Scientometric Exploration of Indian Semiconductor Research: Visual and Analytical Perspectives

Mumtaj Begum, H
PhD Research Scholar,
Department of Library and Information Science
Alagappa University, Karaikudi, Tamil Nadu and
Librarian and Information Assistant Grade-II A
Anna Centenary Library, Chennai, TN, India
E-mail:mumtajh@gmail.com

Raja, S
Research Supervisor and Assistant Librarian
Department of Library and Information Science
Alagappa University, Karaikudi, TN, India
Email: lisraja1979@gmail.com

Abstract

This scientometric research examines semiconductor studies in India using data from the Web of Science Database from 2003 to 2013. The study analyzed 19,290 records and 18,105 journal articles, revealing an increasing trend in publications. The Indian Institutes of Technology (IIT) is the highest contributor, followed by IISc and Bhabha Atomic Research Center. The research focuses on physics, materials science, and chemistry, with engineering leading. The study identified 30,120 authors, including Kumar and Rajagopal. India ranks third in global semiconductor research, with the USA and South Korea leading. The research provides insights into the Indian semiconductor ecosystem, contributors, regional hotspots, and open spaces.

.

Keywords
Scientometric; Semiconductor Research; Visualization; India

Electronic access
The journal is available at www.jalis.in
DOI: **10.5281/zenodo.14235412**

Journal of Advances in Library and Information Science
ISSN: 2277-2219 Vol. 13. No.4. 2024. pp.193-200

1. Introduction

The semiconductor industry has become a cornerstone of technological advancement, powering everything from consumer electronics to critical infrastructure. As the global demand for semiconductors continues to surge, the need for robust research and development (R&D) in this domain has never been more apparent. India, with its growing technical prowess, has increasingly contributed to semiconductor research, establishing itself as a notable player in this field. However, despite its growing presence, comprehensive analyses of India's contributions to semiconductor research remain scarce. With semiconductor technology being pivotal for the future of industries such as artificial intelligence, telecommunications, and energy, understanding the trajectory of Indian research is crucial for policymakers, researchers, and industry stakeholders. This article examined how India is positioning itself in the world of electronics, and what opportunities and challenges lay ahead for its research efforts. Through visual analysis on research data to find out these two experiments the way in which Indian academia and industry are participating with semiconductors is uncovered.

2. Review of Literature

Anand and Aravind (2024) traced recent developments in mesentery research using data from the Web of Science, from 1989 to 2022. Their study indicates that journals are the main medium for publication: 81.7% of papers appeared were in journals (the peak year being 2021). The most prolific journal was The American Journal of Physiology-Heart and Circulatory Physics. As the authors demonstrate through growth trends, author productivity, geographic distribution, and international cooperation, this research offers invaluable insights into future directions of inquiry.Wang et al. (2024) provide a detailed account of the most recent developments in organic semiconductors, citing improvements in materials stability and higher device efficiency. Sharma and Singh (2016) describe the latest whole project, giving many pages to semiconductor products such as specialized low-voltage sensors and circuits. Yang et al. (2015) reviewed progress in organic semiconductors, considering that it was not optimal just to transplant conventional silicon technology.Sharma and Singh (2024) describe the latest whole project, giving many pages to semiconductor products such as specialized low-voltage sensors and circuits. Yang et al. (2024) reviewed progress in organic semiconductors, considering that it was not optimal just to transplant conventional silicon technology.Garcia et al. There was also a paper (2023) on power electronics talking about how far wide bandgap power devices have come. Leaving apart studies conducted by future researchers, C. Nair and B. Reddy (2023) also did a bibliometric study on semiconductor research in India to specify the increment of Indian incipient contributions and focus area at this research theme.

Zhang et al. (2022) discussed higher-power semiconductor materials such SiC and GaN for high efficiency energy conversion systems. Lee and Park (2022), they highlighted that the concord of theory and practice in current semiconductor photonic devices specifically LEDs and laser diodes. Kumar, Patel 2021) pointed out the continuing rise of nanotechnology and how it has significantly changed the game when it comes to semiconductor manufacturing through better raw material processing, device quality. Chen (2021) highlighted two dimensional materials such as graphene and MoS_2, from the perspective of a new material platform with unique properties, and system-level integration for semiconductor applications.

