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*Brief communication*

# On the Possibility of Programmable Scanning and Y-Modulated EM Detection to Study the Charge Heterogeneity of Uracil Crystals

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## ABSTRACT

This study explores the abiotically driven synthesis of uracil under prebiotic conditions, highlighting its formation from hydrogen cyanide (HCN) oligomers. It reviews alternative mechanisms bypassing traditional decarboxylation pathways, emphasizing the role of photochemical reactions initiated by UV radiation. Despite significant progress, challenges remain regarding the integration of uracil-like intermediates into functional RNA strands. From a systemic chemistry viewpoint, the evolutionary trajectory of RNA components was shaped by environmental pressures and competition among diverse nucleotide alternatives. To elucidate this process further, advanced imaging techniques, specifically Y-modulated detection (YMD), are proposed to map microstructural features and charge topographies of synthesized uracil-based prebiotic materials. Initial results demonstrate the feasibility of this approach, providing critical insights into prebiotic assembly pathways relevant to the origins of life. This paper was presented at the CEM-2025 conference (16-19 June 2025) at the Institute of Microelectronics Technology and High-Purity Materials, Chernogolovka.

**Keywords:** abiotically driven synthesis of uracil; acidic hydrolysis.

Uracil (2,4-dihydroxypyrimidine) is universally recognized as a pyrimidine base characteristic of ribonucleic acids (RNAs) but absent in deoxyribonucleic acids (DNAs). Its abiotic synthesis under prebiotic conditions can proceed from oligomers of hydrogen cyanide (HCN) during acidic hydrolysis, yielding concentrations ranging from 0.001% for 1 M HCN solutions up to 0.005% for 0.1 M solutions[1]. However, without resorting to decarboxylation of orotic acid, uracil can be produced by acidic hydrolysis starting from two distinct precursors. Since the 1970s, following Ferris's seminal works, a photochemical reaction has been identified completing probable prebiotic syntheses of uracil and its derivatives beginning solely with HCN as carbon source. Under ultraviolet irradiation (λ = 254 nm), solutions of orotic acid, orotidine, and orotidine-5'-phosphate produce uracil derivatives (via singlet excited states) within pH ranges of 7 to 8.5[2]. A challenge associated with this photochemical pathway arises because orotidine does not occur naturally in RNA due to severely distorted stereochemistry in base pairing of orotidine-containing oligoribonucleotides[3].

From the perspective of systems chemistry[3], considering coexistence of alternative prebiotic forms of nitrogen bases, sugars, and linkers, selection of modern RNA components (including uracil) occurred throughout chemical evolution out of a precursor library. Their incorporation into the "RNA World" must have preceded phase separation and subsequent elimination from supramolecular systems, colloidal structures, polyelectrolyte complexes, microcrystals, and partially ordered media (soft matter). Consequently, investigating the microstructure and charge topography of synthesized uracil structures/crystals analogous to those formed during prebiotic stages appears essential, given their differing topological and charge characteristics compared to biological counterparts derived either from synthetic pathways in chemical evolution or cellular biosynthesis routes.

To achieve this goal, we propose developing a technique for mapping microstructures and charge distributions capable of detecting inclusion regions by monitoring extreme points of charge density. For this purpose, we suggest utilizing Y-modulated detection (YMD) technology, enabling proportional visualization of peak amplitudes (higher peaks corresponding to higher localized charges). Our previous publications[4,5] demonstrated successful application of YMD in studying charge distribution patterns on RNA crystal lattices and xenonucleic acids. An illustrative example of charge distribution mapping on uracil crystals using YMD Scanning Electron Microscopy (SEM) is presented in **Figure 1**.

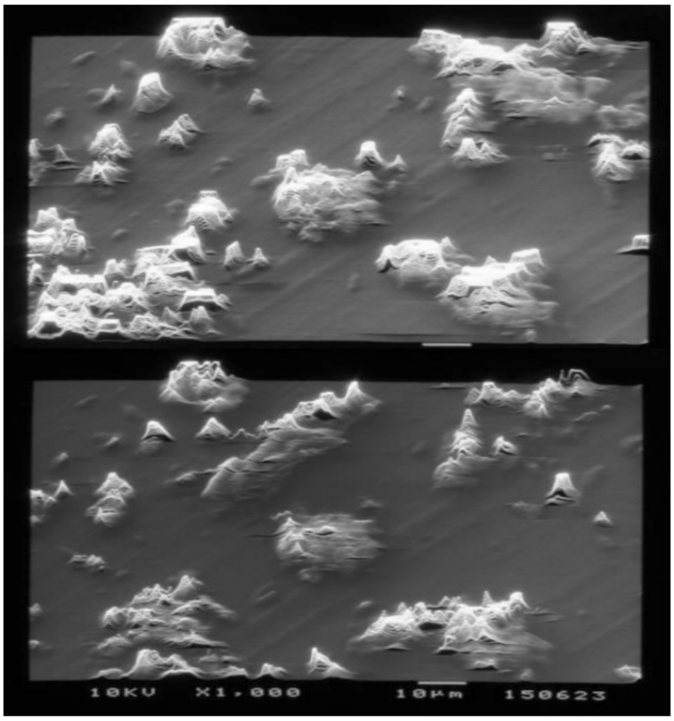


**Figure 1:** Registration of the "charge topography" of uracil crystals using YMD. Charge peaks corresponding to the structural and chemical heterogeneities of the crystals are visible.

## 1. Author Contributions

Aleksandrov P.L. - Automation of the JEOL JSM scanning electron microscope with YMD; 3D fabrication of an adapter for a digital camera. Designing and soldering electronic circuits and connecting cables (2018-2019, 2025-2026).

Filippov M.K. - Restorations of the vacuum systems of the JEOL JSM scanning electron microscope with YMD mode, cleaning of the scanning electron microscope column, design of a new power supply source, replacement of technical oils (2018-2025).

Gradov O.V. - YMD experiment design, instrumentation development and modernization (unfortunately, destroyed now). Conceptualization and writing. Time-resolved SEM and time-resolved SEM-YMD experiments on JEOL JSM-based setups.

Maklakova I.A. - Time-resolved SEM and time-resolved SEM-YMD experiments on JEOL JSM-based setups.

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