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Ternary Elements In Nanotechnology

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Summary

The research performs a comprehensive review of the literature on ternary elements in nanotechnology, contextualizing the current scenario of scientific advances in this field. The general objective is to deepen the understanding of the properties, synthesis methods and applications of these nanostructured systems. The adopted methodology consists of a literature review, exploring sources in the SCIELO, Google Scholar and CAPES databases over the last 10 years, both in Portuguese and English. The analysis of the results obtained seeks to identify trends, significant advances and gaps in knowledge, contributing to the current state of knowledge on ternary elements in nanotechnology.

***Keywords**: Nanotechnology. Ternary elements. Nanostructured properties. Synthesis of nanomaterials.*

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I. Introduction

Nanotechnology, a multidisciplinary field in constant expansion, has triggered remarkable advances in science and technology, with applications ranging from electronics to medicine. Within this fascinating scenario, an area of growing interest emerges: the investigation of "Ternary Elements in Nanotechnology". Understanding and manipulating systems composed of three distinct elements at the nanometric scale presents unique challenges and opportunities, promising to unveil new frontiers for innovative applications (MARTINS, TRINDADE, 2012).

According to Kumar, Rajni and Prasad (2023) Nanotechnology, in broad terms, refers to devices with dimensions in the range of 1 to 100 nm, while nanofabrication involves the manipulation of matter at the nanoscopic scale to create structures and patterns with specific function that enable nanotechnology.

The manipulation of nanoscale structures through nanoscience and nanotechnology has received increasing attention, driven by the potential positive impact on social and environmental sectors . These disciplines are expected to play a key role in an industrial revolution, driving global economic growth. The large investments in research and development, notably by the United States, Japan, China and South Korea, highlight the global importance of these areas, while Brazil actively contributes through the National Program for Development in Nanoscience and Nanotechnology (FERREIRA, 2019; ZANONI, 2019; OZIN et al, 2009).

The anticipated benefits range from the acceleration of chemical and physical reactions to the advanced integration of molecular electronics with silicon technology. Despite the notable increase in scientific dissemination, some challenges persist, demanding strategic partnerships between the academic and industrial sectors. Nanotechnology not only seeks innovations, but also aims to generate products and market opportunities, with the potential to transform established industries. Global collaboration between industry, academia and government institutions becomes crucial to accelerate the development of new products, while at the same time a review of business models is necessary, considering the high added value of nanomaterials and the search for reduced environmental impact. This evolution promises more sustainable processes, improved energy efficiency and the possible adoption of renewable sources, aligning with a perspective of sustainable development (ZANONI, 2019 ; FERREIRA, RANGEL, 2009).

Nanotechnology, characterized by the precise control of matter at nanometric dimensions, offers a unique stage to explore extraordinary properties of materials. When focusing on ternary systems, we refer to compositions that involve three fundamental components. This approach gains relevance when considering that the inclusion of a third element can drastically alter the physical and chemical properties of nanostructured materials, providing new possibilities for the design of devices and applications.

The primary objective of this research is to conduct a literature review on ternary elements in nanotechnology, aiming to deepen the understanding of the properties, synthesis and applications of these nanostructured systems. The specific objectives of the research are: To investigate the specific physical and chemical properties associated with ternary systems in nanotechnology, analyzing how the inclusion of a third element impacts the nanostructured characteristics; to review the methodologies for synthesis and fabrication of ternary elements at the nanometric scale, evaluating the advances and challenges associated with these processes; and to explore the potential applications of ternary elements in nanotechnology in different fields, highlighting significant contributions to electronics, medicine, energy or other relevant areas.

Given the diversity of definitions and interpretations in the literature on ternary elements in nanotechnology, the central problem of this research lies in the lack of a consolidated understanding of the characteristics, synthesis methods and applications of these systems. As a result, the lack of consensus hinders the effective implementation of these innovative materials in practical applications.

Thus, this literature review seeks to fill this gap, providing an integrated view of recent advances and persistent challenges in research on ternary elements in nanotechnology.

II. Methodology

This research adopted a methodological approach based on bibliographic review to investigate the panorama of scientific advances in the last 10 years, prioritizing the SCIELO, Google Scholar and CAPES databases. The selection of these databases aims to cover a broad spectrum of sources, including scientific journals, dissertations and academic theses.

