

# Quantum Optics: A Scientometric Assessment of India's Publications during 1996-2021

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## ABSTRACT:

**Objectives:** The present study examines the publication output of authors from India on the topic of "Quantum Optics" during 1996-2021 using bibliometric methods. **Methods:** The Indian publications as listed in the Scopus database were identified by using "Quantum Optics" in the "Title" tag. **Results:** 67274 global publications emerged on the topic of "Quantum Optics" during 1996-2021. India contributed only 2108 publications on this topic and constituted a 3.13% share of global output. About 30.0% share of Indian publications received external funding support and were involved in international collaboration, respectively. The 455 organizations and 635 authors participated unevenly in the research on this topic, with the highest number of publications (96) emerging from the Indian Institute of Science, Bangalore, followed by the University of Calcutta (80 publications), Harish Chandra Research Institute, Allahabad (69 publications) and Tata Institute of Fundamental Research, Mumbai (68 publications). Indian Association for Cultivation of Science (IACS), Kolkata (69.9 and 5.68) registered the highest citation impact per paper and relative citation index, followed by Physical Research Laboratory, Ahmedabad (23.23 and 1.89), Harish Chandra Research Institute, Allahabad (22.93 and 1.86) and Tata Institute of Fundamental Research, Bombay (22.72 and 1.85). The highest number of publications (33) is contributed by G.S. Agarwal, followed by A.K. Pati (32 papers), A. Pathak (31 papers), and P.K. Panigrahi (29 papers). G.S. Agarwal (40.82 and 3.32) registered the highest citation impact per paper and relative citation index, followed by P.K. Panigrahi (21.83 and 1.77), A.K. Pati (21.06 and 1.71), and A. Pathak (19.87 and 1.61). The journals that published the highest number of publications (233) were *Physical Review A* (233 papers), *Quantum Information Processing* (109 papers), *Physics Letters Section A* (74 papers), and *Spectrochimica Acta Part A* (61 papers). *Physical Review Letters* (62.30) was the most impactful journal in terms of citations per paper, followed by the *Journal of Optics (United Kingdom)* (24.92), *Physical Review E* (19.07), and *Journal of Optics B. Quantum & Semiclassical Optics* (18.85), *Journal of Physical Chemistry C* (18.58). The most commonly investigated topics (keywords) in terms of frequency of appearances were quantum optics (1390), followed by nonlinear optics (520), quantum theory (407), quantum entanglement (283), photons (223), and quantum computers (223). **Conclusion:** Over the last two decades a large number of publications have emerged in the area of "Quantum Optics", which are creating a significant impact on the development of many diverse quantum technologies both in India and abroad.

**Keywords:** Quantum Optics, India, Publications, Bibliometrics, Scientometrics.

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## INTRODUCTION

Quantum optics, literally the study of quantized light, has morphed into an area for the investigations of the interactions

between light and matter, with an emphasis on qualitative microscopic models, time dependence, and coherence.<sup>1</sup> Accurate control of these interactions allows experimentalists to create quantum states of matter and light that can be used for tests of fundamental physics and quantum technological applications.<sup>2</sup> During the second part of the 20th century, experimental and theoretical progress developed together; nowadays quantum optics provides a testbed for many

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fundamental aspects of quantum mechanics such as coherence and quantum entanglement.<sup>2</sup> In addition to studying quantum mechanics, quantum optical states have been exploited for several applications, such as quantum-state engineering, quantum communication, quantum cryptography protocols, enhanced metrology and sensing, quantum optical integrated circuits, quantum imaging, and quantum biological effects.<sup>3</sup>

Although several bibliometrics studies have been undertaken in the past on the topics related to “Quantum technologies”,<sup>4-11</sup> and optics<sup>[12-16]</sup> none of the existing bibliometric studies were focused on “Quantum Optics”, particularly in the Indian context.

In this background, the present study aims to assess the Indian research output on “Quantum Optics”, based on select absolute and relative bibliometric indicators. The study, in particular, aims to assess India's publications output on this topic, in terms of overall parameters such as its Indian output and global share, citation impact, extent of funded research and international collaborations, leading Indian organizations and authors and their collaborative linkages, leading journals publishing papers on this topic and characteristics of high-cited papers.