3. Research Methodology

The type of research carried out in this work is exploratory, descriptive and quantitative based on the techniques and tools of bibliometric analysis of the documents stored in the Web of Science bibliographic database. This is one of the world's most important databases of bibliographic references and citations of periodical publications. The data was downloaded on April 2023 for time span of 20 years (2003-2023). VOS viewer bibliometric tool is also used for coupling the data. The search string was "Semi Conductor" address as "India" and customize the period of time '2003 to 2023'. After screening the total dataset of 19290 entries journal article were 18105 selected for the study, all these downloaded bibliographic details were transferred to Google sheet application and data was analyzed as per objective of the study.

3.1 Statement of the problem

An extensive scientometric analysis was carried out to evaluate Indian Semi Conductor Research Outputs, and a new outlook on the same prevailed from this work. The purpose of the research is to find out about research trends, publication influences, collaborative networks and knowledge gaps in the field of Indian Semi Conductor. The direction to be taken for future research efforts is guided with the help of this study and serves as a database during International Patent Classification for Semiconductor Patents decisions on Indian Semi Conductor development activities.

3.2 Objectives of the Study

1. Identify the growth pattern and analyze the Relative Growth and Doubling Time
2. Assess the impact of the metrics of most prolific Authors and productive Journals
3. Identify the major Research organization in the field Indian Semiconductor Research
4. To Explore the global contribution to the Indian semi conductor research
5. To Create visual representations of bibliographic Networks and Impacts

4. Data Analysis and Discussion

4.1 Growth Pattern, Relative Growth and Doubling Time

Table 1 reveals clear case of record growth year by year can be traced in the contribution analysis. The number of records steadily increased from 2003 to 2007, with peaks of 267 in 2003 and 425 in 2006 followed by a slight decrease to a total of 417 records reported during the year .The first stage shows the initial growth, though perhaps with a little variability. In the year 2008 to 2012 showed a stronger uptrend, with number of records nearly doubling from 540 in 2008 to 671 in 2012. This period was defined by more consistent growth, especially during 2008to 2009 and 2012 to 2013 when the golden years of high and sustained growth were recorded. Overall the contributions show a rising trend, but with some fluctuations.

Doublings derived from annual growth rates do not show such a clear signal of the dynamics of change over the years. Years of high growth, ie 2006 with a rate of 31.60% and again in 2008 at 29.48%, are close to no doubling time showing an explosive progress in those years. Similarly, and counter-intuitively, years with slower rates of growth such as 2011 (4.66%) or 2014 (14.69%), have longer doubling times which reflect scores indicating slow but steady growth. Years with low growth rates, such as 2019 (3.54%) and 2022 (2.83%), show even longer doubling times, indicating weak growth. Doubling times do not apply to years with negative growth rates (e.g. 2007: −1.88%, 2020: 0.16%), because these are indicative of these rates show a decrease instead of an increase. This Analysis illustrates those changes ingrowth rates are immediately reflected in the speed of doubling, such as faster doubling times with higher rates and slower or no doubling time with negative or low growth rates.

Table 1 Growth pattern of Semiconductor Research in India

Sl No.	Publication Year	Record Count	% of 18,105	Relative Growth	Doubling Time
1	2003	267	1.48%	0	0
2	2004	298	1.65%	11.62	5.98
3	2005	323	1.78%	8.4	8.25
4	2006	425	2.35%	31.6	2.2
5	2007	417	2.30%	-1.88	0
6	2008	540	2.98%	29.48	2.35
7	2009	660	3.65%	22.22	3.12
8	2010	643	3.55%	-2.58	0
9	2011	673	3.72%	4.66	14.87
10	2012	671	3.71%	-0.3	0
11	2013	783	4.33%	16.71	4.15
12	2014	898	4.96%	14.69	4.71
13	2015	908	5.02%	1.11	62.46
14	2016	1,043	5.76%	14.83	4.68
15	2017	1,110	6.13%	6.44	10.77
16	2018	1,241	6.85%	11.79	5.89
17	2019	1,285	7.30%	3.54	19.59
18	2020	1,287	7.56%	0.16	433.53
19	2021	1,488	8.75%	15.61	4.44
20	2022	1,530	8.68%	2.83	24.5
21	2023	1,495	7.46%	-2.29	0

