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Trends Research Synthesis of TiO_2 Thin Films as Solar Cell Materials (2015-2024): A Systematic Review

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Abstract: Research in the field of solar cells continues to increase along with the development of the times and human needs for renewable energy sources. One of the fields of study that is often used as a research topic is the development of Thin Film Solar Cells or known as Thin Film Solar Cells (TFSC). This research aims to identify and analyze research trends of synthesis of TiO_2 thin films as solar cell materials. This research method is descriptive and analytical. The data used in this research was obtained from documents indexed by Google Scholar from 2015-2024 using Publish or Perish and Dimension.ai. Research procedures use PRISMA guidelines. The data identified and analyzed are the type of publication, publication source, and the title of research on synthesis of $Ti0_2$ thin films as solar cell materials that is widely cited. The data analysis method uses bibliometric analysis assisted by VOS viewer software. The results of the analysis show that research trend on synthesis of TiO_2 thin films as solar cell materials indexed by Google Scholar from 2015 to 2024 has experienced increases and decreases. There are many documents in the form of articles, proceedings, chapters, preprints, monograph and edited books that discuss research about synthesis of TiO_2 thin films as solar cell materials. Key words that are often used in research about it are dye sensitized cell, electrode, electron, characterization, etc.

Keywords: Review; Solar cell; Synthesis; TiO_2 thin films

Introduction

Research in the field of solar cells continues to increase along with the development of the times and human needs for renewable energy sources (Mitrašinović, 2021; Rathore et al., 2021). Based on data from the Central Statistics Agency (BPS), Indonesia's population is projected to be 275.77 million in 2022. This number is up 1.13% compared to last year's 272.68 million. This very large population has a large energy need. Energy needs are needed to meet the needs of electricity, transportation, industry, households, and other sectors (Kumar et al., 2023). Climate change is a long-term change in the Earth's weather patterns and temperatures caused by increased greenhouse gas emissions. The need for clean energy today is essential to reduce greenhouse gas emissions and address the impacts of climate change. Clean energy, such as solar and wind, does not produce greenhouse gas emissions and is continuously renewable. Switching to clean energy also creates new economic opportunities and promotes sustainability. To meet these energy needs, Indonesia is considered to have great potential for developing solar cell-based energy technology in Indonesia (Karim et al., 2019).

Research about solar cells began with the first generation that utilized silicon and germanium as the main raw materials, then the second generation utilizing semiconductor raw materials, and the third generation utilizing organic materials in the form of Dye-Sensitised

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Solar Cells (DSSC) (Efaz et al., 2021; Roy et al., 2021). Continuously increasing research studies in the field of solar cell technology are certainly because the main source of this technology is utilizing sunlight which is unlimited to replace other energy in the future. Solar cells are a technology that is composed of semiconductor materials with the principle of converting sunlight into electrical energy through the photovoltaic effect (Bredas et al. 2017; Husain et al. 2018; Nayak et al. 2019). One of the fields of study that is often used as a research topic is the development of Thin Film Solar Cells or known as Thin Film Solar Cells (TFSC) (Saif et al., 2023; Sharma et al., 2022; Underwood et al., 2023).

Thin Film Solar Cells (TFSC) are one type of solar cell whose development process is by adding thin layer technology as the basic material for making solar cells (Doyan et al., 2022; Rizaldi et al., 2022). This thin layer becomes one of the components that will later be absorbent to sunlight. The development of thin films based on solar cells can be synthesized or made using various compounds, both organic, inorganic, metal, and metal-organic, which can be conductors, semiconductors, superconductors, and even insulators (Liu et al., 2022; Meng et al., 2020; Song, 2021). One of the compounds that is often used in research on thin films based on solar cells is Titanium Dioxide (TiO_2) (Eliyana et al., 2020; Suriani et al., 2019; Yadav et al., 2020).

Titanium Dioxide (TiO_2) is a type of semiconductor material that has environmentally friendly properties because it does not produce pollutants, requires relatively low costs, has a small energy band gap of around 3.2 eV, has good stability, and is free from photo corrosion (Okto & Munasir, 2023; Setyawan & Suryani, 2024; Shabrina et al., 2023). The TiO_2 compound has three types of crystal structures, namely anatase, brookite, and rutile (Allen et al., 2018; Eddy et al., 2023; Žerjav et al., 2022).

