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Scientometric Analysis and Systematic Study of Nanomaterial Synthesized via CVD, Sol-Gel, and VPG Methods: A Big Data Clustering Perspective

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Abstract

Nanomaterials have massively attracted the attention of researchers in the last decade. Their outstanding properties can increase industrial product performance. Nanomaterials are widely used in medical, electronics, construction, agriculture, and environment sectors. The properties of nanomaterials highly depend on the synthesis methods. Chemical vapor deposition (CVD), sol-gel, and vapor phase growth (VPG) are some of the synthesis methods of nanomaterials that growth rapidly. A deeper understanding is needed to know their research interrelationship and development. This study performed scientometric analysis to gain nanomaterials research interrelationship and development. An understanding of nanomaterial research direction is essential to determine future research. The Scopus database was used to retrieve publication documents related to selected keywords. VOSviewer software was used to examine the scientometric analysis based on three different keywords (CVD, Sol-gel, VPG). A total of 6000 documents have been listed and split into each keyword, respectively divided from 320 journals that have relevance with chemical vapor deposition keyword, 277 journals of sol-gel keyword, and 468 journals of vapor phase growth. The final keywords connected were obtained after manual filtering post-processing. The scientometric analysis result was presented in networks and clusters of keywords. Each keyword has a link to the other that represents the connected variable in the research. The trend of nanomaterials research in the current and future can be analyzed from research networks.

*Keywords:*Nanomaterials, Scientometric analysis, Chemical vapor deposition, Sol-gel, Vapor phase growth

1. Introduction

The use of nanotechnology has grown rapidly in the past decade. Nanotechnology is one of the latest sophisticated technology that studies nano-scale objects (0.1 up to 100 nm) [1]. The concept of nanotechnology has attracted attention massively caused of the quantum phenomenon, which has given significant revolutionary in science and technology in the world [2]. Based on the strategy of the Europe Union in 2020, nanotechnology is one of the key enabling technology identified [3]. This strategy is expected to boost many industries' performance. Nanomaterials can be used in medical [4,5], electronics [6], agriculture [7], construction [8], environment [9], automotive [10], and energy [11]. Nanomaterials are widely used as the main material for drug delivery devices in the medical scope. Its outstanding mechanical, optical, and electrical properties are required in the electronics industry [12].

The properties, structures, and morphologies of nanomaterials are highly dependent on the synthesis method used [13]. Many researchers have explored the development of methods for the nanomaterial synthesis process to obtain the optimal result. There are two kinds of methods for nanomaterial synthesis method, namely top-down and bottom-up [14]. Top-down is a synthesis method to convert bulk material into nano-sized material. While the bottom-up is the opposite of the top-down method, combining and growing the atom or molecule into nano-sized. Mechanical milling, thermal evaporation, and sputtering are examples of the top-down method [15]. The bottom-up methods are chemical vapor deposition (CVD), sol-gel, and vapor phase growth (VPG). Of these various methods, chemical vapor deposition (CVD), sol-gel, and vapor phase growth (VPG) are the methods that are widely used in the process of synthesizing nanomaterials.

Chemical vapor deposition (CVD) is one of the most widely used methods in nanomaterials synthesis. This method is relatively easy by placing a thin coating of the gaseous reactant on the substrate. A chemical reaction occurs when the gas touches the surface of a heated substrate in the reaction chamber. As a result, a thin film is formed on the substrate surface [16]. The study conducted by Kanies et al. [17] demonstrated that thermoluminescence and optically enhanced luminescence reaction of Al_2O_3 as a material coating that deposited were successfully determined using the CVD method. The materials are proven to be used for corrosion resistance and can improve the mechanical properties of the system. The materials can also be joined with carbon and used as an excellent radiation dosimeter. Al_2O_3's unique combination of optoelectronic, dosimetric, and preventative characteristics positions this for dual-use implementations in nonproliferation, retrospective dosimetry, nuclear forensics, protective measures, emergency response, and nondestructive examination. In the nanotechnology areas, CVD was reported by many researchers as used for the primary synthesis materials [18,19]. Chemical vapor deposition (CVD) reported was used to synthesize multi-walled carbon nanotubes (MWCNTs) on nickel oxide (NiO)

