

Evaluation of Urea Crystals Grown under High Magnetic Force Fields by Physical Vapor Transport

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Producing high-quality and/or high-performance materials is essential across various fields. Materials processing under external fields, such as magnetic fields, represents one promising approach to address these challenges. In high magnetic fields exceeding approximately 10 T, magnetic field effects, such as magnetic orientation, can be observed even in paramagnetic or diamagnetic materials. The magnetic force acting on such feeble magnetic materials in large magnetic field gradients can be comparable to the gravitational force. When the upward repulsive magnetic force cancels out the downward gravitational force, the material experiences a quasi-microgravity condition. Conversely, if the magnetic force acts in the same direction as gravity, the material can be regarded as being in a hypergravity state. Materials processing under such conditions is attracting attention as a novel technique, as both magnetic field effects and microgravity or hypergravity effects can be simultaneously utilized.

Urea, a transparent diamagnetic organic compound, holds significant promise for nonlinear optical applications. The fabrication of large, optically high-quality crystals is the key to realizing these applications. In our pursuit of high-quality urea crystals, we have demonstrated a physical vapor transport method under high magnetic and magnetic-force fields. To investigate crystal growth, a custom-built transparent glass heater furnace was employed, enabling in-situ observation during heating and cooling. Crystal growth experiments were conducted in magnetic fields of up to 25 T and magnetic force fields of up to $\pm 1750 \text{ T}^2/\text{m}$ using 15-T and 25-T cryogen-free superconducting magnets (CSMs) installed at High Field Laboratory for Superconducting Materials, IMR, Tohoku University. A commercially available test tube (OD: 12 mm) was used as a growth chamber, and the open end was connected to a vacuum pump to reduce pressure. Urea crystallized on a quartz plate placed inside the test tube, which could be removed for subsequent observation. We found that the crystallized position shifted depending on the direction and magnitude of the magnetic force, indicating that the temperature distribution within the furnace influences crystal growth. In fact, differences in magnetic force conditions resulted in variations in crystal size. In this study, we discuss the relationship between magnetic force and the obtained crystals, based on observation using an optical microscope, X-ray pole figure measurement, and polarized light microscopy.