TiO_2 (titanium dioxide) is a commonly used material in DSSC dye-sensitized solar cells. TiO_2 material has a porous structure and high surface roughness providing a large surface area for light absorption. Light entering through TiO_2 is absorbed by the dye bound to the TiO_2 surface, and this light energy is converted into electrons. The electrons injected into TiO_2 can then be used to generate electric current through an external circuit that allows it to last for a long time (Boro et al., 2018). However, if reviewed more deeply in terms of physical characteristics, the surface of the thin layer is still rough because the TiO_2 compound is basically in powder form (Bhernama et al., 2017). Therefore, this research wants to know the research trend of the synthesis of TiO_2 thin films as solar cell materials. It is hoped that this research can become a reference in developing further research related to $Ti0_2$ thin films as solar cell materials.

Method

This research method is descriptive and analytical, which aims to understand and describe research trends in the synthesis of TiO_2 thin films as solar cell materials. The data used in this study was obtained from information sources indexed by Google Scholar using analytical tools such as Publish or Perish and Dimension.ai. To carry out a search on Google Scholar, keywords related to research trends on the synthesis of TiO_2 thin films as solar cell materials.

In this research, an analysis was carried out on 1,000 documents that had been indexed by Google Scholar between 2015 and 2024. The Google Scholar database was chosen as a place to search for documents because Google Scholar applies consistent standards in selecting documents to be included in its index, and Google Scholar displays more documents than the top databases (Hallinger et al., 2019, 2020; Zawacki-Richter et al., 2019). To filter data that has been collected via Publish or Perish, researchers used the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.

Result and Discussion

This research aims to describe research trends on synthesis of TiO_2 thin films as solar cell materials conducted from 2015 to 2024. Research documents on research trends synthesis of TiO_2 thin films as solar cell materials are taken from documents from 2015 to 2024. Figure 1 is presented below regarding research trends on the synthesis of $Ti0_2$ thin films as solar cell materials.

Figure 1 shows that the trend in research on the synthesis of $Ti0_2$ thin films as solar cell materials from 2015 to 2024 has increased. Where the research trend is increase in the number of publications from 2015 to 2017. However, in 2018 to 2019 the research trend on the synthesis of TiO_2 thin films as solar cell materials has decreased. After that, the research trend increase again in 2020, before decrease again in 2021 to 2024. The variative trend in research on the synthesis of $Ti0_2$ thin films as solar cell materials indicates that research in the field of solar cells continues to increase along with the development of the times and human needs for renewable energy sources.

In 2015 there were 34 publications related to the synthesis of TiO_2 thin films as solar cell materials, then this will continue to increase to 57 publications in 2017. After that it decreased to 39 publications before increased again in 2021 with 42 publications. Below are also table 1 presented research of synthesis of TiO_2 thin films as solar cell materials based on the type of publication.

