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The Development of Strontium Titanate Nanoparticle Research: A Bibliometric Computational Mapping Analysis

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Abstract

Purpose: The aim of this study was to determine the progress of research on Strontium Titanate (SrTiO3) nanoparticles through a bibliometric approach and also using computational mapping analysis using VOSviewer.

Methodology/approach: The keyword "SrTiO3 nanoparticle, Strontium Titanate" is used, then the article is selected based on the title and abstract. We conducted an analysis of articles discussing SrTiO3 nanoparticles and their relationship to problem areas using VOSviewer.

Results/findings: A total of 667 relevant articles were found based on these keywords. Articles used in the last 11 years, from 2012 to 2022. The results showed that SrTiO3 nanoparticles can be divided into 3 fields: "SrTiO3" with 163 links and 1092 total link strength, "Nanoparticle" with 175 links and 1697 total link strength, and "Strontium Titanate" with 170 links and 1459 total link strength. It was found that the research trend of SrTiO3 nanoparticles was increasing. In 2012 to 2015 there was an increase from 29 articles in 2012 to 46 articles in 2015. There was a decrease from 2015 to 40 articles in 2016. From 2016 to 2022 there was a significant increase in the number of articles from 40 articles in 2016 to 93 articles in 2022.

Limitations: This study did not discuss in depth the relationship between the terms in this SrTiO3 nanoparticle study.

Contribution: The results of this study can be used as a reference to find out the trend of research on nanoparticle materials which has increased, so that it can be a potential for further development of SrTiO3 nanoparticle applications.

Keywords: *Bibliometric, Strontium Titanate, SrTiO3, Nanoparticle, VOSviewer.*

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1. Introduction

Metal oxides with perovskite structure and general formula ABO3 have been studied in recent years due to their diverse and unique properties. Strontium titanate, $SrTiO_3$, is a perovskite material with a cubic unit cell with a lattice parameter of 3.905. The octahedral corner of the $SrTiO_3$ shared TiO_6 unit forms a tightly bonded network that serves as the lattice's structural backbone (Neaton & Rabe, 2003). $SrTiO_3$ often applied as a substrate for the epitaxial growth of high temperature superconductors. Besides that, $SrTiO_3$ can be used in macroelectronics, ferroelectric, and optoelectronics applications (Phoon, Lai, Juan, Show, & Chen, 2019). Recent studies on $SrTiO_3$ have demonstrated it has high potential for practical use, such as fuel cells8 and gas sensors (Schultz, Brown, & Ohodnicki Jr, 2015).

Bibliometric analysis can be used to determine the progress of research in the field of $SrTiO_3$ nanoparticles. Bibliometric analysis is a type of research data meta-analysis that assists researchers in studying the bibliographic information and citation analysis of articles released in journals and other scientific literature (Al Husaeni & Nandiyanto, 2022). There have been numerous reports on bibliometric analysis, including economic bibliometric analysis (Firmansyah & Faisal, 2019); (Rusydiana, 2019); (Castillo-Vergara, Alvarez-Marin, & Placencio-Hidalgo, 2018); (Nandiyanto, Al Husaeni, & Al Husaeni, 2021; Nederhof & Van Raan, 1993); (Modak, Lobos, Merigó, Gabrys, & Lee, 2020), bibliometric analysis in research on chemistry (Grandjean, Eriksen, Ellegaard, & Wallin, 2011); (Ho, 2012), chemical research on vocational school (Mulyawati & Ramadhan, 2021), dataset portrays decreasing number of scientific publication (Castiblanco, Ramirez, & Rubiano, 2021), engineering (Neaton & Rabe, 2003); (Chun, 2009), management bioenergy (Nugraha, 2022),publication of techno-economic education (Setiyo, Yuvenda, & Samuel, 2021), engine performance (Nandiyanto, Biddinika, & Triawan, 2020b), application in robotic hand systems (Nandiyanto, Biddinika, & Triawan, 2020a), educational research (Soegoto, Soegoto, Luckyardi, & Rafdhi, 2022), and magnetite nanoparticle (Fauziah, 2022).

