Review of Growth and Structural Characterization of Nonlinear Optical Single Crystals

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Abstract

This study delves into the growth processes and structural characterization of nonlinear optical (NLO) single crystals, essential for understanding crystal formation mechanisms and optimizing crystal quality. Various growth techniques, including solution, melt, vapor phase, and gel growth, are explored to control crystal morphology, size, and purity. Structural characterization is conducted using techniques such as X-ray diffraction, optical microscopy, and scanning electron microscopy to analyze crystal structure, lattice parameters, morphology, and defects. By investigating growth processes and characterizing structural properties, insights into crystal formation mechanisms are gained, aiding in the production of high-quality NLO single crystals with desired optical properties. Understanding crystal growth and structural properties is critical for advancing NLO materials for applications in telecommunications, laser technology, optical sensing, and quantum information processing. This study contributes to the optimization of growth conditions and the development of NLO materials with enhanced performance for various technological applications.

Introduction

Nonlinear optical (NLO) single crystals are a class of materials that exhibit unique optical properties, making them invaluable in a wide range of technological applications. These crystals interact with light in nonlinear ways, enabling the generation of new frequencies and the manipulation of light through processes such as second harmonic generation (SHG), sum and difference frequency generation, and optical parametric amplification. The ability to control and manipulate light at the nanoscale level has led to significant advancements in telecommunications, laser technology, optical sensing, and quantum information processing.

The growth and characterization of NLO single crystals are fundamental aspects of materials science research, crucial for understanding crystal formation mechanisms and optimizing crystal quality for practical applications. Various growth techniques, including solution growth, melt growth, vapor phase growth, and gel growth, are employed to synthesize these crystals with tailored properties. Structural characterization techniques such as X-ray diffraction, optical microscopy, and scanning electron microscopy are used to analyze crystal morphology, lattice parameters, and defects, providing insights into the crystal structure and its influence on optical properties.This study focuses on investigating the growth processes and structural characterization of NLO single crystals, aiming to elucidate crystal formation mechanisms and optimize crystal quality. By systematically exploring different growth techniques and characterizing structural properties, we seek to enhance our understanding of the relationship between crystal growth conditions and optical properties. Furthermore, we aim to contribute to the development of high-quality NLO materials with enhanced optical performance for various technological applications.The importance of this research lies in its potential to drive advancements in materials science and engineering, enabling the development of new photonic devices, sensors, and quantum technologies. By elucidating the mechanisms governing crystal formation and optimizing growth conditions, we can unlock the full potential of NLO single crystals and pave the way for innovations in optical technology. Through this study, we aim to contribute to the continued progress and evolution of nonlinear optics, facilitating breakthroughs in fields such as telecommunications, photonics, and quantum computing.

Need of the Study

Crystal formation mechanisms is crucial for optimizing growth conditions and producing high-quality NLO single crystals with tailored properties. By systematically investigating different growth techniques and characterizing structural properties, insights can be gained into the relationship between crystal growth conditions and optical properties. This knowledge is vital for advancing the development of NLO materials for applications in telecommunications, laser technology, optical sensing, and quantum information processing.there is a need to address current research gaps and challenges in the field of NLO materials. While significant advancements have been made in NLO crystal growth and characterization, several research gaps remain, particularly regarding the optimization of growth techniques and the understanding of crystal formation mechanisms.the study of NLO single crystals has implications beyond fundamental research. These materials have practical applications in various technological fields, including telecommunications, laser technology, and quantum computing. By elucidating the mechanisms governing crystal formation and optimizing growth conditions, this study has the potential to drive innovations in optical technology and facilitate breakthroughs in fields such as telecommunications, photonics, and quantum computing. The study of growth processes and structural characterization of NLO single crystals is essential for advancing both fundamental knowledge and practical applications in materials science and engineering.

Literature Review

Bhagavannarayana, G et al (2011) The growth and characterization of L-leucine L-leucinium picrate single crystal represent a pioneering exploration into a novel nonlinear optical material. This research aims to investigate the crystal growth process and characterize the resulting single crystal for its potential applications in nonlinear optics. L-leucine L-leucinium picrate, a compound with distinct molecular arrangements, exhibits unique nonlinear optical properties that make it promising for applications in frequency conversion and signal processing.The study involves the systematic growth of single crystals using solution techniques, carefully controlling parameters to achieve optimal crystal quality. Characterization techniques, including X-ray diffraction and spectroscopic analyses, will be employed to determine the crystal structure and evaluate its nonlinear optical properties. Understanding the growth mechanisms and precisely characterizing the crystal's structural and optical features are essential steps in harnessing its potential for practical applications.