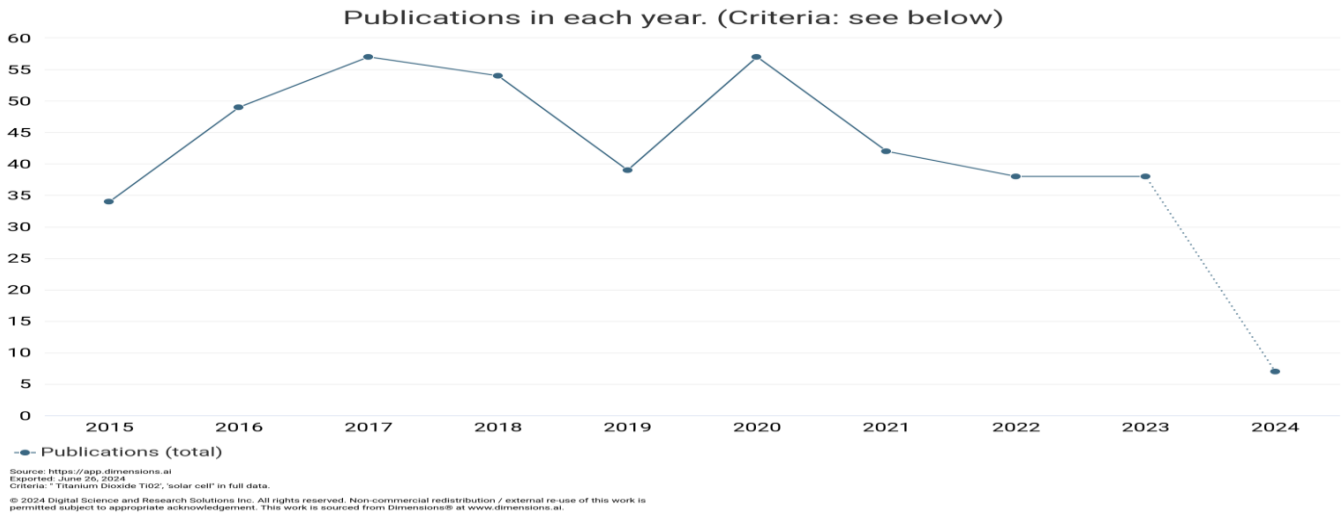

Figure 1. Research trends in synthesis of TiO_2 thin films as solar cell materials

Table 1. Trends in Synthesis of TiO_2 Thin Films as Solar Cell Materials Research Based on Publication Types

Publication Type	Publications
Article	960
Edited Book	839
Chapter	379
Proceeding	248
Monograph	232
Preprint	6

Based on Table 1, it is known that research synthesis of $Ti0_2$ thin films as solar cell materials from 2015 to 2024 contained in 6 types of publications. In the form of articles there were 960 documents, chapters as many as 379 documents, proceedings as many as 248 documents, edited books as many as 839 documents, monograph with 232 document and preprints as many as 6 documents. Research synthesis of TiO_2 thin films as solar cell materials in article form is the type of publication that contains the most research compared to other types of publications. Meanwhile, the type of publication contains the least amount of research results synthesis of TiO_2 thin films as solar cell materials is a preprint. Research conducted by Oltarzhevskyi (2019) states that an article is a complete factual essay of a certain length created for publication in online or print media (via newspapers, magazines or bulletins) and aims to convey ideas and facts that can convince and educate. These articles are usually published in scientific journals both in print and online (Suseno et al., 2020).

Below are also table 2 presented top ten (10) sources title trends in research on synthesis of TiO_2 thin films as solar cell materials which are often cited by other researchers related to this matter. Table 2 shows that the most widely published source of research trends on synthesis of TiO_2 thin films as solar cell materials is the Journal of the American Ceramic Society, namely 124 publications with 341 citations and an average citation of 2.75. Journal of the American Ceramic Society (JACerS) is a leading ceramic science and engineering journal. Publishing research across the field of ceramic and glass materials, this journal has consistently been a valued source for impactful ceramic materials science research for more than 100 years. Below are also table 3 presented top ten (10) article title trends in research on synthesis of $Ti0_2$ thin films as solar cell materials which are often cited by other researchers related to this matter.

Table 2. Top 10 Sources Title Trend of Synthesis of $Ti0_2$ Thin Films as Solar Cell Materials Research in 2015-2024

Name	Publications	Citations	Citations Mean
Journal of the American Ceramic Society	124	341	2.75
Ceramic Engineering and Science Proceedings	57	97	1.70
The Electrochemical Society Interface	54	28	0.52
Proceedings of SPIE--the International Society for Optical Engineering	51	188	3.69
Ceramic Transactions Series	51	132	2.59
NATO Science Series E:	38	2,308	60.74
NATO Science Series C:	33	2.320	70.30
Eos	27	46	1.70
Journal of Photochemistry and Photobiology A Chemistry	25	4,757	190.28
Journal of The Electrochemical Society	22	1,449	65.86

Table 3 shows that research on the synthesis of $Ti0_2$ thin films as solar cell materials that is widely cited by other researchers is about "The Effect Of Sulfur-And Carbon-Codoped TiO_2 Nanocomposite On The Photocatalytic And Mechanical Properties Of Cement Mortars" which is 3.00 (Hohol et al., 2020). Then the research entitled "Synthesis and Characterisation of Nanostructured TiO2 for Photocatalytic Applications" was cited 0.88 times (Albetran, 2016). Research by Chandra et al. (2017) entitled "Recent Progress in Dye Sensitized Solar Cells" is also widely cited by other researchers, namely 0.86 per year. Kadem (2017) in his research entitled "P3HT:PCBM-based organic solar cells : Optimization of active layer nanostructure and interface properties" was cited 0.71 per year.