Over the last 11 years, the number of published studies on $SrTiO_3$ materials has increased, and nearly 667 articles with the keywords " $SrTiO_3$ nanoparticles, strontium titanate" were successfully published for various applications between 2012 and 2022. This demonstrates the significance and attraction of this challenging research. This study used VOSviewer software to conduct computational studies on mapping bibliometric analysis of articles indexed by Google Scholar. This study was carried out for these results to be used as a reference for researchers looking for the latest research trends in nanomaterials and conducting research for the development of new applications for $SrTiO_3$ nanoparticles.

2. Method

The research from publications in Google Scholar-indexed journals served as the basis for the article information used in this research. We chose the Google Scholar database for this study because it is open-source platform. To collect research data, a manager citation tool called Publish or Perish was used. The software Publish or Perish was used to conduct a literature review on the topic we chose. The research was conducted in several stages:

(i) Data collection on publications using the publish or perish sofware,
(ii) Processing of bibliometric information for articles obtained using the Microsoft Excel program,
(iii) Computational mapping analysis of bibliometric publication data using the VOSviewer application, and
(iv) Analysis of computational mapping analysis results.

Publish or Perish's article data search is used to filter publications using the keyword " $SrTiO_3$ nanoparticle, Strontium Titanate" based on the requirements of the publication's title. The papers that were used were released between 2012 and 2022. Everything was collected in September 2022. Research information systems (.ris) and comma separated value format (*.csv) files were used to export the articles that were gathered and met the criteria for analysis in this study. Bibliometric maps were also used with VOSviewer to visualize and assess trends. After that, the article data from the original database was mapped. Utilizing the network (co-citation) between existing items, VOSviewer was used to produce three different mapping publications: network visualization, density visualization, and overlay visualization. A bibliometric map was made with the keyword frequency set to at least three occurrences. As a result, 278 terms and keywords were obtained and eliminated.

3. Results and Discussion

3.1. Publication data search results

667 data articles that matched the research criteria were discovered through the Google Scholar database's application reference manager publish or perish data search. The information was gathered in the form of article metadata, which included the author's name, title, year, journal name, publisher,

quantity of citations, links to the article, and related URLs. In the VOSviewer analysis of this study, some examples of published data are shown in Table 1. The 10 top articles with the most citations were used as the data samples. The total number of citations from all the articles used in this study is 12418. There are 1241.80 citations per year, 18.62 citations per paper, and an average of 4.10 authors, average h-index and g-index for all articles are 57 and 83, respectively.

Table 1. $SrTiO_3$ nanoparticles publication data

No.	Author	Title	Year	Cites
1	(Hao, 2013)	A review on the dielectric materials for high energy-storage application	2013	690
2	(Bera et al., 2014)	Perovskite Oxide $SrTiO_3$ as an Efficient Electron Transporter for Hybrid Perovskite Solar Cells	2014	265
3	(M. Liu, Qiu, Miyauchi, & Hashimoto, 2013)	Energy-level matching of Fe (III) ions grafted at surface and doped in bulk for efficient visible-light photocatalysts	2013	258
4	(S. Liu & Zhai, 2015)	Improving the dielectric constant and energy density of poly (vinylidene fluoride) composites induced by surface-modified $SrTiO_3$ nanofibers by polyvinylpyrrolidone	2015	216
5	(Assirey, 2019)	Perovskite synthesis, properties and their related biochemical and industrial application	2019	131
6	(Wang et al., 2018)	$BiFeO_3$-$BaTiO_3$: A new generation of lead-free electroceramics	2018	130
7	(Jia et al., 2013)	Composite Sr_2TiO_4/ $SrTiO_3$ (La, Cr) heterojunction based photocatalyst for hydrogen production under visible light irradiation	2013	121
8	(Kang, Lim, Song, & Park, 2012)	Organic-inorganic composite of g-C3N4–$SrTiO_3$: Rh photocatalyst for improved H2 evolution under visible light irradiation	2012	118
9	(Piskunov et al., 2015)	C-, N-, S-, and Fe-Doped TiO2 and $SrTiO_3$ Nanotubes for Visible-Light-Driven Photocatalytic Water Splitting: Prediction from First Principles	2015	113
10	(Kumar, Kumar, Bahuguna, Sharma, & Krishnan, 2017)	Two-dimensional carbon-based nanocomposites for photocatalytic energy generation and environmental remediation applications	2017	112