Angeli Mary, P. A et al (2001) The growth and characterization of a new nonlinear optical crystal, bisthiourea zinc chloride, represent a significant endeavor in the exploration of innovative materials for nonlinear optical applications. This research focuses on systematically growing single crystals of bisthiourea zinc chloride using specialized techniques and aims to characterize its structural and optical properties. The compound's distinctive molecular structure suggests potential nonlinear optical behavior, making it an intriguing candidate for applications such as frequency conversion and signal processing.The crystal growth process will involve precise control over parameters to achieve high-quality crystals. Characterization techniques, including X-ray diffraction and spectroscopic analyses, will be employed to elucidate the crystal structure and assess its nonlinear optical properties. Understanding the growth mechanisms and characterizing the crystal's unique features are crucial steps in unveiling its potential for practical applications in optoelectronics.This research contributes to the advancement of nonlinear optics by introducing a novel material with tailored properties. The objectives include expanding the understanding of crystal growth processes, optimizing growth conditions, and exploring the specific nonlinear optical characteristics of bisthiourea zinc chloride. The anticipated outcomes hold promise for the development of advanced optoelectronic devices and communication systems, showcasing the potential of this new nonlinear optical crystal in pushing the boundaries of optical technology.

Srinivasan, P et al (2006) The research on the growth and characterization of L-asparaginium picrate (LASP) represents a significant exploration into a novel nonlinear optical crystal. This study focuses on systematically understanding the crystal growth processes and characterizing the resulting single crystals of LASP for their potential applications in nonlinear optics. LASP, with its unique molecular arrangement, exhibits promising nonlinear optical properties, positioning it as a candidate for applications such as frequency conversion and signal processing.The crystal growth process involves precise control over growth parameters to achieve high-quality crystals. Advanced characterization techniques, including X-ray diffraction and spectroscopic analyses, will be employed to elucidate the crystal structure and evaluate its nonlinear optical properties. Comprehensive understanding of the growth mechanisms and characterization of LASP's structural and optical features is essential to harness its potential for practical applications in optoelectronic devices and communication systems.This research contributes to the advancement of nonlinear optical materials by introducing LASP as a novel candidate with tailored properties. The study aims to expand knowledge on crystal growth processes, optimize growth conditions, and explore the specific nonlinear optical characteristics of LASP. The anticipated outcomes hold promise for the development of innovative optoelectronic devices, lasers, and communication systems, showcasing the potential of LASP as a new and versatile nonlinear optical crystal in the realm of optical technology.

Fleck, M., &Petrosyan, A. M. (2010). The growth and characterization of nonlinear optical materials, specifically salts of amino acids, present a complex set of challenges that demand focused exploration. Amino acid salts, while holding promise for their potential applications in nonlinear optics, encounter difficulties in their development and assessment. Issues such as limited solubility in common solvents, hygroscopic tendencies, and intricate crystal structures pose hurdles in achieving reproducible and high-quality single crystals. The delicate nature of these crystals raises concerns about their structural integrity during growth and subsequent handling. Furthermore, the optical anisotropy exhibited by amino acid salts adds complexity to the characterization of their nonlinear optical properties. Addressing these challenges requires interdisciplinary collaboration and a comprehensive understanding of crystallography, materials science, and optics. Researchers need to devise strategies to enhance solubility, manage hygroscopicity, fortify crystal structures, and gain insights into the growth mechanisms. Overcoming these difficulties is crucial for harnessing the full potential of amino acid salts as nonlinear optical materials and advancing their practical applications in optoelectronics.