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using ethanol as the carbon precursor based on a study obtained by Chan et al. [20]. The study discovered two factors influencing CNT development by changing many parameters during CVD: the catalyst size and precursor flow channel. With a constant gas flow rate, the precursor-flowing channel with a diameter of 12 cm effectively produced the maximum carbon production. Other parameters, such as temperature and pressure, are reported by Kun et al. [21] to understand the polymer composite micro-nano porous structure in its char layer. They [20] proposed that the precursor flowing channel varies with furnace temperature and gas flow rate. Furthermore, when the milling duration rose, the size of the synthesized NiO fluctuated. The 7-h milled NiO particles had a more fragmented site, a smaller nucleation site, and a higher surface area for carbon deposition. Another study conducted by Deng et al. [22] manufactures Ga-free AlInN in the close-coupled showerhead (CCS) using the reactor metalorganic chemical vapor deposition (MOCVD) method. The nanostructures served as potential applications in LEDs materials, LDs, photodetectors, and HEMTs technologies. The recent investigation led by Liu et al. [23] summarised the use of CVD technology in anti-bacterial technology. They discovered CVD is a good technology because of its benefits, including simple equipment, diverse precursors, and continuous and uniform features. The research conducted by Vega et al. [24] reported that a very simple low temperature-atmospheric pressure chemical vapor deposition was used to fabricate c-oriented and transparent ZnO films with UV/visible luminescent ratio on glass substrates. Highly oriented and dense columnar ZnO films were grown at low temperatures. This method gives a significant energy saving.

Sol-gel is another type of method that is widely used. The ease of the synthesis process is one of the advantages of the sol-gel method. This method is a combination of sol and gel. Sol is a colloidal solution consisting of solid particles deposited in a liquid. At the same time, the gel is a solid macromolecule dissolved in water. The sol-gel process involves several processes, namely hydrolysis, polycondensation, aging, drying, and calcination [2]. Many researchers reported successfully synthesizing different materials using sol-gel methods. Neiro et al. [25] used the inorganic sol-gel technique to synthesize alpha-alumina efficiently. The combination contained 87% $Al(OH)_3$ and 55% Al_2O_3. This effective process was developed utilizing a basic procedure that included salts as precursors and ultimate calcination. Chwatal et al.[26] reported an experimental and simulation study on a sol-gel system that allowed a quick solution and determination. Thermal and UV curing was used using an atmospheric pressure plasma jet system in a sol-gel system. The sol-gel coating product shows an antiviral and anti-bacterial effect verified by 99,98% to 100% of infectious load reduction. Another study about sol-gel was reported by Cai et al. [27]. They found that a block-structured lithium-ion battery anode material $ZnMn_2O_4$ can be successfully synthesized via the citric acid sol-gel combustion method. Due to the limited theoretical capacity of commercial graphite, it is widely known that Spinel $ZnMn_2O_4$ anode material offers great research value as a viable alternative anode material for lithium-ion batteries. Different materials were also reported successfully synthesized via sol-gel and applied in different applications, such as nano-cerium oxide (CeO_2) for composite films for ultraviolet blocking [28], recycling process from waste hen eggshells for the adsorption of lead ion [29], Er^{3+} doping in SnO_2 nanoparticles for semiconductor materials [30], $ZnWO_4$ and $Zn_{0.9}Cu_{0.1}WO_4$ nanoparticles for anti-bacterial applications [31], Pristine cobalt ferrite $CoFe_2O_4$ modified by the Dy^{3+} rare-earth ions for sensors devices [32], and anatase Tb/Tourmaline/TiO2 NTs for photocatalyst applications [33].