3.1. Research development in the field of $SrTiO_3$ nanoparticles

Table 2 displays the development of $SrTiO_3$ nanoparticle research that has been published in a journal that is indexed by Google Scholar. According to the information in Table 2, there were 664 articles discussing $SrTiO_3$ nanoparticle research between 2012 and 2022. There were 29 articles published in 2012, 30 articles in 2013, 41 articles in 2014, 46 articles in 2015, 40 articles in 2016, 57 articles in 2017, 68 articles in 2018, 83 articles in 2019, 90 articles in 2021, and 93 articles in 2022. The development of $SrTiO_3$ nanoparticle research published in the Google Scholar indexed journal is shown in Table 2. Figure 1 depicts the progression of $SrTiO_3$ nanoparticle research over the previous 11 years, from 2012 to 2022. Based on Fig. 1, it is known that $SrTiO_3$ nanoparticle research has advanced from 2012 to 2015 and from 2016 to 2022. The number of publications has increased from 29 in 2012 to 46 in 2015, demonstrating this trend. However, there was a decrease from 2015 to 2016, going from 46 articles to

40 articles. There were 53 in 2016, and there were 152 in 2022. The data indicates that interest in $SrTiO_3$ nanoparticle research has grown recently, as has the popularity of research on this material.

Table 2. Number of Publication using "$SrTiO_3$ nanoparticles" as the topic keywords in the past 11 years

Year of Publication	Number of Publication
2012	29
2013	30
2014	41
2015	46
2016	40
2017	57
2018	68
2019	83
2020	87
2021	90
2022	93
Total	664
Average	60,36

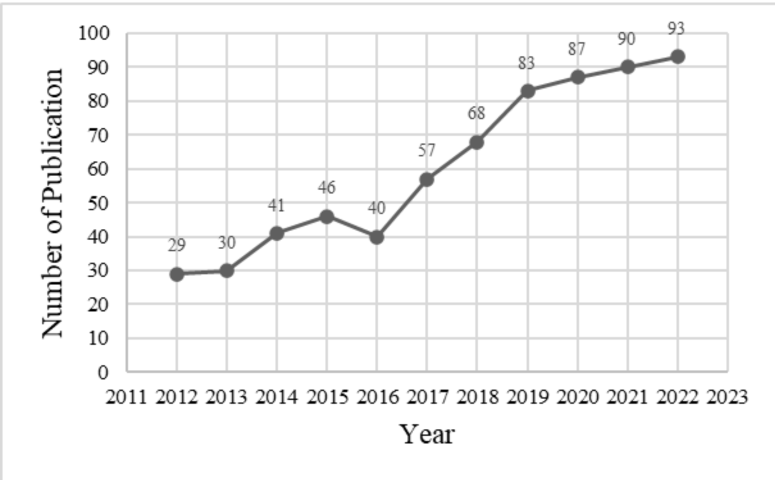

Figure 1. Development of $SrTiO_3$ nanoparticles research

3.2. Visualization of $SrTiO_3$ nanoparticles topic area using VOSviewer

The data from the article was evaluated to computational mapping. Computational mapping was done using VOSviewer. 177 items were founded using the computational mapping results. Every item connected to strontium titanate nanoparticles that was discovered in the data. All of these items are separated into the following 8 clusters:

(i) Cluster 1 has 31 items and marked in red the 54 items are barium strontium titanate, barium titanate, bati03, calcium titanate, ceramic, chemical formula, chemistry, deposition, dielectric property, electrical property, film, influence, interface, investigation, microstructure, nano, optical property, phase, semiconductor, sol gel, sol gel method, solution, structural, study, substrate, temperature, thin film, titanate, zno, and zno nanoparticle.