This research data is comparable to data on the increasing trend of research on the synthesis of TiO_2 thin films as solar cell materials from 2015 to 2024. This means that in that year, research related to it was continuously cited by other researchers. In the articles researched and written by these researchers, there are many terms/keywords related to synthesis of TiO_2 thin films as solar cell materials. Below are presented ten (10) popular keywords related to synthesis of TiO_2 thin films as solar cell materials.

Table 3. Top 10 Citations on Trend of Synthesis of $Ti0_2$ Thin Films as Solar Cell Materials in 2015-2024

Cites/year	Year	Author	Title
3.00	2020	M Hohol et al.	The Effect Of Sulfur-And Carbon-Codoped Tio2 Nanocomposite On The Photocatalytic And Mechanical Properties Of Cement Mortars
0.88	2016	H M M Albetran	Synthesis and Characterisation of Nanostructured TiO2 for Photocatalytic Applications
0.86	2017	KA Chandra, SS Gill	Recent Progress in Dye Sensitized Solar Cells
0.71	2017	BY Kadem	P3HT:PCBM-based organic solar cells : Optimisation of active layer nanostructure and interface properties
0.67	2018	A. B. Sreebha, S. Suresh, C. O. Sreekala and V. P. Mahadevan Pillai	Volume holographic gratings in acrylamide-based photopolymer to provide selective light as an added input for improving the performance of dye-sensitized solar cells
0.60	2019	J Peper	Studies of Titanium Dioxide Nanoparticles: Thermodynamics and Reactivity
0.50	2020	Yulia Nadhirah,R.D. Kusumanto, Abu Hasan	Increasing Efficiency of Dye-Sensitized Solar Cell (DSSC) Originating from Yellow Sweet Potato Extract as Dye Sensitizer: Effect of Acetic Acid, Polyethylene Glycol, and Polyvinyl Alcohol as $Ti0_2$ binders
0.50	2022	Z Varga, E Racz	A Numerical Model and a Code Development for Photogeneration Rate Calculation for a Dye Sensitized Solar Cell
0.33	2015	FB Fauzi	Research and development of CdS/CdTe solar cells incorporating ZnTe layers
0.13	2016	D Aldakov, V I-Hristova, P Reiss, S SANCHEZ	Method for depositing nanoparticles on a nanostructured metal oxide substrate

Table 4 shows that the keywords that often appear related to research on the the synthesis of $Ti0_2$ thin films as solar cell materials are dye sensitized cell efficiency, 9 times with a level of 1.93. Research about solar cells began with the first generation that utilized silicon and germanium as the main raw materials, then the second generation utilizing semiconductor raw materials, and the third generation utilizing organic materials in the form of Dye-Sensitised Solar Cells (DSSC) (Efaz et al., 2021; Roy et al., 2021). Table 4 also shows that characterization is also a keyword that appears frequently in research trends on the synthesis of TiO_2 thin films as solar cell materials, namely 19 times with a relevance of 1.17. There are many articles that synthesis and characterization TiO_2 or other materials as solar cell (Rizaldi et al., 2022; Yadav et al., 2020; Shabrina et al., 2023).

Table 4. Keywords on Trend Synthesis of TiO_2 Thin Films as Solar Cell Materials Research in 2015-2024

Terms	Occurrences	Relevance
Dye sensitized cell efficiency	9	1.93
Counter electrode	32	1.50
Electron	10	1.45
Characterization	19	1.17
Solar energy	10	1.00
Photovoltaic performance	15	0.88
Organic dye	17	0.87
Nanoparticle	39	0.81
Solar cell	87	0.63
Photoanode	55	0.31

Below are the visualization is accomplished by generating a landscape map, which offers a visual representation of subjects related to scientific studies. The outcomes of bibliometric mapping for the co-word network in articles related to the topic synthesis of TiO_2

thin films as solar cell materials are illustrated in Figure 2.