The keywords used in the search covered the key terms related to the scope of the research. In the context of nanotechnology, terms such as "nanomaterials", "nanofibers", "self-organization", "nanometric catalysis" and "tertiary elements" were included. The careful selection of keywords aimed to optimize the relevance of the results. The search used inclusion criteria and considered articles, dissertations and theses published in the last 10 years, published in Portuguese or English and that presented significant contributions to the understanding of the topic.

Studies that were published within the 10-year time frame, that did not fit into the predetermined languages or that did not directly contribute to the research objectives, ensuring focus on the scope of nanotechnology, were excluded from the research. Incomplete research and research that was not fully available on the internet were also excluded. Document selection followed a two-stage approach. In the first stage, titles and abstracts were assessed according to the inclusion and exclusion criteria. In the second stage, the full texts of the documents selected in the previous stage were reviewed to ensure consistency and relevance.

III. Results And Discussion

After investigation, some works were selected for discussion according to pre-determined criteria. The table below presents a summary of the selection.

Author/Year	Methodology	Objective	Conclusions
Alves, O. L., et al. (2002)	THE	Review the main foundations and applications of the Metalorganic Precursor Decomposition technique, *MOD* , in obtaining thin films involving multicomponent, multilayer systems and doped materials, mainly in the last ten years.	The technique has grown significantly, mainly due to the good results regarding the preparation of multicomponent oxide systems with compositional, structural and morphological control, in a relatively simple way. This has opened new opportunities for obtaining materials with well-defined electrical and optical properties.
Ariga, Katsuhiko, et al. (2019)	Literature review	Study the fundamentals and most relevant applications of the Metallo-Organic Decomposition (MOD) technique, mainly within the last decade.	Collaboration between biology and chemistry using self-assembly-based nanoarchitecture can achieve advanced goals, with chemical modification offering molecular engineering strategies for biology. This process is conceptually related to the rapid advancement of spatiotemporal nanoarchitecture in advanced sciences and technologies.
Amanda Ventura (2017)	Literature review	Review the main foundations and applications of the Metalorganic Precursor	In MOD, reaction control is not usually an obstacle, as is the case with the sol-gel process, in which the absence of reaction control can generate compounds

		Decomposition, MOD, technique in obtaining thin films involving multicomponent, multilayer systems and doped materials.	whose structures and properties are not reproducible. Furthermore, there are still many systems of scientific and technological interest for which the MOD technique has not been considered, thus opening up a vast field for basic and applied research.
Faraz, T, et al. (2017)	Applied research	Development of a novel plasma enhanced atomic layer deposition (PEALD) process for SiNx using a mono-aminosilane precursor, di(sec-butylamino)silane (DSBAS, SiH3N(sBu)2) and N2 plasma.	Corrosion resistant material using di(sec-butylamino) silane and N2 plasma
Ferreira, H.S., Rangel, M.C. (2009)	Literature review	Study of the potential for application in catalysis	MOD has been used with satisfactory results to obtain various types of materials in the form of thin films with controlled stoichiometry. Such films can be deposited using different techniques (*dip coating, spin coating,* etc.). By modulating the heat treatment, type of precursor and other process variables, the desired structure can be achieved.
Figueiras, ARR, Coimbra, AB, & Veiga, FJB (2014)	Literature review	Studies of Applications and Perspectives in Health	Recently, the study and application of nanoparticles have provided a great contribution to clinical practice, mainly in the areas of medical imaging and controlled drug release.
Jeevanandam, J, et al. (2018)	Nanotechnology Review	Applications in nanoscience	Exploration of applications in nanoscience, emphasizing Beilstein J. Nanotechnol. [
Jin, Rongchao (2012)	Impacts of nanotechnology on catalysis by precious metal nanoparticles	Revision	Analysis of the impacts of nanotechnology on catalysis.
Kumar, Sahu Mahendra, et al. (2023)	Recent advances in nanotechnology	Revision	Highlights recent advances in nanotechnology.
Kung, Harold H., Kung, Mayfair C. (2004)	Nanotechnology Review	Applications and potentials in heterogeneous catalysis	Exploration of the applications and potential of nanotechnology in heterogeneous catalysis.
Lima, Érica KA de, et al. (2022)	Literature review	Applications such as bioceramics	It is noted that HA is of great interest for technological innovations, bringing advances in bioengineering and improving existing applications.
Lombardo D, et al. (2020)	Self-assembly of nanomaterials and biomaterials	Bottom-up approach for formation of functional nanostructures	Discussion on self-assembly for formation of nanostructures.
Lucero, A. T., & Kim, J. (2018)	Literature review	Brief review of precursor chemistry	Concise review of precursor chemistry for ALD of silicon nitride.
Martins, M. A., Trindade, T. (2012)	Literature review	Discuss fundamental concepts related to the synthesis and properties of inorganic nanoparticles with diverse properties.	The development of new nanomaterials, such as supramolecular and composite hybrid structures, is also a current topic in which functionalized NPs are understood by chemists as a new class of reagents. In this regard, it is worth mentioning the recent - revisiting of the Periodic Table in which aggregates (*clusters*) appear as new chemical structural units in the development of new materials.
Mercante, L.A., et al. (2021)	Electrospun nanofibers	Advances in the last decade	Review on advances in electrospun nanofibers and their applications [16].
Oliveira, I.M., et al. (2020)	Self-assembly of metal nanoparticles	Process for developing new materials	Exploration of self-assembly of metallic nanoparticles and its role in the development of new materials [.
Pinto, Tarciane da Silva (2023)	Preparation and characterization of carbon dots	Applications as sensors for metal ions	Research on the preparation and characterization of carbon dots and their applications as sensors [20].
Santos, CIL, et al. (2020)	Synthesis and characterization of quantum dots	Controlled release of bee repellent pheromones	Synthesis of mesoporous silica nanoparticles for controlled release of bee repellent pheromones [21].