(ii) Cluster 2 has 29 items and marked in green the 45 items are activity, ag nanoparticle, analysis, analytical grade, aqueous solution, au nanoparticle, characterization, chemical, chemical structure, combination, composite, degradation, development, further purification, heterojunction, nanocomposite, nanocube, nanoparticle, novel, photocatalytic degradation, photocatalytic performance, presence, process, removal, strontium titanate nano, synthesis, tio, titanium dioxide, and visible light.

(iii) Cluster 3 has 26 items and marked in blue the 41 items are addition, catalyst, chemical state, comparison, effect, enhancement, example, formation, insight, Ion, mechanism, modification, order, oxidation, oxygen, photocatalyst, powder, pt nanoparticle, reduction, spray pyrolysis, srtio3, structure, ti02, titanium, visible light irradiation, and x ray photoelectron spectroscopy.
(iv) Cluster 4 has 25 items and marked in yellow the 34 items are batio, chemical bond, chemical bonding, composition, dye sensitized solar cell, electronic structure, energy storage property, experiment, ferromagnetism, hand, high chemical, mean, morphology, oxygen vacancy, particle, photoluminescence, preparation, sample, size, srtio3 ceramic, srtio3 film, srtio3 photocatalyst, sto, and surface.
(v) Cluster 5 has 22 items and marked in purple the 28 items are barium, bulk, chemical composition, chemical energy, chemical environment, chemical potential, dopant, element, energy, hydrogen, hydrogen production, Increase, organic dye, paper, recent year, role, site, solar energy, system, water, and water splitting.
(vi) Cluster 6 has 19 items and marked in light blue the 20 items are application, electrospinning, fabrication, hydrothermal method, hydrothermal synthesis, journal, low temperature, low temperature synthesis, metal nanoparticle, nanofiber, perovskite, perovskite material, photocatalytic property, present work, review, srtio3 nanoparticle, sto nanoparticle, strategy, and wet chemical method.
(vii) Cluster 7 has 13 items and marked in orange the 15 items are chemical property, chemical stability, high chemical stability, low cost, oxide, perovskite strontium titanate, perovskite structure, photocatalytic activity, promising photocatalyst, property, srtio, strontium, and thermoelectric property.
(viii) Cluster 8 has 12 items and marked in brown the 15 items are anode, chemical reaction, defect chemistry, growth, lao, lanthanum, metal, performance, physical property, solid oxide fuel cell, strontium titanate, and work.

Each existing cluster illustrates how one term relates to another. Each term has a label that is indicated by a colored circle. Depending on how frequently a term occurs, the size of the circle changes for each term. The size of the label circle correlates favorably with the use of the term in the abstract and title (S. Liu & Zhai, 2015). The label size increases with the frequency of the term. The three components of the mapping visualization examined in this study are network visualization (see Fig. 2), overlay visualization (see Fig. 3), and density visualization (see Fig. 4).