Figure 2 shows the results of bibliometric keyword mapping on research trends on the synthesis of TiO_2 thin films as solar cell materials. In Figure 2 there are 54 keyword items that are often used in research on the synthesis of TiO_2 thin films as solar cell materials from 2015 to 2024. Figure 2 also contains 5 clusters, where the first cluster is colored red and consists of 16 keyword items, namely dye sensitized solar cell, electron, nanoparticle, photovoltaic performance, etc. The second cluster in green consists of 14 keyword items, namely characterization, electrode, fabrication, natural dye, etc. The third cluster in blue consists of 11 keyword items, namely gratzel, oregan, solar cell, technology, etc. The fourth yellow cluster consists of 11 keyword items, organic dye, application, effect, etc. The fifth purple cluster consists only 2 keyword items, namely photo anode and ZnO.

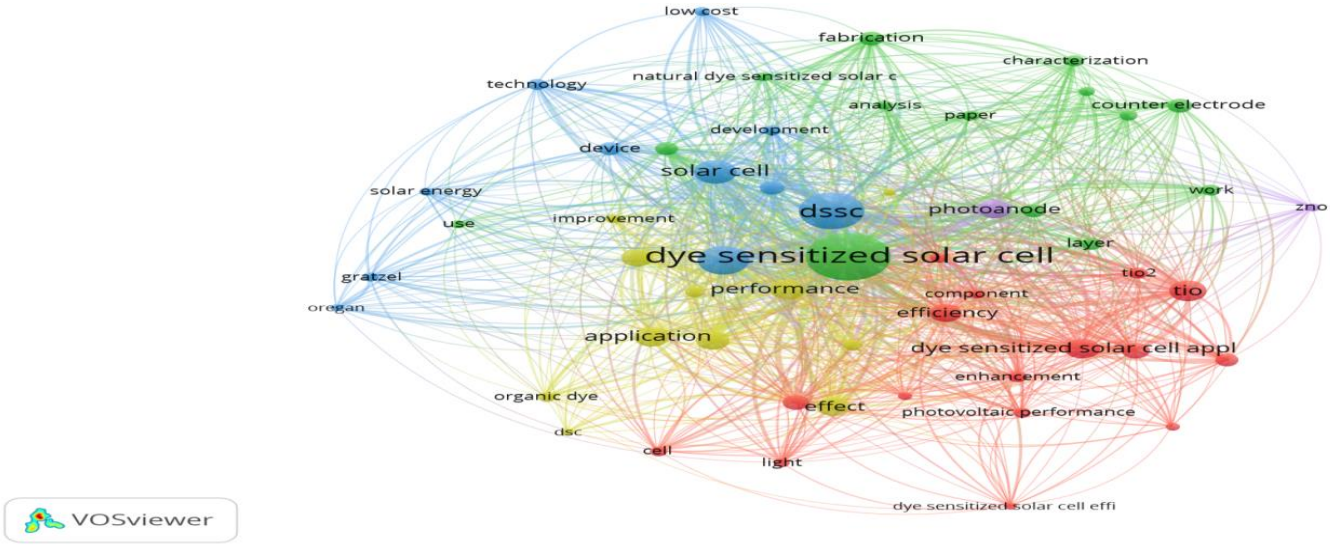

Figure 2. Network visualization on trend synthesis of TiO_2 thin films as solar cell materials research

Figure 2 above also shows that network visualization shows the network between the terms being visualized. Keywords classified into six clusters are arranged in a color chart showing the divisions/clusters that are connected to each other. The results of this analysis can be used to determine keyword research trends in the last year. This analysis shows several keywords that are often used in research on the synthesis of TiO_2 thin films as solar cell materials. The more keywords that appear, the wider the visualization displayed. Below are also presented keywords regarding the synthesis of TiO_2 thin films as solar cell materials based on overlay visualization.