Shah, Syed Shaheen, et al. (2021)	Review on Jute in Nanotechnology	Current status and future prospects	Assessment of current status and future prospects of jute in nanotechnology [22].
Yadav, S., Sharma, A.K., Kumar P. (2020)	Self-assembly at the nanoscale	Therapeutic delivery	Discussion on nanoscale self-assembly for therapeutic delivery [23].
Zanoni, E. T., et al. (2019)	Synthesis and evaluation of mesoporous silica nanoparticles	Controlled release of bee repellent pheromones	Synthesis of mesoporous silica nanoparticles for controlled release of bee repellent pheromones [24].

IV. Properties Of Ternary Elements In Nanotechnology

In this topic, we will explore the specific physical and chemical properties associated with ternary systems in nanotechnology, and discuss how the addition of a third element can influence fundamental characteristics such as electrical conductivity, mechanical strength, thermal stability, and other relevant properties. Analyzing these properties will be essential to understanding the potential impact of ternary elements in various applications.

For Cremonezzi (2017), the properties of ternary elements in nanotechnology play a crucial role in determining the unique characteristics and behaviors of these materials at the nanometric scale. The addition of a third element to a binary structure can result in significant changes in several physical and chemical properties. An essential aspect is the modulation of electronic properties, where the presence of the third element can directly influence electrical conductivity and energy bands, opening up new possibilities for applications in advanced electronic devices. In addition, mechanical properties, such as strength and ductility, can be drastically affected by the introduction of a third element, promoting greater versatility in applications that demand materials with specific strength characteristics.

Another notable property is the thermal response of the nanostructured ternary elements. The presence of the third element can significantly influence the thermal stability of the material, enabling its use in high-temperature environments or as key components in thermoelectric devices. In addition, optical properties, such as light absorption and emission, can be tuned by the ternary combination, providing innovative opportunities in areas such as optical sensors and nanomaterials for solar energy applications (LIMA et al., 2022, SANTOS 2020).

In this context, Pedrosa (2007) emphasizes that the introduction of a third element into a nanostructured structure can substantially alter the thermal conductivity of the material. Depending on the nature of this third element, the material may exhibit greater resistance to heat flow or, alternatively, improved thermal conductivity. This ability to adjust thermal properties is essential, for example, in advanced electronic devices, where efficient heat dissipation is crucial for performance and durability.

Furthermore, Santos (2020) explains that the thermal response of nanostructured ternary elements is particularly relevant in applications involving high-temperature environments. Materials capable of maintaining their structural integrity and functionality under extreme thermal conditions are valuable for sectors such as aerospace, automotive, and energy. Nanotechnology provides a unique platform for designing and developing ternary materials that resist these adverse conditions, expanding the possibilities for application in hostile environments.