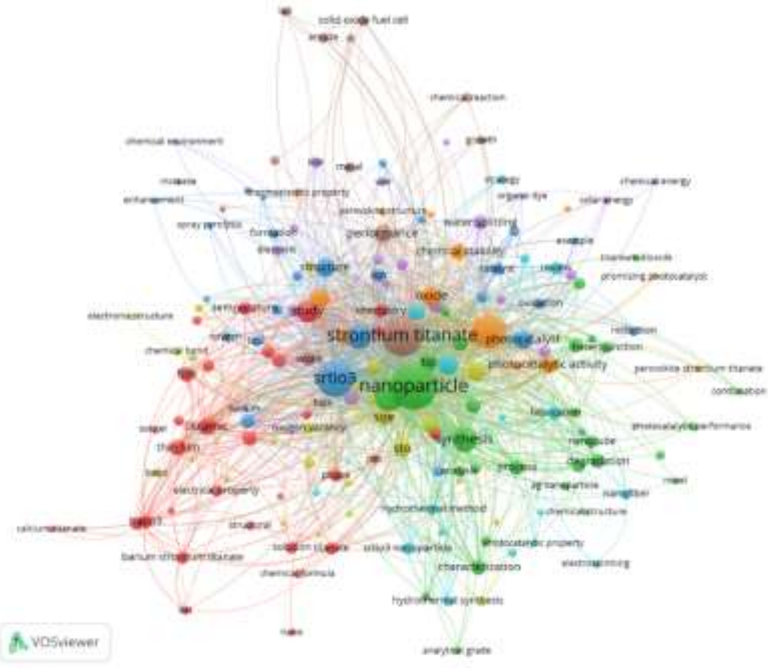

Figure 2. Network visualization of $SrTiO_3$ nanoparticle keyword

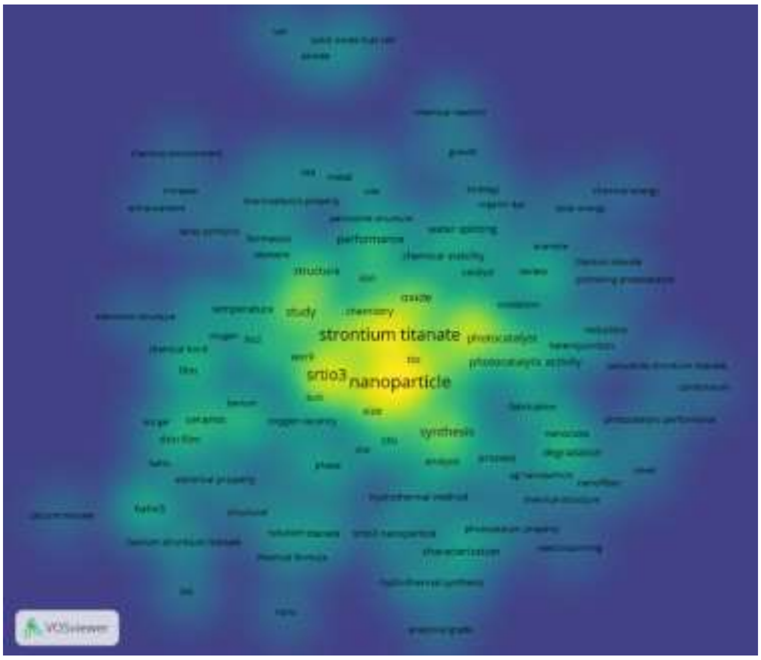

Figure 3. Density visualization of $SrTiO_3$ nanoparticle keyword

The relationship between the terms is shown in Figure 2. An interconnected network is used to represent the relationship between terms. The clusters of each term that are frequently studied and connected to the study of mechanical engineering education are shown in Figure 2. The visualization of density is shown in Figure 3. According to density visualization, a term will appear more frequently when the yellow color is brighter and the circle that contains its labels is larger. This indicates that extensive research has been done on terms that are related. In contrast, there aren't many studies on the term if the color of the term fades closer to the color of the background. As can be seen from Fig. 3, research has been done on terms such as nanoparticle, strontium titanate, $SrTiO_3$, SrTiO, synthesis, chemistry, oxide, structure, property, and application.