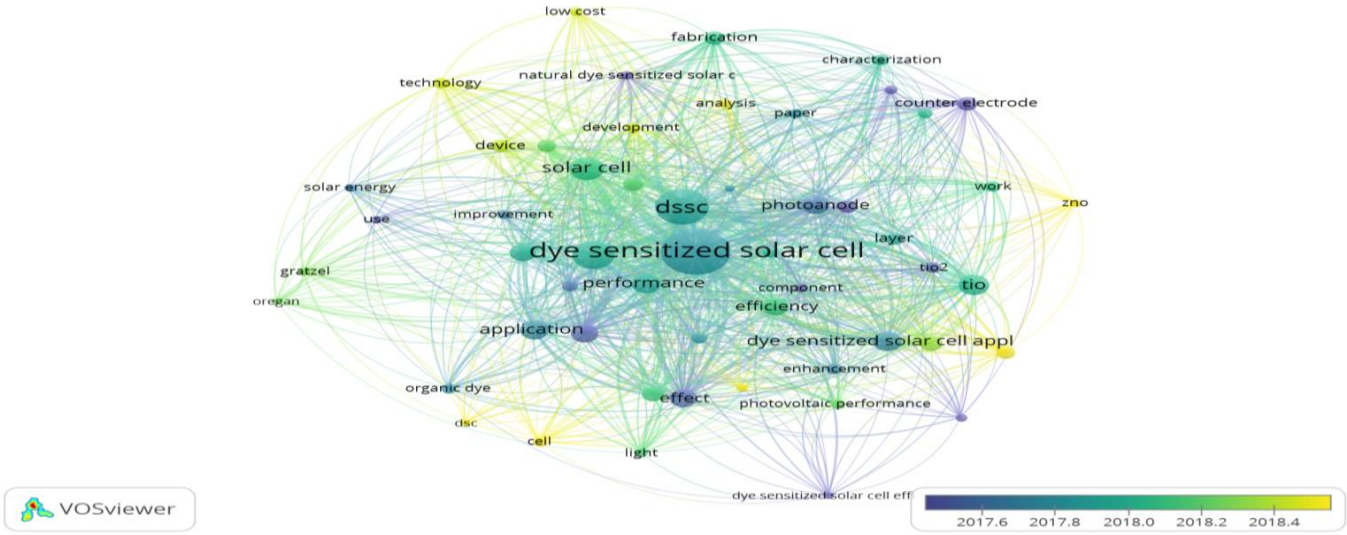

Figure 3. Overlay visualization on trend synthesis of TiO_2 thin films as solar cell materials research

Figure 3 shows the trend of keywords related to research on synthesis of TiO_2 thin films as solar cell materials in Google Scholar indexed journals from 2015 to 2024. Trends in the themes of writing articles related to synthesis of TiO_2 thin films as solar cell materials from the oldest to the newest year are marked with purple, blue themes, turquoise, dark green, light green and yellow. In the picture below you can see that the dye sensitized solar cell, photoanode, electrode, graphene, etc. This shows that these keywords were widely used by researchers in 2017. In 2018, the keywords that frequently appeared were solar cell, TiO_2, characterization, ZnO, photovoltaic performance, etc.

Research on synthesis of TiO_2 thin films as solar cell materials is one area of research that has developed rapidly in recent years. The following also presents keywords for synthesis of TiO_2 thin films as solar cell materials research based on density visualization.

Figure 4 shows density visualization. The density of research themes is shown in bright yellow. The brighter the colors of a theme, the more research is done. The fainter the color means the theme is rarely researched (Kaur et al., 2022; Liao et al., 2018). Faintly colored themes such as electrode, ZnO, fabrication, natural dye are dimly colored keywords. This shows that these keywords can be used as a reference for further research. Doyan et al. (2023) and Bahtiar et al. (2023) stated that yellow indicates keywords that are currently and frequently used in research, like dye sensitized solar cell, solar cell, TiO_2, photoanode, etc.