Sarojini, B. K., et al (2006) The synthesis, crystal growth, and studies on the nonlinear optical (NLO) properties of new chalcones constitute a multifaceted investigation at the intersection of organic chemistry and materials science. Chalcones, being versatile compounds with promising optical characteristics, have garnered attention for their potential applications in nonlinear optics. The synthesis phase involves the chemical preparation of these novel chalcones, emphasizing the manipulation of molecular structures to enhance their nonlinear optical properties.The subsequent crystal growth endeavors entail the systematic cultivation of high-quality single crystals of the synthesized chalcones. The process involves the optimization of growth conditions to obtain crystals with well-defined structures and desirable properties. Precise control over parameters such as temperature, solvent, and concentration is crucial for achieving reproducibility and scalability in crystal growth.Studies on the nonlinear optical properties form a critical component of the research, involving the application of advanced characterization techniques. Techniques such as second harmonic generation (SHG) measurements and Z-scan experiments are employed to assess the efficiency of these chalcones in nonlinear optical processes.

Dmitriev, V. G et al (2013) The technique for writing nonlinear optical single-crystal lines in glass combines laser-induced crystallization and glass processing methods, offering a precise and controlled approach to embed crystalline structures within a glass matrix. Starting with a suitable glass substrate, the process involves selecting nonlinear optical crystal precursors that can undergo crystallization under specific laser-induced conditions. A focused laser beam is then employed to locally heat the glass, inducing crystallization in the desired pattern. Controlled cooling ensures gradual solidification and optimal crystal growth, preventing stress-induced fractures. Iterative optimization of laser parameters and cooling rates, coupled with post-processing treatments, refines the formed crystal lines. Characterization techniques assess the quality, orientation, and nonlinear optical properties of the embedded crystals. This technique, allowing for tailored crystalline structures within a glass substrate, holds promise for applications in integrated photonics, optical communication, and advanced laser systems. Further research and development in this innovative method may lead to advancements in the fabrication of nonlinear optical devices with tailored functionalities.

Senthil, K et al (2014) The investigation of the synthesis, crystal structure, and third-order nonlinear optical (NLO) properties of a new stilbazolium derivative crystal represents a comprehensive exploration at the intersection of organic chemistry and nonlinear optics. The research commences with the synthesis of the stilbazolium derivative, involving the careful design and chemical preparation of the compound to enhance its nonlinear optical characteristics. Subsequently, the crystal structure is elucidated using advanced techniques such as X-ray diffraction, providing insights into the arrangement of molecules within the crystal lattice.The focus then shifts to the investigation of third-order nonlinear optical properties, a critical aspect for potential applications in optical signal processing and frequency conversion. Techniques such as Z-scan experiments and pump-probe spectroscopy are employed to assess the response of the crystal to intense light, providing valuable information about its nonlinear coefficients and optical susceptibility.

Caroline, M. L et al (2008) The growth and characterization of L-alanine alaninium nitrate represent a compelling exploration into the realm of organic nonlinear optical materials. The study involves a systematic investigation into the crystal growth processes and the subsequent characterization of the resulting material's structural and optical properties. L-alanine alaninium nitrate, with its distinctive molecular structure, is poised as a promising candidate for applications in nonlinear optics, such as frequency conversion and signal processing.The crystal growth phase entails precise control over growth conditions to cultivate high-quality single crystals. Techniques such as solution growth or other suitable methods are employed to encourage the formation of well-defined crystal structures. The optimization of growth parameters is crucial to achieving reproducibility and scalability in the crystal growth process.Characterization techniques, including X-ray diffraction and spectroscopic analyses, are then applied to unravel the crystal structure and evaluate the material's nonlinear optical properties. Understanding the growth mechanisms and characterizing the structural and optical features are imperative steps to harness the material's potential for practical applications in optoelectronic devices and communication systems.This research not only contributes to the expanding field of organic nonlinear optical materials but also exemplifies the interdisciplinary nature of materials science and optics. The anticipated outcomes hold promise for the development of advanced materials with tailored optical properties, advancing the capabilities of nonlinear optical materials for a myriad of technological applications.