A thorough understanding of these properties is essential to guide the controlled manipulation of ternary elements in nanotechnology, aiming to optimize their performance in different application contexts. The exploration of these specific properties will allow the development of tailored nanostructured materials, aligning with the growing demands for innovations in various industries and research areas. (JEEVANANDAM et al, 2018).

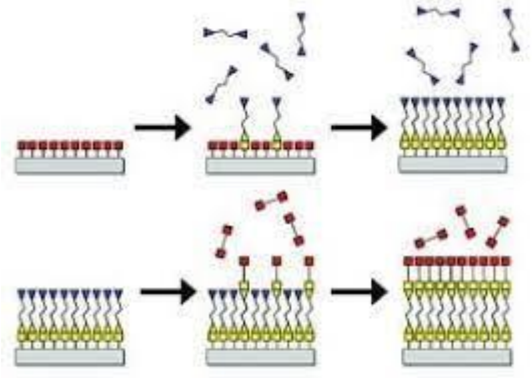
V. Methods Of Synthesis And Manufacture Of Nanostructured Ternary Elements

This topic will address the methodologies for synthesis and fabrication of ternary elements on the manometric scale, as well as chemical vapor deposition (CVD) techniques, synthesis by sol-gel methods, self-assay approaches, among others. A critical review of these methods will allow an in-depth understanding of the challenges and advances in the controlled production of nanostructured ternary materials.

The synthesis and fabrication of nanostructured ternary elements constitute a critical step in the development of materials with optimized properties for various applications in nanotechnology. Several methods are employed for the controlled production of these materials, aiming to obtain specific nanostructures that exploit their unique properties.

One of the most common methods is chemical vapor deposition (CVD), a process in which chemical precursors are introduced into a controlled atmosphere as shown in the figure **Error! Reference source not found.**, resulting in the deposition of atoms or molecules on the surface of the substrate. The careful selection of precursors and reaction conditions allows the production of ternary materials with precision at the nanometric scale. This technique is particularly effective in the production of thin films and nanostructured coatings (FARAZ et al. 2017).

Figure 1Chemical vapor deposition



Source: Faraz et al (2017)

Chemical Vapor Deposition (CVD) is a fundamental process in the fabrication of nanostructured materials and thin films at the nanometric scale. This method is based on the chemical reaction of gaseous precursors that deposit atoms or molecules on the surface of a substrate, forming a solid film. The CVD process involves several steps as described by Faraz et al (2017):

- Introduction of Precursors: Gases containing chemical precursors are introduced into a reaction chamber. These precursors are molecules that contain the elements needed to form the desired material.
- Chemical Reaction: The precursors undergo a chemical reaction in the presence of heat, usually by heating the substrate. This results in the decomposition of the precursors and the release of chemical species that react with each other.
- Deposition: The reaction products are deposited on the substrate surface, where they agglomerate and form a solid layer. The temperature, pressure and flow of the precursors are carefully controlled to obtain the desired film properties.
- Film Growth: The deposition process continues until the desired film thickness is achieved. Film growth is highly dependent on the reaction conditions and the choice of precursors.

CVD offers several advantages, including the ability to produce thin films with high purity, compliance with complex substrates, and precise control of film thickness. In addition, it allows the deposition of materials in three-dimensional shapes, such as nanowires and nanotubes, providing significant versatility in the production of nanostructured structures (ALVES et al., 2002; FARAZ et al., 2017).

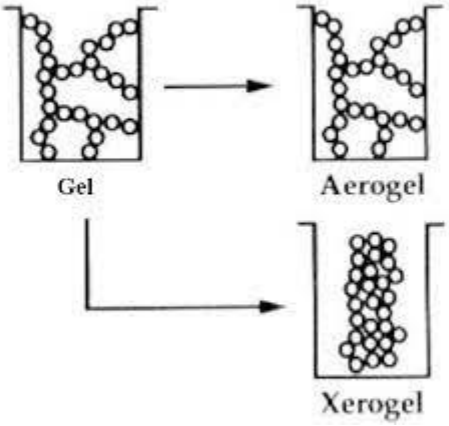
In nanotechnology, CVD is often used to manufacture materials such as graphene, carbon nanotubes, semiconductor films, and advanced coatings. Its application in electronic devices, sensors, solar cells, and other fields highlights the importance of this technique in producing nanostructured materials with specific properties for modern and advanced applications.