## MATERIALS AND METHODS

Publications as listed in the Scopus database (<https://www.scopus.com>), with at least one author from India and addressing the issues of ‘Quantum Optics’ were identified using a relevant search strategy, which used the keyword “Quantum Optics” in the field tag, “Keyword” for the search and retrieval, and subsequently the search was limited to publication years 1996–2021. The search on the topic yielded 67,274 global records and when the same search strategy was restricted to India, the total numbers of publications were 2108. The analytical provisions as provided in the Scopus database were utilized to ascertain the distribution of publications by broad subject areas, collaborating countries, contributing authors, affiliating organizations, and the journals in which the articles were published. The citations to publications were counted from the date of their publication till 17.2.2022. The study used selected quantitative and qualitative indicators to quantify and evaluate the performance of the most productive organizations, authors, and journals. To evaluate and visualize the collaborative interaction among the most productive countries, organizations, authors, and keywords, VOSviewer and Biblioshiny app for bibliometrix were used.

KEY (quantum AND optics) AND PUBYEAR > 1995 AND PUBYEAR < 2022 AND (LIMIT-TO (AFFILCOUNTRY, “India”))

## ANALYSES AND RESULTS

### Global Publication Output and Top 15 Countries

The global output of “Quantum Optics” comprised 67,274 publications, which annually increased from 718 publications in 1996 to 3,073 in 2021, registering a 13.12% average growth. The global cumulative publications increased from 20296 during 1996–2008 to 46974 during 2009–2021, registering 131.44% absolute growth (Table 1).

Among these global publications on “Quantum Optics”, 19,772 publications (97.42%) emerged from the top 15 countries, which were cited 53,935 times and these Figures constituted more than 100.0% share of the total citations. On further analysis, it was observed that only five countries contributed publications more than the average group productivity (1318.13) and these included the USA (17300

**Table 1: Annual Growth of Global and India's Publications on “Quantum Optics”.**

Publication Year	Global	India		
	TP	TP	TC	CPP
1996	718	19	522	27.47
1997	618	15	145	9.67
1998	647	13	144	11.08
1999	641	16	195	12.19
2000	1143	22	761	34.59
2001	1024	18	174	9.67
2002	2002	17	199	11.71
2003	1517	20	316	15.8
2004	1448	24	493	20.54
2005	1598	23	326	14.17
2006	2697	16	172	10.75
2007	1906	17	223	13.12
2008	4337	52	1195	22.98
2009	4205	74	1260	17.03
2011	4857	111	3153	28.41
2012	2676	81	1089	13.44
2013	4213	97	1154	11.9
2014	2855	121	2030	16.78
2015	3242	139	2777	19.98
2016	3378	151	2472	16.37
2017	3856	168	1820	10.83
2018	3790	214	2178	10.18
2019	4863	231	1484	6.42
2020	3773	217	787	3.63
2021	3073	169	190	1.12
1996-2008	20296	272	4865	17.89
2009-2021	46974	1836	21093	11.49
1996-2021	67274	2108	25958	12.31

TP=Total Publications, TC=Total Citations, CPP= Citation per Paper

**Table 2: Profile of Top 15 Countries in Global Output on Quantum Optics.**

Sl. No	Name of the country	TP		% TP			
		1996-08	2009-21	1996-21	1996-08	2009-21	1996-21
1	USA	6166	11134	17300	30.38	23.75	25.72
2	China	1575	10200	11775	7.76	21.76	17.5
3	Germany	2234	6136	8370	11.01	13.09	12.44
4	U.K.	1573	4292	5865	7.75	9.16	8.72
5	Japan	1688	3081	4769	8.32	6.57	7.09
6	France	1185	3057	4242	5.84	6.52	6.31
7	Russia Federation	1252	2247	3499	6.17	4.79	5.2
8	Italy	981	2495	3476	4.83	5.32	5.17
9	Australia	659	2220	2879	3.25	4.74	4.28
10	Canada	644	2195	2839	3.17	4.68	4.22
11	Spain	418	1754	2172	2.06	3.74	3.23
12	India	272	1836	2108	1.34	3.92	3.13
13	Switzerland	358	1244	1602	1.76	2.65	2.38
14	Austria	356	1055	1411	1.75	2.25	2.1
15	South Korea	411	989	1400	2.03	2.11	2.08
	Total of 15 countries	19772	53935	73707	97.42	115.06	109.56
	Global total	20296	46874	67274			
	Share of top 15 countries in global total	97.42					