4.2 Major Research Areas of Indian Semi Conductor Research :

Table 2 Major Research Areas of Indian Semi Conductor Research

Sl No.	Research Areas	Record Count	% of 153
1	Physics	83	54.25%
2	Materials Science	69	45.10%
3	Chemistry	44	28.76%
4	Science Technology Other Topics	28	18.30%
5	Engineering	27	17.65%
6	Optics	9	5.88%
9	Nuclear Science Technology	6	3.92%
7	Instruments Instrumentation	5	3.27%
8	Metallurgy Metallurgical Engineering	5	3.27%
9	Computer Science	2	1.31%
10	Electrochemistry	2	1.31%

Indian semiconductor research the distribution of research areas clearly shows a strong emphasis on few critical areas in Indian semiconductor research. Because it is the fundamental discipline underlying due to which physics heads with the major number of entries making 54.25 % of total research focus internationally, which reflects importance from semiconductor material research point of view, followed by Materials Science with 45.10%, highlighting the material properties and phenomena essential for semiconductor technologies. Chemistry also has a significant contribution (28.76%) for this research, which make it clear that the importance of chemical process and properties in semiconductor development. Fewer than 20% of all major awards are obtained with respect to other scientific areas such as Science Technology Other Topics (18.30%, representing the lowest contribution), together with Engineering (17.65%) highlighting what appears to be a wide interdisciplinary perspective. The analysis shows that the data patterns indicate an overall emphasis on physics, Materials science and chemistry as top priority research domains, alongside a range of other disciplines which have elements in common with those.

4.3 Institution and Author Collaboration:

Semiconductor research in India is significantly contributed by a total number of 5423 institutions contribute for semiconductor research in India with top institutes such as Indian Institute of Technology (IIT) contributes 1703 documents, 40451 citations and total link strength 1325. This is followed by the

Indian Institute of Science (IISc) with 890 contributions, 26387 citations, and a link strength of 872. Bhabha Atomic Research Center which contributes to 502 publications,11433 citations, and a link strength of 626. Other notable institutions such as the National Institute of Technology (651 papers, 12959 citations, 540 link strength) and Jadavpur University(429 papers,6853 citations, 458 link strength) strengthen India's standing in semiconductor research through its high volume and high impact.

Fig 1 shows the VOSviewer visualization displays a co-authorship network of institutions, where 523 institutions have met the threshold of 13,456, indicating substantial research activity.

Table 3 Affiliated Research Institution wise Contribution

Sl No.	Affiliated Reaserch Institutions	Contributions	Citations	Total Link strength	Sl No.	Affiliated Reaserch Institutions	Contributions	Citations	Total Link strength
1	Indian Institute of Technology	1703	40451	1325	11	SRM Institute of Science & Tech	206	[illegible]	[illegible]
2	Indian Institute of Science	890	26387	872	12	University of Calcutta	291	[illegible]	[illegible]
3	Bhabha Atomic Research Center	502	11433	626	13	Indian Association for the Cultivation of	487	16020	306
4	National Institute of Technology	651	12959	540	14	Academy of Scientific & Innovative Research	201	3430	303
5	King Saud University	194	5096	532	15	SN Bose National Center for Basic Sciences	195	4242	303
6	Jadavpur University	429	6853	458	16	Yeungnam University	124	2140	280
7	CSIR	286	8617	399	17	University of Delhi	335	6439	279
8	King Khalid University	106	1467	354	18	Inter-University Accelerator Center	150	2489	277
9	Anna University	335	7650	344	19	Indian Institute of Technology Delhi	329	[illegible]	[illegible]
10	Homi Bhabha National Institute	186	1750	339	20	Jawaharlal Nehru Center for Advanced	267	13038	264

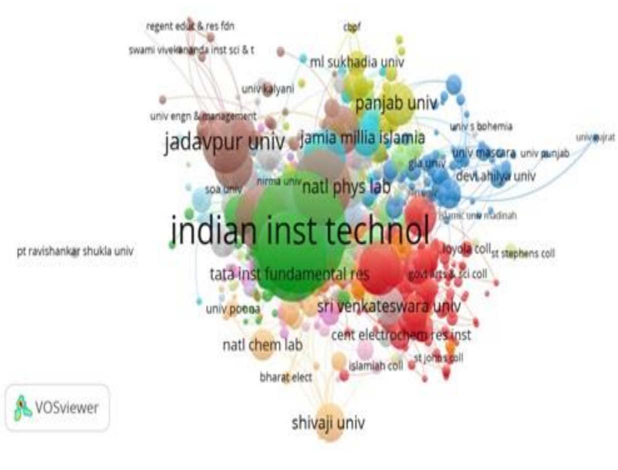

Fig 1. Visualization of Institutional Networks

4.4 Authorship and Co Authorship:

Analysis of the authorship pattern reveals that most of the papers published are collaborative. The number of single-authored is low for 407 while multi-authors feature more. There is a strong trend towards large collaboration the largest number of records, 16,695, was on papers with more than five authors. For three authors the number is somewhat higher (3,966) and for four authors it is still significant (3,247). Combined these numbers to record as 3,563 double-author works and 2,242 five-authors publications. In the end, the findings come down on favor of teams being more attractive for participation in collaborative research.