According to Alves et al (2002), another relevant approach is the synthesis by sol-gel methods, a chemical process that involves the formation of a gel from inorganic or organic precursors, followed by thermal treatments to generate solid materials. This method offers control over the morphology and composition of the final material, being applicable in the production of nanostructured ternary elements with porous structures and specific properties.

The sol-gel method, which had its origins in the 19th century, found significant application only after the Second World War, standing out from the 1950s onwards. This process is distinguished by its homogeneity, effective thickness control and relatively lower cost when compared to other techniques, such as Chemical Vapor Deposition (CVD), Molecular Beam Epitaxy (MBE) and Sputtering (MACIEL, et al, 2005).

In essence, sol-gel is a chemical procedure designed to synthesize a colloidal suspension of solid particles in a liquid called sol. Subsequently, a dual-phase material composed of a solid containing a solvent, called a wet gel, is formed. This gel represents a solid structure filled with a second phase of colloidal dimensions, whether a liquid or gas, establishing an interconnected three-dimensional network. When the solvent is removed, the wet gel converts to a xerogel through drying at ambient pressure or to an aerogel through drying above critical pressure and temperature conditions (FERREIRA, 2009; MACIEL et al, 2005).

Figure 2- Diagram illustrating the volume reduction in the transition from gel to xerogel and aerogel



Source: Maciel et al (2005)

The transition from the sol to gel state, also known as "gelations", begins with the formation of aggregated solid fragments that grow until they extend throughout the sol (FERREIRA, 2019).

Furthermore, self-assembly approaches have gained prominence, exploiting molecular interactions to guide the spontaneous organization of nanoscale components. This technique is particularly valuable in the creation of complex nanostructures, such as nanowires or nanoparticles, by using intermolecular forces to direct the formation of the desired structure (OLIVEIRA, et al, 2020).

According to Oliveira et al (2020), the self-assembly approach, also known as self-assay, is a fundamental concept in nanotechnology that is based on the ability of certain materials to spontaneously organize themselves into more complex and ordered structures on a nanometric scale. This strategy takes advantage of the natural molecular interactions between the material's constituents, such as Van der Waals forces, hydrogen bonds, hydrophobic and electrostatic interactions, to guide the arrangement of the components and form well-defined structures.

Currently, matter can be shaped, positioned, and organized at the nanoscale through two approaches called top-down and bottom-up nanofabrication. The first uses beams of ions, electrons, photons, and atoms to sculpt matter from macroscopic to nanoscopic dimensions in a serial manner, forming functional constructs with specific utility. The second approach allows these constructs to self-organize from nanometric building blocks in a parallel manner (KUMAR; RAJNI; PRASAD, 2023) .

The self-organization paradigm, present in chemistry, physics, materials science, engineering, biology, and medicine, has matured scientifically in the last two decades, allowing its numerous properties to be explored in nanofabrication. Its potential is remarkable in several applications, such as the formation of monolayers of alkanethiols on gold for various lithography, electrostatic self-organization in layers of alternating charge polyelectrolytes for smart drug delivery vehicles, conjugated self-assembled nanocrystals for medical diagnostics, self-assembled semiconductor nanowires for flexible electronics, self-assembled microspheres for opal optics, periodic mesoporous carbons for lithium solid-state battery anodes, and self-separated microphase block copolymers as nanolithographic masks for silicon-based flash memories (YADAV, SHARMA, KUMAR, 2020; KUMAR, RAJNI, PRASAD, 2023) .

These examples highlight how self-organization has driven nanofabrication and facilitated nanotechnology. Defining self-organization scientifically has been challenging due to its terminology and practice that cross boundaries between fields, span multiple length scales, and encompass a variety of forces. Nature demonstrates control of self-organization at length scales ranging from the cosmological to the atomic and subatomic. Humans can control self-organization at a more limited range, from the atomic to the meter scale (Ariga et al., 2019).

Self-organization implies spontaneity, where a structure forms from modular building blocks, generating an ordered pattern from a disordered state. The interaction between the building blocks is crucial to this process, rather than the generally stronger binding forces within them (KUMAR, RAJNI, PRASAD, 2023) .

The successful self-organization of building blocks into organized structures depends on the precise control of their size, shape, and surface properties. Therefore, a primary goal of self-organization is to synthesize building blocks with specific dimensions and shapes and, through chemical control of their surface properties (such as charge, hydrophobicity, hydrophilicity, functionality), gain command over the attractive and repulsive forces between them, allowing them to spontaneously self-assemble at multiple length scales to create an integrated chemical, physical, or biological system with specific function and utility (YADAV, SHARMA, KUMAR, 2020; KUMAR, RAJNI, PRASAD, 2023; ARIGA et al, 2019) .