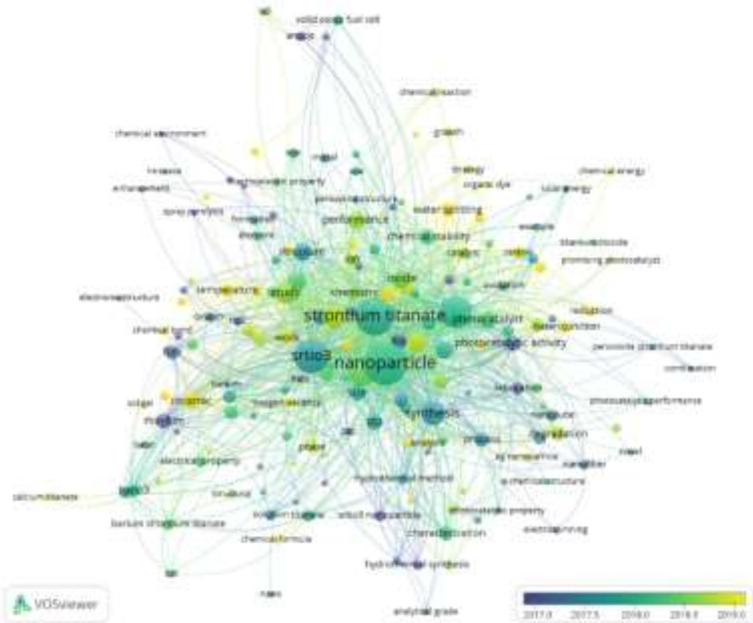

Figure 4. Overlay visualization of $SrTiO_3$ nanoparticle keyword

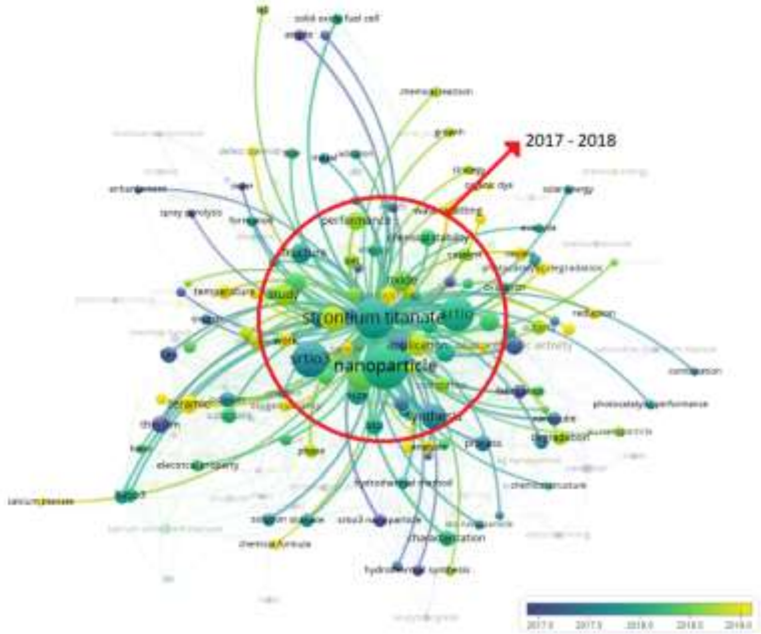

Figure 5. Overlay visualization of strontium titanate term in 2017 to 2018

Figure 4 illustrates the overlay visualization used in the research on mechanical engineering education. This overlaying visualization demonstrates the novelty of studies on associated terms. Research on $SrTiO_3$ nanoparticles was primarily conducted from 2017 to 2018, as shown in Figure 4, which is further explained in Figure 5. It has taken quite some time for the term $SrTiO_3$ nanoparticle to become well-known in scientific circles. This makes it simple for us to conduct fresh research on $SrTiO_3$ nanoparticle.