Table 4 Authorship Pattern

Sl No	Authorship Pattern	No. of Authors	CI
1	Single Author	407	98.50%
2	Double Author	3563	
3	Three Authors	3966	
4	Four Authors	3247	
5	Five Authors	2242	
6	More Than Five Authors	16695	
	Total	**30120**	

In India, authorship and co-authorship in the field of semiconductor research is found to be highly collaborative, with a total of 30,120 authors involved. The leading contributor is Kumar, A. with 76 documents and an 1463 citations giving it a total link strength of 86. V. Rajagopal Reddy has contributed 95 documents with 2154 citations and link strength (S) of 47, along with Reddy, V.Also Kumar, Sandeep and Choudhary, R.N.P., both of them with 66 documents having themselves over then 1300 citations. Ray, Partha Pratim and Ghosh, Hirendra N. have authored another 64 articles apiece as well with these papers receiving citations of 1335 and 1487. They are hence the core researcherthe ones driving semiconductor research because of their high citation count and having strong collaborative link in India. Fig 2 represents the VOSviewer visualization illustrates a co-authorship network, with "Kumar, Sandeep," "Ghosh, Hirendra N.," and "Ray, Partha Pratim" as central figures, reflecting their significant roles in collaboration due to their larger nodes.

Different colored clusters represent tightly connected groups of researchers.

Table 5 Most Productive Authors

Sl No.	Authors	Affiliated Institutions	Record Count	% of 18,105	H index
1	Kumar A	Gurukul Kangri Vishwavidyalaya	445	2.46%	5
2	Kumar S	DAV University, Jalandhar	292	1.61%	19
3	Ghosh S	Vikram University	226	1.25%	10
4	Singh S	National Institute of Technology Patna	219	1.21%	18
5	Kumar P	Graphic Era University	212	1.17%	15
6	Kumar R	Garg PG Degree College	201	1.11%	5
7	Kumar M	Mahatma Jyotiba Phule Rohilkhand University	164	0.91%	5
8	Das S	National Institute of Technology Meghalaya	161	0.89%	9
9	Kumar V	Indian Institute of Technology Dhanbad	153	0.85%	13
10	Singh A	Thapar Institute of Engineering & Technology	142	0.78%	6

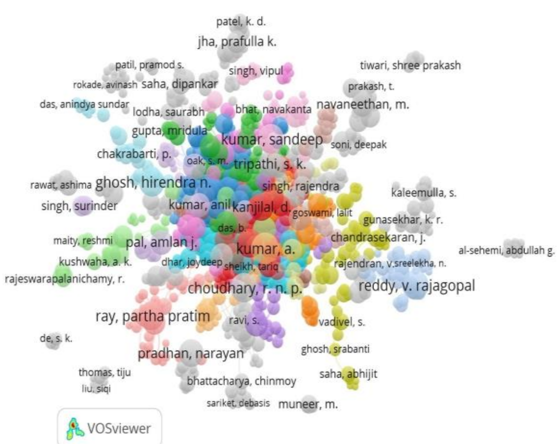

Fig 2 Net work Visualization of Authors Contributions

4.5 Journals preference for the communication by the researchers

In Indian semiconductor research, Some of the top journals in Indian semiconductor research are known for their high impact and importance. Journal of Applied Physics is the top with 504 articles and an H index of 350, it was published by the American Institute of Physics in USA who has an impact factor of 3.2. After this journal, the second is Journal of Alloys and Compounds with 426 records published by Elsevier B.V. in Netherlands and having an H-index of 215 that also sounds very good about again a high impact factor 6.2.It publishes 374 records with a high H-index of 338, and it is the Journal of Physical Chemistry C that you can read in this scientific journal by American Chemical Society in the USA with an impact factor of 3.3.Lastly, the Journal of Materials Science: Materials in Electronics has 368 records, published by Springer in NY, USA, and features a H-index of 97 and an impact factor of 2.8. These journals are instrumental in the progress of the semiconductor research happening in India and that is a testimony to their massive output, impact on the Indian semiconductor research landscape.