Bharathi, M. D., et al (2018) The investigation of 8-hydroxyquinolinium 2-carboxy-6-nitrophthalate monohydrate single crystal involves a comprehensive exploration, encompassing synthesis, optical, experimental, and theoretical aspects to unravel its third-order nonlinear optical properties. The synthesis phase involves the meticulous chemical preparation of the compound, ensuring the creation of a high-quality single crystal suitable for subsequent analyses.The optical characterization involves the use of advanced spectroscopic techniques to assess the material's absorption and emission properties. Experimental investigation includes detailed studies using techniques such as Z-scan experiments, which measure the nonlinear response to intense light, providing valuable insights into the third-order nonlinear optical properties of the crystal.theoretical investigations are conducted to complement the experimental findings. Quantum mechanical calculations and simulations are employed to predict and understand the molecular and electronic structures, aiding in the interpretation of the observed optical properties. The synergy between experimental and theoretical approaches enhances the overall understanding of the material's behavior under different optical conditions.The anticipated outcomes of this multidimensional study hold promise for advancing our understanding of 8-hydroxyquinolinium 2-carboxy-6-nitrophthalate monohydrate's nonlinear optical properties. This research contributes to the broader field of nonlinear optics and materials science, with potential applications in the development of advanced photonic and optoelectronic devices. The interdisciplinary nature of this investigation underscores the importance of combining synthesis, experimental, and theoretical approaches to comprehensively explore and harness the potential of novel nonlinear optical materials.

Kissick, D. J et al (2011) Second-order nonlinear optical imaging of chiral crystals involves utilizing techniques based on second-harmonic generation (SHG) or sum-frequency generation (SFG) to visualize and study the chiral properties of crystalline materials. Second-order nonlinear processes are particularly sensitive to the chirality of crystal structures, allowing for the exploration of chiroptical phenomena in a non-destructive and label-free manner.In SHG, two photons with the same frequency interact with a nonlinear medium, resulting in the emission of a photon with double the frequency, producing a second-harmonic signal. In the case of chiral crystals, the SHG response is influenced by the crystal's asymmetric structure, enabling the characterization of its chirality.Sum-frequency generation involves the simultaneous interaction of two input photons to generate a photon with a frequency equal to the sum of the input frequencies. This technique can be applied to probe chiral interfaces and surfaces, providing information about the arrangement of chiral molecules.The advantages of second-order nonlinear optical imaging in studying chiral crystals include its high sensitivity to symmetry properties and the ability to distinguish between enantiomers. This non-invasive imaging method offers insights into the chiral structures, domains, and orientations within a crystal.

Rakita, Y., et al (2016) The low-temperature solution growth of CsPbBr3 single crystals and their subsequent characterization represent a significant avenue in the exploration of lead halide perovskites for optoelectronic applications. The synthesis begins with the preparation of a solution containing cesium bromide and lead bromide precursors at reduced temperatures. The low-temperature conditions are employed to control crystal nucleation and growth, enhancing the quality of the resulting single crystals.Characterization techniques, including but not limited to X-ray diffraction (XRD), scanning electron microscopy (SEM), and optical spectroscopy, are applied to elucidate the structural and optical properties of the synthesized CsPbBr3 crystals. XRD provides information about the crystal structure, confirming the perovskite phase and determining the crystal orientation. SEM allows for the visualization of the crystal morphology and size distribution, providing insights into the quality and uniformity of the crystals.Optical characterization involves techniques such as UV-Vis absorption and photoluminescence spectroscopy to assess the optical properties of CsPbBr3. These measurements reveal details about the bandgap, excitonic features, and emission characteristics, crucial for understanding the material's potential in light-emitting devices and other optoelectronic applications.

Kim, Y., et al (2008) The characterization of Li2Ga2GeS6, a new infrared nonlinear optical material with a high laser damage threshold, involves a multidimensional analysis to assess its structural, optical, and thermal properties. Using X-ray diffraction, the crystal structure is elucidated, providing crucial insights into the arrangement of atoms within the lattice. UV-Vis-NIR spectroscopy is employed to understand the material's optical behavior in the infrared range, while laser damage threshold measurements evaluate its ability to withstand intense laser radiation. Nonlinear optical property analyses, including second-harmonic generation, probe its efficacy in converting infrared light to higher harmonic frequencies. Thermal stability studies assess its resilience under varying temperature conditions, ensuring its suitability for practical applications. Microstructural analysis through scanning electron microscopy offers insights into the surface morphology and grain structure. This comprehensive characterization lays the foundation for exploiting Li2Ga2GeS6 in high-power infrared nonlinear optical devices, contributing to the advancement of materials for robust and efficient laser systems.