Vapor phase growth is an ecologically friendly technology that does not require extra materials or procedures and yields high-quality nanomaterials. The approach of vapor phase growth is commonly employed to produce several materials, such as SnO_2 and Ag/ TiO_2 [34,35]. Moreover, the technology of VPG attracts many researchers to use it for their primary synthesis [36,37]. Aligned Cesium Tin Halide Perovskite ($CsSnX_3$; X = Br, I) Nanowires c using a facile and robust vapor-phase epitaxial method by Chen et al. [38]. The $CsSnX_3$ can further be used as potential materials for optoelectronic devices, making physical research easier to explore. Another study conducted by Li et al. [39] showed that the Controllable Vapor-Phase Growth technique can be implemented to synthesize Inorganic Perovskite Microwire Networks. The results can potentially be used as solar cell materials, light-emitting diodes, and high-efficiency and temperature-stable photodetectors. VPG also can be used to synthesize 2D material, as reported by Xu et al. [40]. The 2D materials that can be successfully synthesized are Palladium diselenide (PdSe2), stable layered material with a pentagonal structure with excellent electrical and optoelectronic performance. Their study showed that by using VPG, the thickness, size, nucleation density, and morphology of $PdSe_2$ nanosheets can be tuned. Several studies further investigate Pb as the main element in their study and create different nano shapes; palladium (Pd) nanorods [41], PbI_2 polycrystalline thin film [42]. Many different materials are reported can be developed using this technique with unique applications, such as 3D FeNi@NCNT that is used as Efficient Oxygen Electrocatalysts for Zinc-Air Batteries [43]; Zn_2GeO_4 nanorods array as excellent semiconductor materials, i.e., light-emitting systems, photodetector, photocatalysis, and negative thermal expansion devices [44]; Mg-doped ZnO nanowire networks applied as highly sensitive and selective detection of ethanol [45]; boundary-rich layered double hydroxide nanosheet arrays for highly efficient water splitting, which used combines methods of ultrasound-seeded vapor-phase-transport growth [46]; and NiO/ZnO nanowire-heterostructures for gas sensing [47].

The three methods mentioned above that successfully synthesize nanomaterials are proven and used by many researchers around the world. Chemical vapor deposition, sol-gel, and vapor phase growth have been developed and combined with different methods. Hence, as the authors know, the compilation of the big data related to the mapping of the keywords, research cluster, and main journal published in these three types of synthesis remains unclear. To fill this emptiness, the present study uses software to gather data and cluster the three different nanomaterials syntheses to understand better new clues for the following research and a suitable journal that can be used for young researchers to do their research. Furthermore, a deeper understanding of the interrelationships between these nanomaterial synthesis methods is also presented. In this study, a scientometric analysis and review will be carried out on these nanomaterial synthesis methods to understand their development and interrelationships. The scientometric study will focus on research on the nanomaterial synthesis process in the last decade. The results of this study will be explained in detail and in-depth regarding the development and interrelationships of the nanomaterial synthesis method.

2. Research Method

An in-depth understanding of the development of nanomaterial synthesis methods is needed. This understanding will then be used to determine the direction of future research. This study used several methods, namely data collection and scientometric analysis. Scientometric analysis has been used to map the direction of research topics in the last decade. Fig. 1 describes the flow of the research methodology in this study. The data are gathered from the Scopus database. The present study has three main keywords: chemical vapor deposition (CVD), sol-gel, and vapor phase growth (VPG). The data was then downloaded based on the keywords and then analyzed.

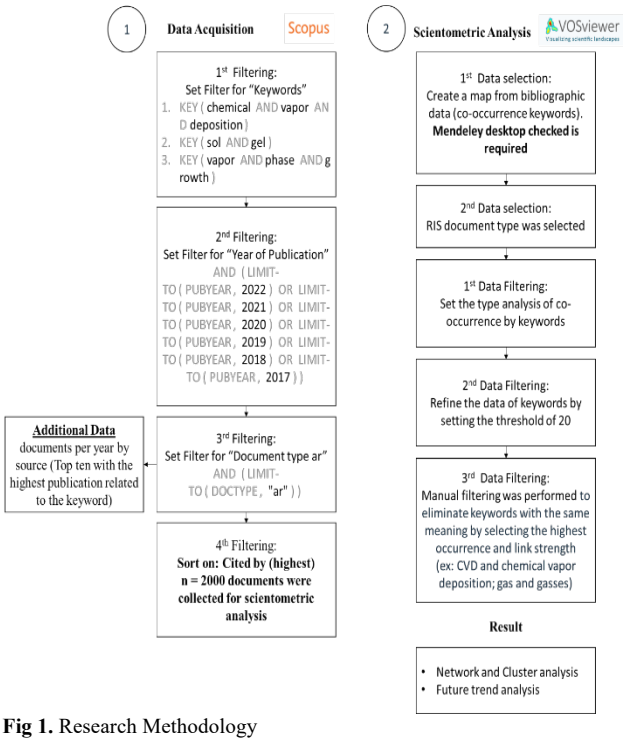

Fig 1. Research Methodology

2.1. Data Acquisition

Retrieving data is an essential part of this research. As suggested by Zheng et al. (2021) [48], there are two criteria in data acquisition, namely 1) contemporary and relevance and 2) quality assurance. All publications used in this study were retrieved between 2017 to 2022 and gradually filtered to get the relevant topic. Database selection is one of the processes in data acquisition. Scopus database was chosen as the literature database because it has a broad scope.