In the absence of external influences, static self-organization of building blocks is driven by energy minimization to form static equilibrium structures. In the presence of external influences, a dynamically self-organizing system can prevail, adjusting to the surrounding environment by residing in an energy minimum caused by the influx of energy into the system. As soon as the energy supply ceases, the minimum disappears, and the system disorganizes. This phenomenon is exemplified by any living organism, which represents a perfect example of dynamic self-organization, reducing entropy by absorbing energy from the environment (ARIGA et al., 2019).

The self-assay process is inspired by the way biological systems organize themselves autonomously, such as in the formation of proteins and nucleic acids. In nanotechnology, this approach is applied to create materials and devices at extremely small scales, taking advantage of the unique properties that emerge at this scale (YADAV, SHARMA, KUMAR, 2020; LOMBARDO et al, 2020).

Self-organization of materials, known as self-assay, is a crucial strategy in the design of nanostructured systems, being fundamental for the creation of advanced materials and their application in nanomaterials and biotechnology. This process involves the interaction between disordered building blocks, leading to the spontaneous formation of more ordered structures on a nanometric scale. In the area of biomaterials, self-organization allows the occurrence of highly specific functions through the interaction of several macromolecular components. Examples include the folding of polypeptide chains in proteins and the conformational changes of nucleic acids, essential processes in several biological functions (LOMBARDO et al, 2020).

To advance the construction of functional materials at atomic and molecular levels, structural control and investigation at the nanoscale are crucial. The development of multifunctional nanostructures and biomaterials uses advanced self-organization techniques, such as supramolecular chemistry and host-guest processes. The reversibility of non-covalent forces enables the dynamic adaptation of the structure of nanostructures in response to internal and external stimuli, providing flexibility in the design of smart materials and functional nanodevices (ARIGA et al., 2019) .

This precision in chemical structure engineering allows the modulation and control of morphology, as well as the efficient use of non-covalent forces, introducing concepts such as chirality, signal processing and molecular recognition. In summary, self-organization plays a crucial role in the fabrication of advanced materials, paving the way for innovations in several scientific and technological areas (KUMAR; RAJNI; PRASAD, 2023).

By using self-assay, researchers can design nanostructured materials with specific properties, tailoring the functionality of the material according to the precise arrangement of its constituents. This is crucial for several applications, including electronic devices, sensors, biomimetic materials, controlled drug release systems, among others. In addition, the self-assay approach offers significant advantages in terms of efficiency and cost, since it allows the controlled formation of complex structures without the need for traditional, often expensive, fabrication methods (OLIVEIRA, et al. 2020; KUMAR; RAJNI; PRASAD, 2023).

Continuous research and development of these methods aims to overcome challenges inherent in the synthesis of nanostructured ternary elements, such as obtaining homogeneous particle sizes and ensuring reproducibility. A deeper understanding of these techniques is essential to optimize the production of these advanced materials, contributing to significant advances in nanotechnology and its practical applications.

VI. Potential Applications Of Ternary Elements In Nanotechnology

This topic will focus on the practical applications of ternary elements in nanotechnology, exploring significant contributions in areas such as electronics, medicine, energy and other relevant fields. Case studies will be analyzed, highlighting how the unique properties of ternary elements can be exploited to develop innovative devices, advanced nanocomposites or next-generation biomedical therapies.

The potential applications of ternary elements in nanotechnology present a promising and innovative field of research. Ternary elements refer to compounds consisting of three distinct chemical elements, and their incorporation into nanotechnology opens doors to a variety of advanced applications (ARIGA et al, 2019).

In nanostructured systems, ternary elements can play a crucial role, offering unique and adaptable properties. For example, the specific combination of ternary elements in nanomaterials can result in highly tunable electronic, optical, magnetic and catalytic properties. This versatility makes these materials ideal for diverse applications, from next-generation electronic devices to efficient catalysts (CASTILHO, 2017).

In the area of electronic devices, the integration of ternary elements into nanostructures can lead to the development of more efficient transistors, advanced storage memories, and highly sensitive sensors. The ability to adjust the properties of these elements offers fine tuning, allowing the customized design of devices to meet specific performance requirements (PINTO, 2023; SHAH, et al, 2021).