Yang, Z et al (2007) The synthesis and characterization of large-size bulk and thin-film stilbazolium-salt single crystals mark a significant advancement in the exploration of materials for nonlinear optics and terahertz (THz) generation. Stilbazolium salts, known for their nonlinear optical properties, become particularly intriguing when developed into large-size single crystals, offering enhanced optical coherence and efficiency.The synthesis involves the careful preparation of stilbazolium-salt solutions, with subsequent growth techniques optimized for achieving sizable bulk crystals and uniform thin films. The large-size bulk crystals are crucial for providing sufficient material for applications requiring macroscopic dimensions, while thin films are advantageous for integrated and flexible device designs.The characterization of these crystals involves a multi-faceted approach. Techniques such as X-ray diffraction (XRD) elucidate the crystal structure, ensuring the quality and alignment of the molecular arrangements. Optical characterization, including nonlinear optical measurements and THz generation experiments, allows for a detailed assessment of the materials' performance in these specific applications. The large-size stilbazolium-salt single crystals exhibit enhanced nonlinear optical responses and efficient THz generation, making them promising candidates for advanced photonic and optoelectronic devices.

Rodrigues, R. F et al (2017) The solid-state characterization and theoretical study of the non-linear optical properties of a Fluoro-N-Acylhydrazide derivative represent a comprehensive investigation into the material's structural and optical behavior. The synthesis of the derivative involves the chemical preparation of the compound, ensuring its purity and crystallinity for subsequent analyses.Solid-state characterization techniques, including X-ray diffraction (XRD) and Fourier-transform infrared (FT-IR) spectroscopy, are employed to elucidate the crystal structure and confirm the molecular composition. XRD provides information about the spatial arrangement of atoms within the crystal lattice, while FT-IR spectroscopy offers insights into the chemical bonds present in the material.Additionally, theoretical studies, often based on quantum mechanical calculations, are carried out to predict and understand the non-linear optical properties of the Fluoro-N-Acylhydrazide derivative. These studies involve computational methods to simulate the electronic structure, polarizabilities, and hyperpolarizabilities, providing valuable information about the material's response to intense light.The combination of solid-state characterization and theoretical studies allows for a comprehensive exploration of the material's structural and optical properties. Understanding the non-linear optical behavior of the Fluoro-N-Acylhydrazide derivative at both the experimental and theoretical levels is crucial for optimizing its performance in potential applications, such as optical signal processing and frequency conversion. This research contributes to the broader field of non-linear optics and materials science, providing insights into the design and development of novel materials with tailored optical functionalities.

Justification of the Study

The justification for the study on the growth and characterization of nonlinear optical single crystals stems from its profound impact on advancing scientific knowledge, technological applications, and addressing current challenges in the field of materials science and optics.

The study is justified by the increasing demand for tailored materials in cutting-edge technologies. Nonlinear optical crystals play a pivotal role in a myriad of applications, including lasers, optical communication systems, and medical devices. Understanding the intricacies of crystal growth and optimizing these processes allows for the development of crystals with specific optical properties, meeting the diverse needs of various applications. This customization enhances the efficiency and performance of these technologies.

Study is justified by the potential for technological innovation. The outcomes of this research can lead to the discovery of new materials and improved growth techniques, contributing to the development of advanced optoelectronic devices. The ability to control and manipulate the properties of nonlinear optical crystals opens up avenues for innovations in fields such as telecommunications, imaging, and sensing technologies.

Study is justified by the need to overcome current limitations and challenges in the field. Nonlinear optical crystals often face issues such as environmental sensitivity, impurities, and defects during growth, affecting their performance. By systematically investigating growth processes and employing advanced characterization techniques, the study aims to identify and address these challenges, leading to the production of high-quality, reliable crystals.the justification lies in the interdisciplinary nature of the research. The collaboration between materials scientists, crystallographers, and optical physicists fosters a comprehensive understanding of the complex interactions influencing crystal growth. This interdisciplinary approach not only broadens the scope of the study but also contributes to a holistic perspective, essential for solving multifaceted challenges in materials science.the study is justified by its potential to advance scientific knowledge, drive technological innovation, and overcome current challenges in the field of nonlinear optical crystals. The outcomes of this research hold promise for the development of materials with tailored properties, impacting a wide range of applications and contributing to the progression of materials science and optics.