The data acquisition process was performed up to four steps of a filtering process to get the most relevant data. The screening process on the Scopus database was carried out with three different keywords. The keywords used are chemical vapor deposition, sol-gel, and vapor phase growth. Document filtering based on the publication year and document type was conducted to refine the data. Two thousand publication documents were obtained after sorting based on the highest citation number for each keyword. Furthermore, manual checking of publication documents using a Mendeley desktop was performed to increase the relevance of each keyword to the research topic. The completed algorithm of the document filtering process is shown in Fig 1.

2.2 Scientometric analysis

The scientometric analysis is a method for obtaining an overview and mapping the research structure. It can provide information about the latest research developments and find research gaps in the future. The open-source software VOSviewer was utilized to create a network visualization and modeling in this study, then grouped based on the research cluster [48]. The scientometric analysis method in this study was used to review the nanomaterial synthesis methods, namely chemical vapor deposition, sol-gel, and vapor phase growth.

The RIS documents of each keyword were used as the big data. In VOSviewer software, the analysis was processed based on keyword co-occurrence. All the documents have been checked using the Mendeley desktop to ensure the keyword's relevance and availability in each document. The threshold is set by 20 to refine the keywords. The invalid or the same-meaning keyword can be eliminated using manual filtering. The detailed process shows in Fig 1.

3. Results and Analysis

3.1. Chemical Vapor Deposition

Based on the screening process mentioned in section 2, 2000 publication documents were analyzed by VOSviewer software. From the result, 320 journals with 2000 documents have relevance with the chemical vapor deposition keyword. The top ten journals with the highest number of documents are summarized in Table 1. All journals with the chemical vapor deposition keyword have an average year of publication in 2018. ACS Applied Material and Interfaces Journal have the highest number of documents, with 139 or 7% of total publication documents with chemical vapor deposition keywords. The network and cluster visualization were obtained from scientometric analysis using VOSviewer. The keyword is the article's core content. The network interrelation of each topic can be provided by keywords [48]. In this study, the threshold of keyword co-occurrence was set to 20. In the chemical vapor deposition keyword, 288 keywords were satisfied with the threshold of 13287 keywords. Post-processing for manual filtering was performed to reduce some keywords with the same meaning, such as chemical vapor deposition or CVD, an oxide film, or oxide films. After the post-processing with manual filtering, the network mapping visualization obtained 213 keywords, 8 clusters, 11637 links, and 51876 total link strength.

Table 1. Top ten journals of CVD keyword

Journal	Number of Publication Documents	Percentage / Total Documents
ACS Applied Materials and Interfaces	139	7%
ACS Nano	125	6%
Advanced Materials	97	5%
Carbon	91	5%
Advanced Functional Materials	74	4%
Journal of Materials Chemistry A	63	3%
Nano Letters	60	3%
Applied Surface Science	58	3%
Nanoscale	58	3%
Journal of Alloys and Compounds	46	2%

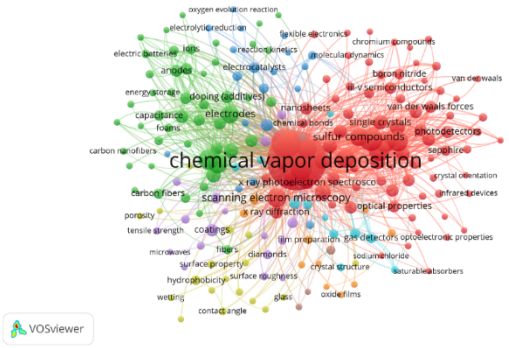

Fig. 2. Network visualization in chemical vapor deposition keyword.