Table 6 Journals preference for the communication by the researchers

Sl No.	Publication Titles	Record Count	Rank	Publisher	Country	H index	Impact Factor
1	Journal Of Applied Physics	504	1	American Institute of Physics	USA	350	3.2
2	Journal Of Alloys And Compounds	426	2	Elsivier B V	Netherland	215	6.2
3	Journal Of Physical Chemistry C	374	3	American Chemical Society	USA	338	3.3
4	Journal Of Materials Science Materials In Electronics	368	4	Springer ,NY	USA	97	2.8
5	Physical Review B	293	5	American Physical Society	USA	497	3.7
6	Materials Chemistry And Physics	291	6	Elsevier B V	Netherland	177	4.3
7	Physica B Condensed Matter	281	7	Elsevier B V	Netherland	130	2.9
8	Materials Letters	276	8	Elsevier B V	Netherland	172	2.7
9	Ieee Transactions On Electron Devices	256	9	IEEE Transactions on Electron Devices	USA	205	3.2
10	Applied Surface Science	251	10	Elsivier B V	Netherland	235	6.3
11	Rsc Advances	244	11	Royal Society of Chemistry	UK	210	3.9
12	Applied Physics Letters	241	12	American Institute of Physics	USA	478	3.5
13	Materials Science In Semiconductor Processing	238	13	Elsevier Ltd	UK	85	4.2
14	Optik	212	14	Elsevier GmbH	Germany	104	3.1
15	Materials Research Bulletin	191	15	Elsevier Ltd	UK	130	5.6

4.6 Global Collaboration with Indian Semiconductor Research

The table 6 enumerates the top 20 contributors to the research connected with Indian seminar among 108 countries analysed. In terms of contributions for the sample provided, India leads by a large margin with 18,105 documents (100% documents within the sample). The dominance of Chinese publications is evident from their 1,036,000 citations and high total link strength score (12,399), while India trails with just above 395,000 citations, and good enough total link strength of 7,448 implying that its research has impact as well as is collaborative. Other significant contributors include the USA, with 895 contributions (4.94%) and 27,343 citations, followed by South Korea with 773 contributions (4.27%) and 19,775 citations. Countries like Saudi Arabia, Japan, and China show contributions ranging between 444 and

478, with notable citation and link strength numbers, suggesting active engagement in this research field.The data reflects a broad international interest in Indian semiconductor related research, with contributions varying in scale but significant in academic impacts.

The VOSviewer visualization highlights in figure 3 , there is a strong global collaboration, with 108 countries meeting the 77 threshold, indicating extensive international research exchange. India is the central node in the green cluster, reflecting its prominent role in global partnerships with major collaboratoring countries

Table 7 Country wise contribution

Sl No.	Country	Contribution	Percetnage	Citations	Total Link strength
1	INDIA	18,105	100.00%	395000	7448
2	USA	895	4.94%	27343	1495
3	SOUTH KOREA	773	4.27%	19775	1282
4	SAUDI ARABIA	478	2.64%	13616	1108
5	JAPAN	444	2.45%	13274	770
6	PEOPLES R CHINA	350	1.93%	11327	891
7	GERMANY	383	2.12%	12038	714
8	ENGLAND	292	1.61%	10359	637
9	TAIWAN	260	1.44%	6478	442
10	AUSTRALIA	194	1.07%	6516	390
11	ITALY	182	1.01%	5240	366
12	FRANCE	170	0.94%	3791	341
13	SINGAPORE	144	0.80%	4318	279
14	MALAYSIA	133	0.74%	3721	343
15	SWEDEN	123	0.68%	2943	246
16	CANADA	122	0.67%	3084	244
17	SPAIN	112	0.62%	2991	261
18	SOUTH AFRICA	95	0.53%	3692	193
19	EGYPT	89	0.49%	2095	243
20	POLAND	86	0.48%	2267	198

The VOSviewer visualization highlights strong global collaboration, with 108 countries meeting the 77 threshold, indicating extensive international research exchange. India is the central node in the green cluster, reflecting its prominent role in global partnerships with major collaboratoring countries