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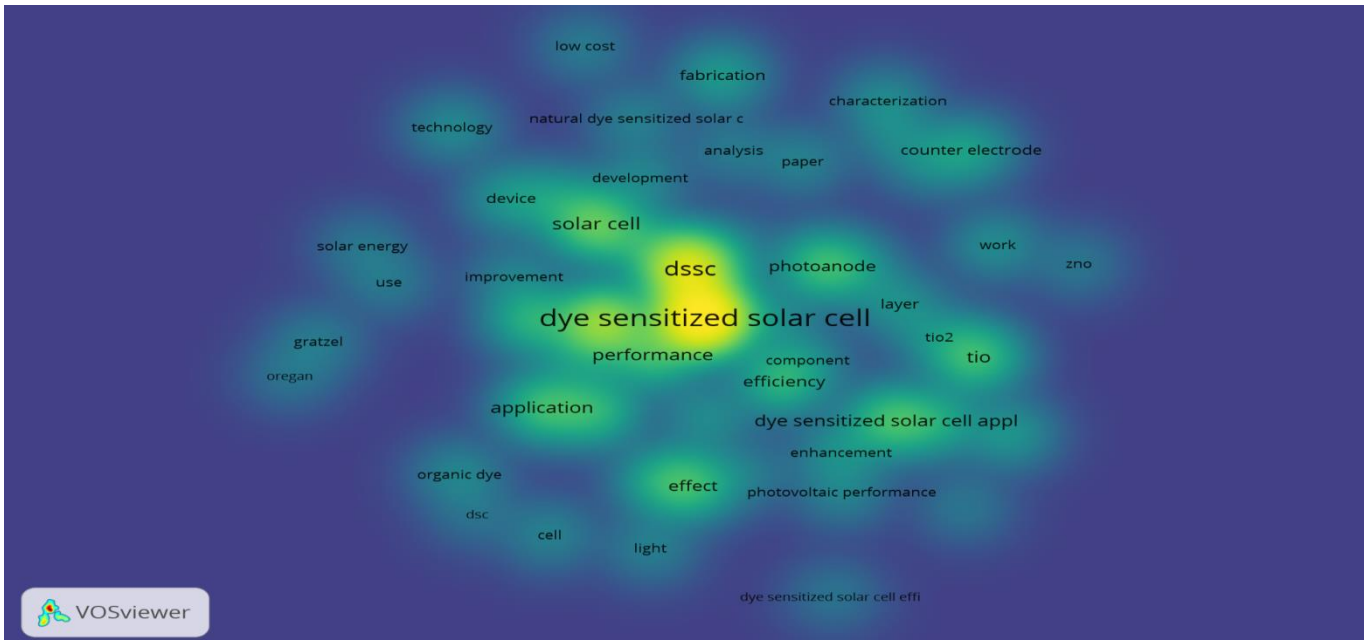

Figure 4. Density visualization on trend synthesis of TiO_2 thin films as solar cell materials research

Overall, continuously increasing research studies in the field of solar cell technology are certainly because the main source of this technology is utilizing sunlight which is unlimited to replace other energy in the future. The research trend in synthesis of $Ti0_2$ thin films as solar cell materials is expected to continue to develop in the next few years. This can be done by one of the fields of study that is often used as a research topic is the development of Thin Film Solar Cells or known as Thin Film Solar Cells (TFSC). However, if reviewed more deeply in terms of physical characteristics, the surface of the thin layer is still rough because basically the TiO_2 compound is in powder form, so treatment is still needed to maximize the potential of this thin layer so that it can absorb sunlight not only in ultraviolet light but also in visible light. The treatment that can be done to improve this performance is by carrying out a dye sensitization process and adding doping.

Conclusion

Research on trends in the synthesis of TiO_2 thin films as solar cell materials has urgency high. Research studies in the field of solar cell technology are certainly because the main source of this technology is utilizing sunlight which is unlimited to replace other energy in the future. The research trend on the synthesis of TiO_2 thin films as solar cell materials indexed by Google Scholar from 2015 to 2024 has experienced increases and decreases. There are many documents in the form of articles, proceedings, chapters, preprints, monograph and edited books that discuss research into the synthesis of TiO_2 thin films as solar cell materials. Key words that are often used in research about it are dye sensitized cell, electrode, electron, characterization, etc.

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