In this context, it is important to highlight the findings of the study by Mercante et al (2021), whose objective is to explore advances in electrospinning in the last 10 years, highlighting its application in biomedicine, environment, sensing and energy, in addition to discussing future trends to optimize the performance of nanofiber manufacturing, offering a comprehensive and inspiring vision for researchers interested in contributing to the development of devices based on electrospun nanofibers.

In the study, the author concludes that the electrospinning technique has evolved significantly since its emergence, standing out as a highly versatile tool in the production of nanofibers (NFs) from various materials. In recent years, its flexibility has been evident, adapting to meet a wide variety of applications and providing adjustable properties. NFs stand out for the combination of characteristics such as the ability to obtain different morphologies through parameter variation, high porosity, expressive surface area and the versatility of functionalization to create hierarchical heterostructures (MERCANTE et al, 2021).

Despite the remarkable advances and the increasing industrial application, some limitations still persist. Safety aspects, especially related to the use of high voltages and flammable solvents during electrospinning on an industrial scale, demand continuous attention. In addition, challenges such as cost-benefit ratio, precise control of NF properties (diameter, morphology, alignment) and ensuring the quality of the final product for specific applications need to be overcome. The Author anticipates by arguing that future developments in the electrospinning technique will depend on effective collaboration between the academic and industrial sectors, aiming to overcome the existing limitations and further strengthen its potential (MERCANTE et al, 2021; SHAH, et al 2021).

Furthermore, nanotechnology based on ternary elements excels in catalytic applications. Catalysis is a crucial field in many industrial and environmental processes, and ternary elements can play a vital role in optimizing catalytic efficiency. Whether in the synthesis of chemical compounds or in the purification of pollutants, ternary nanomaterials offer an innovative approach to improving the catalytic activity and selectivity of catalysts().

For heterogeneous catalysis, which involves the presence of catalysts in distinct states of matter, it is critically important at the nanometric scale or smaller. In this context, nanotechnology plays an essential role, especially in the manipulation of metal catalysts. For many years, metal catalysts have been prepared as nanoparticles dispersed on high surface area supports, such as alumina, silica or activated carbon (MERCANTE et al, 2021).

Another promising area is nanomedicine, where ternary elements can be explored to create customized nanostructures for therapeutic applications. From controlled drug release systems to next-generation imaging agents, nanotechnology based on ternary elements offers innovative solutions to complex challenges in the health area (FIGUEIRAS, ARR, COIMBRA, AB, & VEIGA, 2014).

VII. Final Considerations

Given the above, the investigation of the properties of ternary elements in nanotechnology reveals a dynamic and promising field of research. The analysis of the physical, chemical and thermal properties of these nanostructured materials provides a deeper understanding of their potential impact on various applications. The introduction of a third element can significantly modulate fundamental characteristics, such as electrical conductivity, mechanical strength and thermal stability, expanding the possibilities for innovation in sectors such as electronics, catalysis and medicine.

The research also points out that synthesis methods, such as chemical vapor deposition (CVD), sol-gel synthesis and self-assay, play a crucial role in the controlled fabrication of nanostructured ternary elements. CVD, in particular, stands out for its effectiveness in the production of thin films and coatings, expanding the versatility of these materials for applications in advanced electronic devices and other fields.

Furthermore, according to research analysis, the self-assay approach, inspired by the spontaneous organization of biological systems, offers unique opportunities for creating complex nanostructures. This technique, combined with methods such as sol-gel synthesis, contributes to the diversity and precision in the manufacture of ternary materials with specific properties.

The potential applications of ternary elements in nanotechnology are vast and span areas such as electronics, catalysis and medicine. The ability to tune the properties of these materials enables the development of more efficient electronic devices, highly selective catalysts and customized nanostructures for innovative therapeutic applications.

In view of the above, it is crucial to highlight that continuous research and development of these materials and methods aims to overcome challenges, such as ensuring reproducibility in synthesis and optimizing specific properties. A deep understanding of these techniques is essential to drive significant advances in nanotechnology, contributing to innovation in several scientific and technological areas.

Ultimately, the research analyzed not only expands knowledge about these materials, but also offers promising perspectives for the development of advanced technologies, contributing to innovative solutions to contemporary and future challenges. The alignment between academic research and industry demands is essential to ensure the practical application of these advances, driving progress at the frontiers of science and technology.

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