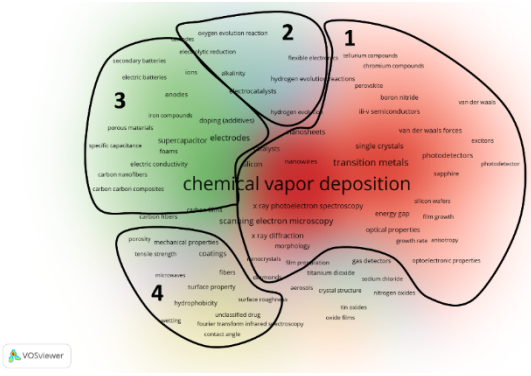

Fig. 3. Cluster visualization in chemical vapor deposition keyword.

The network mapping visualization is presented in Fig. 2. From Fig. 2, the circle size represents the occurrence weight of the keyword. Chemical vapor deposition is the most powerful keyword frequently appearing in network visualization. Chemical vapor deposition has 212 links and 11493 total link strength. Graphene is the most dominant material connected to chemical vapor deposition, with 210 links and 2843 total link strength. This matter has proven by several publications has been conducted. Graphene-encapsulated Au nanoparticles (Au@G) were successfully synthesized by Heguang et al. using chemical vapor deposition [49]. As reported by Qiu et al., 3D nanoporous graphene (np-graphene) was successfully doped with both N and Ni single atoms/clusters using the chemical deposition method [50]. Based on the several research studies that have been conducted, cluster visualization can successfully represent the keyword's connection between chemical vapor deposition and graphene. Scanning electron microscopy is the most used characterization method to characterize the chemical vapor deposition product. The number of links and total link strength represents the link between the keyword and the other [48].

Fig. 3 shows the cluster visualization from the chemical vapor deposition keyword. Two hundred thirteen keywords are divided into 8 clusters with four big clusters. The red color (cluster 1) is the central cluster, and chemical vapor deposition is related to some materials, namely graphene, transition metals, and perovskite. The chemical vapor deposition method has been investigated by research on several materials [51,52]. The present research can prove the strong connection between chemical vapor deposition and the kind of materials. The second biggest cluster is represented by a green color (cluster 3). The carbon nanotube's direct link to its application is presented in green color. Semiconductors and batteries are some examples of carbon nanotube applications. The blue cluster (cluster 2) shows the kind of reactions in chemical vapor deposition. The surface and morphology of chemical vapor deposition products are explained in the yellow cluster (cluster 4), which has a direct link in each keyword.

Hydrophobicity, wetting, and contact angle are the keywords directly linked to chemical vapor deposition. Hydrophobicity is essential in several applications, such as medical and energy. As reported by Cheng et al. [53], superhydrophobic silk fabrics from environmentally-friendly enzyme etching were successfully yielded by methyl trichlorosilane (MTCS) modification using simple thermal chemical vapor deposition at 70ºC. The fabric has excellent mechanical durability and high efficiency in oil separation. Thermal chemical vapor deposition of methyl trichlorosilane has also been performed by Gong et al. to produce a porous and hydrophobic aerogel from cellulose nanocrystals (CNCs). Aerogel shows great potential in environmental applications [54]. Based on the present research, cluster visualization has an excellent specific approach to determining the research.

3.2. Sol-Gel

Sol-Gel is one of the methods to synthesize nano-scale materials. After the data acquisition process, 2000 documents were obtained from the Scopus database. Table 2 summarizes the top 10 journals that obtained the sol-gel keyword. Journal of Alloys and Compounds contributed the highest number of published documents with sol-gel keywords. After analysis based on keyword co-occurrence, the visualization of networks and clusters was obtained. A total of 14490 keywords were obtained. After setting the threshold to 20, the number of keywords reduces to 416. Post-processing manual filtering was performed to reduce the similar keyword. Two hundred sixty-two keywords, 12 clusters, 18727 links, and 96036 total link strengths are shown in Fig. 4.