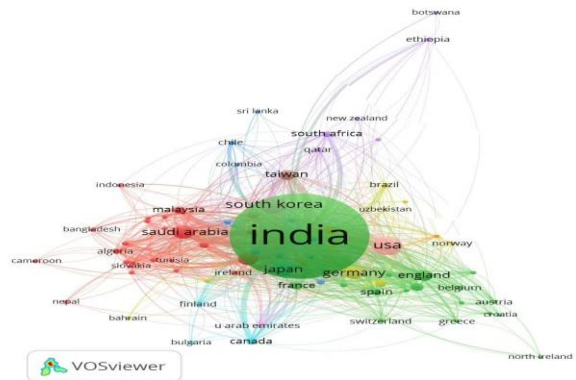

Fig 3 Network Visualization of Global collaboration with Indian Semiconductor Research

4.7 Distribution of Keywords Occurrences:

Analysis of keyword occurrences shows that "SemiConductor" as the strongest term, occurring 2924 times with a log frequency of 3.466 It is further followed by the presence of "Nanoparticles" and "SemiConductors" with good frequencies and low log values. The other keywords of import include "Optical-properties" "Performance," and "Thin-films. These include "Photoluminescence," "Growth" and "Temperature," all of which suggest that the focus was on the material properties and how it propagated. The the analysis results dataset highlights considering semiconductor materials and nano-particles as a key topic of this enormous effort to understand in detail each aspect of these specific features.

Table 8 Zips law of Key word of Occurrences

l No	Keywords	Occur rence	Rank	Log F	Log R	Log C
1	SemiConductor	2924	1	3.466	0	3.466
2	Nanoparticles	1950	2	3.29	0.3	3.59
3	SemiConductors	1886	3	3.276	0.48	3.756
4	Optical-properties	1512	4	3.155	0.6	3.755
5	Performance	1509	5	3.153	0.7	3.853
6	Thin-films	1346	6	3.128	0.78	3.908
7	Photoluminescence	1205	7	3.081	0.85	3.931
8	Growth	1093	8	3.039	0.9	3.939
9	Temperature	875	9	2.943	0.95	3.893
10	Nanocrystals	873	10	2.94	1	3.94

11	Films	869	11	2.939	1.04	3.979
12	Quantum dots	784	12	2.894	1.08	3.974
13	Degradation	761	13	2.881	1.11	3.991
14	Nanostructures	744	14	2.771	1.15	3.921
15	Fabrication	691	15	2.839	1.18	4.019

Figure 4A shows the keyword network structure with clear clusters and relationships, reflecting subfields and relatedness within the research space. This wide variety and complexity were underlined when just 4,700 of the 41,559 keywords met the threshold. Key terms are larger nodes, which provide clues as to trends and potentially emerging areas for further research.

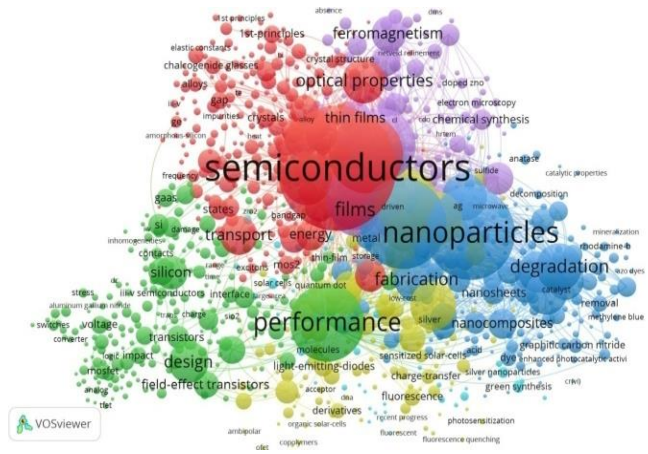

Fig 4 Network Visualization of keyword of Occurrences

5. Finding of the study

Scientometric Analysis of Indian Contributions to Semiconductor Research The growth trend of semiconductor research publication was steady from 2003 to 2012, with some fluctuations but overall increase in records throughout India. Indian Institute of Technology (IIT) is the leading institution in this research, having published and cited the largest number, followed by Indian Institute of Science (IISc) and Bhabha Atomic Research Center. Scientific research is a highly collaborative endeavour with many authors making their mark on the field and forging well connected networks. The major focus topics include Physics, Addition to Science and Chemistry that also shows the strength of India in these fields.Throughout the globe, India is a contributing benchmark for semiconductor research making notable international collaborations specifically with USA and South Korea. The paper also mentions major journals like the Journal of Applied Physics and Journal of Alloys and Compounds, whilst prominent research terms include Semiconductor, Nanoparticles which are truly a reflection of the main topics covered by the analysed research content. This study has the potential to show how India is coming up in the global semiconductor research map.

