alex worked half time first at the National Institute of Standards and Technology in the US and then at Tohoku University in Japan, while spending the other half of his time in Moscow. In 1996, Alex moved to the US and was appointed director of the NASA/Universities Space Alliance at the George C. Marshall Space Flight Center in Huntsville, Alabama, where he worked through 2006. During this time, Chernov focused on the development of a quantitative kinetic and thermodynamic framework for the crystallization of biological macromolecules, which at that time was still a largely empirical field. A highlight of Chernov's work at NASA was the introduction of the impurity depleted zone concept, which explains why and when macromolecular crystals growing from a stagnant solution, as in microgravity, might accumulate fewer defects and thus better diffract x-rays.

Since 2006, Alex has been in the Material Science Division of Lawrence Livermore National Laboratory. Among his major results at LLNL are unravelling the nature of defects on the deuterium-tritium crystal layer, which serves as the laser target for nuclear fusion trials; this analysis resulted in a modified strategy of target delivery for fusion experiments at the National Ignition Facility, which, because of many such advances, recently became the first machine on Earth to achieve "break even", that is, releasing more energy from a fusion reaction than is input to trigger it. Alex also developed analytical theories to quantify the formation of suspended particles by chemical reactions in mixing gases, to reconstruct metal deposition in arc discharge experiment mimicking a nuclear explosion, and to understand the shock re-solidification of zirconium.

Alex has published more than 300 scientific papers and given numerous plenary and invited talks at international conferences and institutions. He has published several books, among which *Modern Crystallography III: Crystal Growth* is viewed as the crystal growth bible.

Over the years, Alex's efforts were acknowledged by top international and national awards. Alex received the inaugural Frank Prize of the International Organization for Crystal Growth (1989). He was inducted in the Academy of Sciences of the USSR (1987) and awarded its Special (1966), Fyodorov (1983), and Shubnikov (inaugural, 1996) Prizes. He received the Government Prize of the Russian Federation in Science and Technology (1998). He was elected a foreign member of the Bulgarian Academy of Sciences (2007). Alex served as President (2007 – 2020) and Vice President (1977–1983 and 1989–1991) of the International Organization for Crystal Growth.

In the following pages of this issue, you will find a summary of the state-of-the-art of crystal growth science presented through the prism of Alex Chernov's interests and achievements.

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