Table 2. Top ten journals of Sol-Gel keyword

Journal	Number of Publication Documents	Percentage / Total Documents
Journal of Alloys and Compounds	130	7%
Ceramics International	124	6%
Applied Surface Science	95	5%
ACS Applied Materials and Interfaces	76	4%
Chemical Engineering Journal	76	4%
Applied Catalysis B: Environmental	70	4%
RSC Advances	48	2%
Journal of Magnetism and Magnetic Materials	44	2%
Journal of Materials Chemistry A	37	2%
Sensors and Actuators, B: Chemical	35	2%

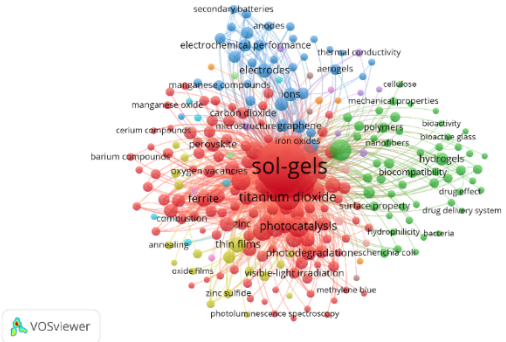

Fig. 4. Network visualization in sol-gel keyword.

Fig. 4 shows a network visualization of the sol-gel keyword. The enormous circle size in the network visualization represents the highest number of link and network occurrences. Titanium oxide is the second-highest number of links, with 239 links and 3352 total link strength. Several researchers reported that the sol-gel method successfully synthesized pure or hybrid titanium oxide [55,56]. Titanium oxide strongly connects to the sol-gel method on the network visualization. A total of 12 clusters with four major clusters appeared on the cluster visualization (Fig. 5). Some materials appear in the red cluster (cluster 1). The most frequently appearing is titanium oxide. The higher density of the red color shows it. Titanium oxide has been used in wide applications such as gas sensors [57], photocatalysis [58,59], and biosensors [60]. Some clusters represent the kind of sol-gel materials, applications, and characterization methods. For example, in the green cluster (cluster 3), several research publications about tissue engineering related to the sol-gel keyword. The far gap between keywords indicates that there is still a lack of interconnected research between the two. It means still having more challenges and chances to develop the related scope in the future. Based on their applications, sol-gel connects several scopes, such as tissue engineering, surface technology, and electronic devices. The recent research about sol-gel has successfully visualized network visualization and cluster visualization.

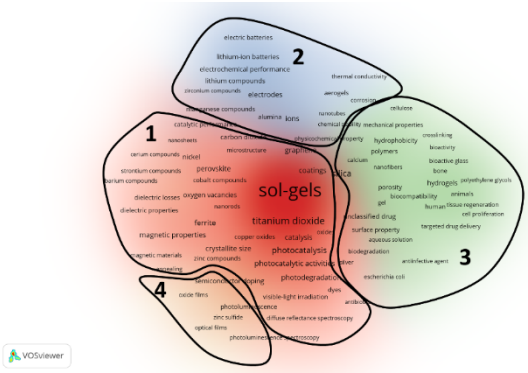

Fig. 5. Cluster visualization in sol-gel keyword.

3.3. Vapor Phase Growth

Vapor phase growth has many advantages in nano-scale materials synthesis. The product's quality and purity are two advantages of synthesizing nano-scale material using vapor phase growth [61,62]. Vapor phase growth was used as the keyword to collect the data for scientometric analysis. A similar data-retrieving process was performed for the vapor phase growth keyword. A total of 2000 publication documents were collected from the Scopus database. Based on the data, 468 journals have relevance with the vapor phase growth keyword. The top ten journals with the highest publication documents are presented in Table 3. The journal of crystal growth has the highest number of documents containing the vapor phase growth keyword. From 2000 documents, the scientometric analysis resulted in 263 keywords that met the threshold. After manual filtering, the keywords reduce to 140 items.

Chemical vapor deposition is the biggest circle in the network visualization, as shown in Fig. 6. Chemical vapor deposition has many relevances to the vapor phase growth research. Some characterizing processes appear on the network, such as scanning electron microscopy and transmission electron microscopy. As reported by several publications, characterizing process plays an important role in determining the result. The research conducted by Muflikhun et al. reported that the shape of nanocomposite can be identified by scanning electron microscopy (SEM) in each baking time variation [63]. On the network visualization, the link connects chemical vapor deposition and semiconductors. It can be interpreted that those keywords have been explained and discussed in the same research and publication. Substrates, growth rates, and nucleations are the most frequently observed topics in vapor phase growth. The keywords are divided into five main clusters (Fig. 7). The red cluster (cluster 1) has the highest link and total link strength compared to the others.