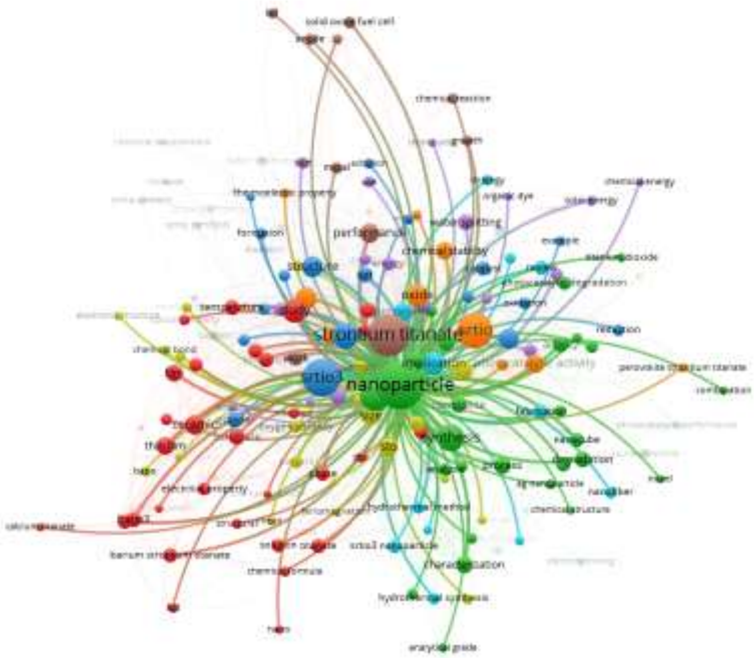

Figure 6. Network visualization of nanoparticle term

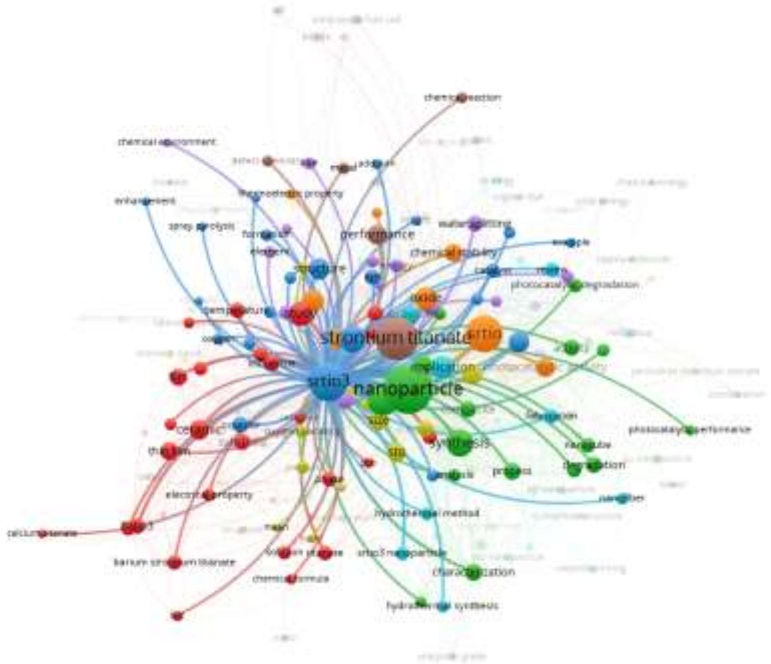

Figure 7. Network visualization of $SrTiO_3$ term

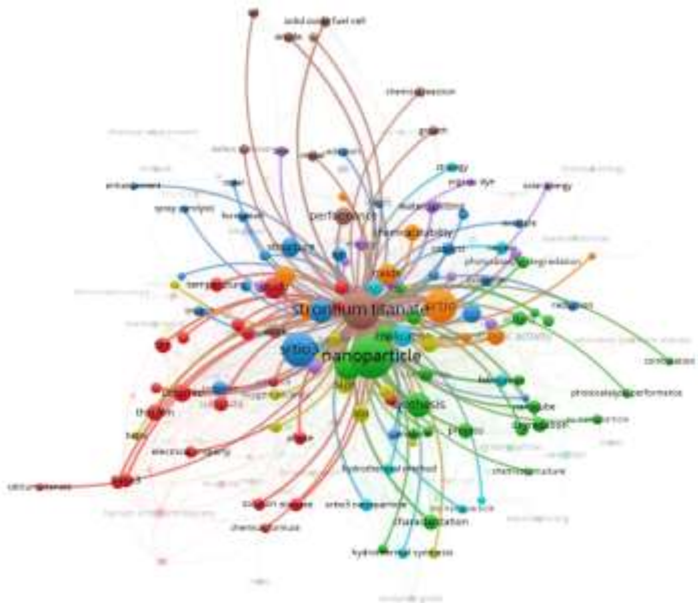

Figure 8. Network visualization of strontium titanate term

These numbers demonstrate that the study of $SrTiO_3$ nanoparticles can be divided into three fields, the first of which is the nanoparticle term, which is present in cluster 2 and has a total of 324 occurrences, 175 total links, and 1697 total links of varying strength. The second term is $SrTiO_3$, which has a total of 163 links, a total link strength of 1092, and 190 occurrences. A strontium titanate term has a total of 170 links, a total link strength of 1459, and 248 occurrences. It belongs to cluster 8.