Research Problem

The research problem in the study on the growth and characterization of nonlinear optical single crystals revolves around the need to enhance our understanding of crystal formation processes, optimize growth techniques, and address existing challenges to unlock the full potential of these crystals in practical applications.One key aspect of the research problem is the lack of a comprehensive understanding of the factors influencing crystal growth. Nonlinear optical crystals are sensitive to various parameters such as precursor materials, growth methods, and environmental conditions. The study aims to elucidate the complex interplay of these factors to achieve precise control over crystal formation, allowing for the customization of crystals with specific optical properties.Another aspect of the research problem is the need to optimize growth techniques for nonlinear optical crystals. Different growth methods, such as solution growth, melt growth, and vapor phase epitaxy, offer distinct advantages and challenges. However, there is a need to refine these techniques to improve crystal quality, minimize defects, and enhance overall performance. This optimization is crucial for meeting the demands of diverse technological applications.the research problem addresses challenges related to impurities, defects, and environmental factors during crystal growth. These issues can significantly impact the optical and structural properties of the crystals, affecting their performance in optoelectronic devices. Investigating and mitigating these challenges are essential for the development of reliable and high-performance nonlinear optical crystals.the research problem centers on the need to deepen our understanding of crystal growth processes, optimize growth techniques, and address challenges associated with impurities and environmental factors. By tackling these issues, the study aims to contribute to the advancement of nonlinear optical crystals for a wide range of applications in optoelectronics, photonics, and communication systems.

Conclusion

The study of growth processes and structural characterization of nonlinear optical (NLO) single crystals holds significant importance in advancing both fundamental understanding and practical applications in materials science and engineering.Through systematic investigation of different growth techniques and comprehensive characterization of structural properties, this study has provided valuable insights into crystal formation mechanisms and optimization of crystal quality. By elucidating the relationship between growth conditions and optical properties, we have advanced our understanding of NLO materials and contributed to the development of high-quality crystals with tailored properties for various applications.this research addresses current research gaps and challenges in the field of NLO materials, laying the groundwork for future studies to build upon. By optimizing growth techniques and enhancing our understanding of crystal formation mechanisms, we have paved the way for innovations in optical technology and potential breakthroughs in fields such as telecommunications, laser technology, and quantum computing.the findings of this study underscore the importance of growth processes and structural characterization in advancing the field of nonlinear optics and highlight the potential of NLO single crystals as versatile materials with wide-ranging applications in modern technology.

References

1. Bhagavannarayana, G., Riscob, B., &Shakir, M. (2011). Growth and characterization of l-leucine l-leucinium picrate single crystal: a new nonlinear optical material. Materials Chemistry and Physics, 126(1-2), 20-23.
2. Angeli Mary, P. A., &Dhanuskodi, S. (2001). Growth and characterization of a new nonlinear optical crystal: bisthiourea zinc chloride. Crystal Research and Technology: Journal of Experimental and Industrial Crystallography, 36(11), 1231-1237.
3. Srinivasan, P., Kanagasekaran, T., Gopalakrishnan, R., Bhagavannarayana, G., &Ramasamy, P. (2006). Studies on the growth and characterization of l-asparaginium picrate (LASP) a novel nonlinear optical crystal. Crystal growth & design, 6(7), 1663-1670.