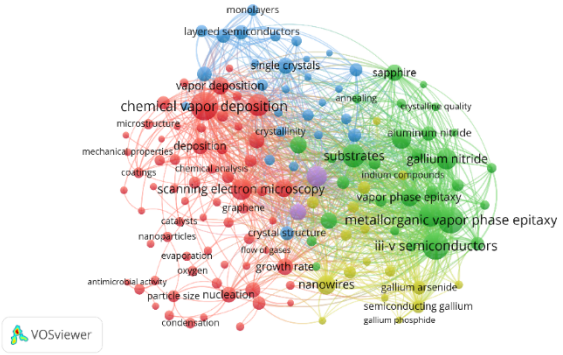

Fig. 6. Network visualization in vapor phase growth keyword.

4. Future trends for user

The data we are provided include the raw data we used to generate the model, as shown in the present study, which are available in the paper's supplementary material. The data can be gathered directly using VOS software for further analysis. Based on the results, the trend can be pointed to 3 different synthesis models, chemical vapor deposition (CVD), Sol-gel, and vapor phase growth (VPG). Fig. 8-10 explains the development of nanomaterial research in overlay visualization. The chemical vapor deposition method has a broad scope of research. Fig. 8 shows that coating technology is the most recent technology developed. The lighter circle color in overlay visualization indicates the newest research on the topic. The research reported by Şakalak et al. on chemical vapor deposition resulted in a superhydrophobic thin film on a substrate [64]. The coating performance was evaluated using contact angle measurement and XPS. Coating technology can enhance the high-voltage electrochemical performance [65].

Table 3. Top ten journals of VPG keyword.

Journal	Number of Publication Documents	Percentage / Total Documents
Journal of Crystal Growth	140	7%
Applied Physics Letters	47	2%
ACS Applied Materials and Interfaces	44	2%
Crystal Growth and Design	42	2%
ACS Nano	41	2%

International Journal of Heat and Mass Transfer	40	2%
Journal of Applied Physics	40	2%
Applied Surface Science	39	2%
Nano Letters	38	2%
Journal of Alloys and Compounds	37	2%

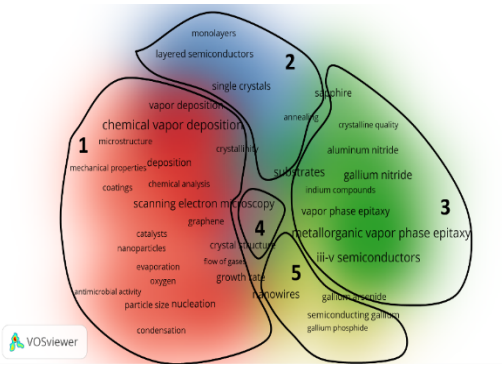

Fig. 7. Cluster visualization in vapor phase growth keyword.

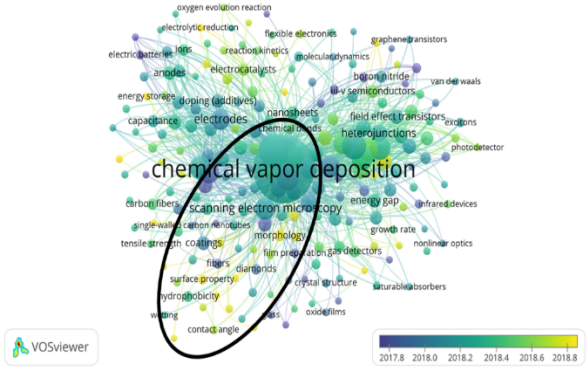

Fig. 8. Overlay visualization in chemical vapor deposition keyword.

Sol-gel overlay visualization is shown in Fig. 9. The sol-gel method leads to the development of bio-synthetized nanomaterial applications. The lightest color and the long distance between links indicate the newest research and the chance to be developed. Biomedicine, biomaterial, biosensor, and tissue engineering are examples of nanomaterial bioapplication. Igal et al. [66] investigated the sol-gel method to produce the antimicrobial textile. In the tissue engineering scope, the sol-gel method has been used to synthesize nanocomposite hydrogel with injectible and biodegradable double-network [67]. Hydrogel is a critical property for biomaterial because of similar to human soft tissue. Therefore, hydrogel is essential for developing drug delivery devices and tissue engineering [68]. Besides biomaterials, sol-gel is widely used in the synthesis method of II-VI semiconductors. II-VI semiconductor is a unique material that contains elements of group ii metallic and iv non-metallic of the periodic table. An example of an II-VI semiconductor material is zinc oxide (ZnO). Zinc oxide is widely used as an essential component such as batteries, sensors, anti-bacterial [69], solar cells [70], and lubricants [71].