Figure 6 displays a network of nanoparticles with other terms, namely strontium titanate, srtio3, srtio, la0, solid oxide fuel cell, anode chemical reaction, growth, site, metal, addition, thermoelectric property, use, strategy, organic dye, formation, structure, ion, energy, performance, insight, water splitting, chemical stability, catalyst, review, example, solar energy, chemical energy, titanium oxide, photocatalytic degradation, oxide, oxidation, temperature, study, perovskite, electronic structure, chemical bond, film, work, sample, application, perovskite strontium titanate, combination, barium, ceramic, powder, substrate, interface, oxygen vacancy, size, sto, preparation, composite, fabrication, nanocube, synthesis, batio, thin film, particle, phase, zno, analysis, process, degradation, novel, ag nanoparticle, nanofiber, chemical structure, electrical property, batio3, structural, mean, ferromagnetism, hydrothermal method, calcium titanate, barium strontium titanate, bst, solution, titanate, chemical formula, nano, srtio3 nanoparticle, characterization, hydrothermal synthesis, and analytical grade.

Figure 7 illustrates the network of connections between $SrTiO_3$ terms and already-existing terms, including chemical reaction, chemical environment, defect chemistry, site, metal, addition, enhancement, spray pyrolysis, thermoelectrical property, formation, performance, water splitting, element, structure, chemical stability, example, ion, energy, catalyst, review, photocatalytic degradation, oxide, temperature, study, perovskite. oxygen, influence, strontium titanate, activity, film, nanoparticle, application, photocatalytic activity, ceramic, powder, thin film, substrate, interface, oxygen vacancy, particle, phase, zno, size, sto, synthesis, composite, analysis, process, fabrication, nanocube, degradation, photocatalytic performance, nanofiber, electrical property, batio3, mean, hydrothermal method, barium strontium titanate, solution titanate, srtio3 nanoparticle, chemical formula, characterization, and hydrothermal synthesis.

Figure 8 depicts a network of relationships between strontium titanates that are linked by the terms la0, solid oxide fuel cell, anode, chemical reaction, defect chemistry, site, metal, addition, growth, strategy, order, enhancement, spray pyrolysis, formation, performance, insight, water splitting, structure, chemical stability, ion, energy, catalyst, review, photocatalytic degradation, oxide, temperature, study, perovskite. oxide, oxidation, reduction, activity, film, work, sample, application, photocatalytic activity, ceramic, powder, thin film, substrate, interface, oxygen vacancy, size, sto, synthesis, composite, fabrication, nanocube, analysis, process, degradation, combination, photocatalytic performance, au nanoparticle, electrical property, calcium titanate, batio3, solution, titanate, chemical formula, srtio3 nanoparticle, hydrothermal method, hydrothermal synthesis, characterization, sto nanoparticle, and chemical structure. These three terms frequently have a high level of relevance and are linked to many other terms. The field of $SrTiO_3$ nanoparticles is still very likely to be studied and linked to other concepts, and this will have a greater effect on the novelty of the research.

4. Conclusion

This study's objective was to compute mapping analysis on the bibliometric information of research articles. $SrTiO_3$ nanoparticles is the topic chosen for this study's publication theme. Through Publish or Perish, the articles were pulled from the Google Scholar database. Titles and abstracts from the library were used in the research. 667 articles that were relevant to the search were found to have been published between the years of 2012 and 2022. The results demonstrate that $SrTiO_3$ nanoparticle research was on the rising trend. There was an increase from 2012 to 2015, going from 29 articles in 2012 to 46 articles in 2015. 40 articles were published in 2016 as opposed to 50 in 2015. The number of articles increased significantly between 2016 and 2022, increasing from 40 articles in 2016 to 93 articles in 2022. The outcomes of this study can be used as a guide to determine the direction of increased research on nanoparticle materials, which may be a possibility for $SrTiO_3$ nanoparticle applications.

Limitation and Suggestion

This study was limited to a general analysis of research developments related to SrTiO3 nanoparticles over the last ten years and did not go into detail about the relationship between the terms in this SrTiO3 nanoparticle study. For the next study, a deeper investigation is required. This bibliometric analysis can be carried out more specifically in terms of the relationship between the terms, as well as the mapping linked to each term, which required to be fully explained further.

Acknowledgments

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