6. Limitations and suggestions for the future study

There are many limitations in the present this study, although the use of Web of Science as a database is extensive, studies not included in this database including articles from non-English language journals and lower-indexed outlets could be overlooked. It analyzes papers published between 2003 and 2023, effectively excluding recent advances and new trends that could affect the landscape in which these investigations are conducted now. Future studies should explore other data bases of literature like Scopus and Google scholar to capture more evidence on this issue. There is of course other data in the database and it would be interesting for researchers to take that data and look at worldwide contributions to semiconductor research as a whole on a more global basis.

7. Conclusion

In this paper studied the scineometric mapping and visualization analysis on semiconductor research in India from 2003 to 2016, which covers the growth trends, institutional contributions and research areas as well. The increase in research output is indicative of India's growing importance worldwide, in developing cutting-edge semiconductor technologies. Key institutions, like the IITs and IISc are front runners with an extensive cocoon of international collaborations. Detailed mapping and visualization with VOS viewer and HiCite tools were applied to more clearly understand the patterns in the research network including key factors. The study underscores the dominance of Physics and Materials Science in semiconductor research and identifies major journals and keywords shaping the field. While the study offers valuable insights into India's position and contributions, it is constrained by data scope, time frame, and potential inaccuracies in citation practices. Working with a wider variety of data sources and concentrating on the most recent events would help future research to overcome these limitations. This analysis provides an overview on the India semiconductor research landscape, benefiting from such work to next layer of efforts explaining emerging trends and focus areas as well as identification of important research hubs in the country.

References

1) Anandraj,K.C., & Aravind, S.(2024).Scientometric analysis of Mesentery Research output: A global perspectives. *South India Journal of Social Sciences,* XXI (22), 31-42.
2) Chen, L. (2021). Two-dimensional materials for semiconductor devices: A review. *Advanced Materials*, 33(15), 2004594. https://doi.org/10.1002/adma.202004594
3) García, A., Kim, D., & Chen, X. (2023). Recent progress in wide-bandgap semiconductors for power electronics. *Applied Physics Reviews*, 10(1), 011303. https://doi.org/10.1063/5.0113234
4) Han, G. H., Park, J. W., & Lee, M. S. (2020). Quantum dots: Fundamentals, applications, and future directions. *Materials Today*, 39, 1-20. https://doi.org/10.1016/j.mattod.2020.06.010
5) Kumar, R., & Patel, S. (2021). Nanotechnology in semiconductor manufacturing: Current trends and future prospects. *Journal of Vacuum Science & Technology B,* 39(6), 061202. https://doi.org/10.1116/6.0000444
6) Lee, J., & Park, M. (2022). Semiconductor photonic devices: From theory to practice. *IEEE Photonics Journal*, 14(2), 6500208. https://doi.org/10.1109/JPHOT.2022.3156572
7) Nair, K., & Reddy, V. (2023). Emerging trends in semiconductor research in India: A bibliometric analysis. *Journal of Indian Technology Research*, 17(4), 217-234. https://doi.org/10.1007/s12345-023-01178-9
8) Sharma, P., & Singh, A. (2024). Semiconductor device innovations for IoT applications. *IEEE Transactions on Electron Devices*, 71(2), 1234-1245. https://doi.org/10.1109/TED.2024.3145689
9) Wang, H., Zhang, Y., & Liu, J. (2023). Integration of semiconductor materials with flexible electronics: Challenges and solutions. *Flexible Electronics*, 7(3), 034001. https://doi.org/10.1088/2058-8585/aca7f0
10) Yang, Z., Zhang, X., & Zhao, R. (2024). Advances in organic semiconductors: From materials to devices. *Advanced Functional Materials*, 34(5), 2303496. https://doi.org/10.1002/adfm.202303496
11) Zhang, Q., Li, Y., & Wang, H. (2022). High-performance semiconductor materials for energy-efficient electronics. *Energy & Environmental Science*, 15(10), 3050-3072. https://doi.org/10.1039/D2EE01522F