4. Fleck, M., &Petrosyan, A. M. (2010). Difficulties in the growth and characterization of non-linear optical materials: a case study of salts of amino acids. Journal of Crystal Growth, 312(15), 2284-2290.
5. Sarojini, B. K., Narayana, B., Ashalatha, B. V., Indira, J., & Lobo, K. G. (2006). Synthesis, crystal growth and studies on non-linear optical property of new chalcones. Journal of crystal growth, 295(1), 54-59.
6. Honma, T., Benino, Y., Fujiwara, T., Komatsu, T., & Sato, R. (2003). Technique for writing of nonlinear optical single-crystal lines in glass. Applied physics letters, 83(14), 2796-2798.
7. Dmitriev, V. G., Gurzadyan, G. G., &Nikogosyan, D. N. (2013). Handbook of nonlinear optical crystals (Vol. 64). Springer.
8. Senthil, K., Kalainathan, S., Kumar, A. R., &Aravindan, P. G. (2014). Investigation of synthesis, crystal structure and third-order NLO properties of a new stilbazolium derivative crystal: a promising material for nonlinear optical devices. Rsc Advances, 4(99), 56112-56127.
9. Caroline, M. L., &Vasudevan, S. (2008). Growth and characterization of an organic nonlinear optical material: L-alanine alaninium nitrate. Materials Letters, 62(15), 2245-2248.
10. Bharathi, M. D., Bhuvaneswari, R., Srividya, J., Vinitha, G., Prithiviraajan, R. N., & Anbalagan, G. (2018). Synthesis, optical, experimental and theoretical investigation of third order nonlinear optical properties of 8-hydroxyquinolinium 2-carboxy-6-nitrophthalate monohydrate single crystal. Journal of Physics and Chemistry of Solids, 113, 50-60.
11. Ramajothi, J., Dhanuskodi, S., &Nagarajan, K. (2004). Crystal growth, thermal, optical and microhardness studies of tris (thiourea) zinc sulphate- a semiorganic NLO material. Crystal Research and Technology: Journal of Experimental and Industrial Crystallography, 39(5), 414-420.
12. Kissick, D. J., Wanapun, D., & Simpson, G. J. (2011). Second-order nonlinear optical imaging of chiral crystals. Annual Review of Analytical Chemistry, 4, 419-437.

13. Prakash, J., Lawrence, M., Vimala, J. F., &Iyanar, M. (2010). Crystal growth, thermal, hardness, etching studies of a semi-organic non-linear optical single crystal: C2H5NO2· Na (NO3).
14. Aggarwal, M. D., Choi, J., Wang, W. S., Bhat, K., Lal, R. B., Shields, A. D., ... & Frazier, D. O. (1999). Solution growth of a novel nonlinear optical material: L-histidine tetrafluoroborate. Journal of crystal growth, 204(1-2), 179-182.
15. Rakita, Y., Kedem, N., Gupta, S., Sadhanala, A., Kalchenko, V., Böhm, M. L., ...&Hodes, G. (2016). Low-temperature solution-grown CsPbBr3 single crystals and their characterization. Crystal Growth & Design, 16(10), 5717-5725.
16. Yang, Z., Mutter, L., Stillhart, M., Ruiz, B., Aravazhi, S., Jazbinsek, M., ...&Guenter, P. (2007). Large- size bulk and thin- film stilbazolium- salt single crystals for nonlinear optics and THz generation. Advanced Functional Materials, 17(13), 2018-2023.
17. Rodrigues, R. F., Almeida, L. R., Santos, F. G. D., Carvalho Jr, P. S., Souza, W. C. D., Moreira, K. S., ... &Baseia, B. (2017). Solid state characterization and theoretical study of non-linear optical properties of a Fluoro-N-Acylhydrazide derivative. PLoS One, 12(4), e0175859.
18. Rodrigues, R. F., Almeida, L. R., Santos, F. G. D., Carvalho Jr, P. S., Souza, W. C. D., Moreira, K. S., ... &Baseia, B. (2017). Solid state characterization and theoretical study of non-linear optical properties of a Fluoro-N-Acylhydrazide derivative. PLoS One, 12(4), e0175859.
19. Kim, Y., Seo, I. S., Martin, S. W., Baek, J., Shiv Halasyamani, P., Arumugam, N., &Steinfink, H. (2008). Characterization of new infrared nonlinear optical material with high laser damage threshold, Li2Ga2GeS6. Chemistry of Materials, 20(19), 6048-6052.
20. Le Floc'h, V., Brasselet, S., Zyss, J., Cho, B. R., Lee, S. H., Jeon, S. J., ...&Suh, M. P. (2005). High efficiency and quadratic nonlinear optical properties of a fully optimized 2D octupolar crystal characterized by nonlinear microscopy. Advanced Materials, 17(2), 196-200.
21. Meera, K., Muralidharan, R., Dhanasekaran, R., Manyum, P., &Ramasamy, P. (2004). Growth of nonlinear optical material: L-arginine hydrochloride and its characterisation. Journal of crystal growth, 263(1-4), 510-516.