Vapor phase growth has many advantages in improving the quality and purity of the nanomaterial product. Low cost and environmentally friendly are the reasons vapor phase growth is promising to be developed in synthesizing nanomaterials. Fig 10 shows the overlay visualization of the vapor phase growth keyword. There are two fields of development orientation in vapor phase growth. Tibayan et al. [34] reported that horizontal vapor phase growth successfully synthesized the UV resistance of Ag/SnO_2 nanocomposite. In other applications, horizontal vapor deposition has been used to synthesize anti-bacterial material [62]. Semiconductors are one of the popular topics on nanomaterials synthesis using the vapor phase growth method. The gap between semiconductor keywords and others indicates the big chance to develop research topics related to semiconductors. The light color circle on the overlay visualization indicates the newest research by year classification.

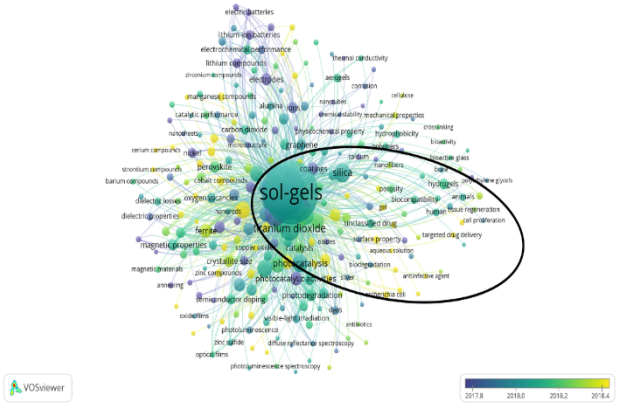

Fig. 9. Overlay visualization in sol-gel keyword.

Scientometric analysis can demonstrate the recent and future trends in developing three different nanomaterials synthesize methods. Overlay visualization gives a clear direction to the related research. This analysis is important to connect the research gap between each keyword. The future trend of the research can be determined by analyzing the link distance and circle color of related research on the topics.

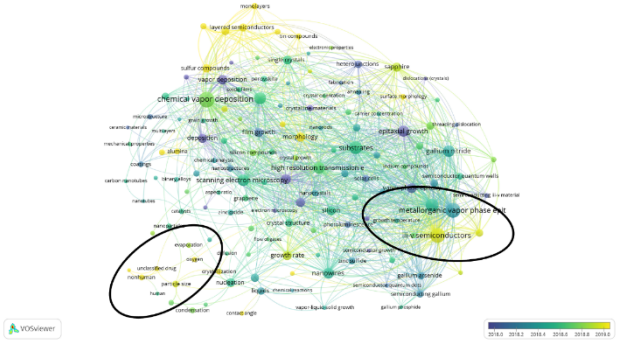

Fig. 10. Overlay visualization in vapor phase growth keyword.

5. Conclusion

Nanomaterials are advanced technology materials that have been widely applied in the industrial sector. Several methods have been developed in the process of synthesizing nanomaterials. These methods are chemical vapor deposition (CVD), Sol-gel, and vapor phase growth (VPG). Scientometric analysis can provide an overview of research development on nanomaterial synthesis methods. Retrieving documents based on keywords in the Scopus database results

in highly relevant documents to the topic. Scientometric analysis using VOSviewer produces networks and clusters related to one another.

The chemical vapor deposition yielded 212 links and 11493 total link strength. Graphene is the second most common keyword after chemical vapor deposition. Eight research clusters formed with four large clusters. The sol-gel method has 239 links and 3352 total link strength. Research on sol-gels has a strong relationship with the scope of tissue engineering, surface technology, and electronic devices. A total of 140 keywords that meet the threshold are obtained in the vapor phase growth. Vapor phase growth has research links with chemical vapor deposition. The scientometric analysis method makes it possible to obtain linkages and relationships between one research variable and another. The current research trends can be obtained and developed in future research.

Acknowledgments
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