TP=Total Publications, %TP=Percentage of Total Publications

publications, 25.72% share), China (11775 publications and 17.50% share), Germany (8370 publications and 12.44% share), U.K. (5865 publications and 8.72% share) and Japan (4769 publications and 7.09% share). The global publication share decreased in the USA, Japan, and Russian Federation (from 1.38% to 6.63%) and increased in all other countries from 0.08% to 12.0% from 1996–08 to 2009–2021 [Table 2].

## Indian Publication Output

### Overall Aspects

Of the 67274 global publications, only 2108 (3.13%) publications had one author from India during 1996–2021. The share of India's publications in global output increased from 1.34% during 1996–2008 to 3.92% during 2009–2021. The 2108 Indian publications received 25958 citations, averaging 12.31 citations per paper (CPP) [Table 1].

Of the 2,108 India publications, only 633 (30.03%) received external funding support. India's publications based on funding increased from 35 during 1996–08 to 539 during 2009–21 and have received 10129 citations, averaging 16.00 CPP. The major Indian funding agencies supporting India's research on "Quantum Optics" were the Department of Science and Technology, Government of India (204 papers), followed by University Grants Commission (95 papers), Council of Scientific and Industrial Research (82 papers), Science and Engineering Board (74 publications), Department of Science and Technology, Kerala (66 publications), Department of Atomic Energy (39 publications), Ministry of Human Resource

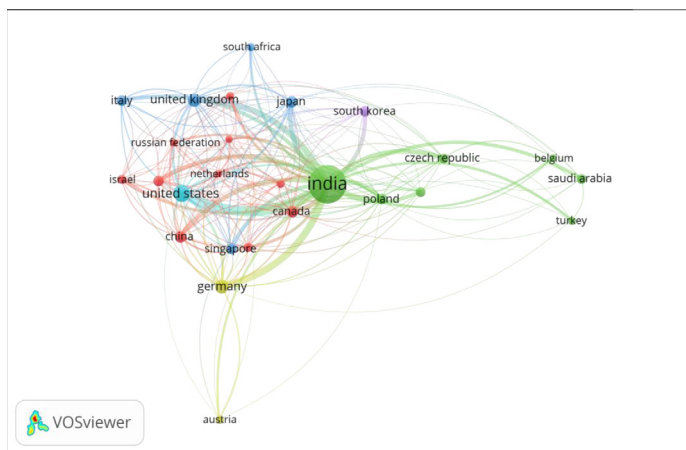
Development (29 papers), Defense Research and Development Organization (17 papers), etc. The major foreign funding agencies supporting India's publications in this area were the National Natural Science Foundation of China and National Science Foundation, USA (21 publications each), Bangladesh Council of Scientific and Industrial Research (20 publications), Engineering and Physical Sciences Research Council and Deutsche Forschungsgemeinschaft (14 publications each), etc. Of the 2108 India publications, articles constituted the largest publication share (80.12%), followed by conference papers (14.33%), reviews (1.71%), and others less than 1.0%: book chapters (0.95%), letters (0.24%), book, note and short survey (0.05% each).

Of the 2108 India publications, 609 (28.89%) were published as international collaborative publications (ICP). The share of ICPs increased from 25.74% (70) during 1996–08 to 29.36% (539) during 2009–21. These ICPs received 13222 citations, averaging 21.71 CPP. India's international collaboration has increased in China and Poland (from 4.88% to 5.81%) and decreased in all other countries among the top 10 from 0.33% to 11.52% during 1996–2008 to 2009–2021. Among India's ICPs, the USA contributed the largest publication share (22.66%), followed by Germany (13.96%), the U.K. (10.18%), Canada (7.06%), etc. In terms of research impact per paper of foreign collaborative partners in India's ICP, Italy registered the largest impact (67.83), followed by the USA (36.81), U.K. (34.90), China (32.98), Japan (32.74), etc. (Table 3).

**Table 3: Distribution of Papers by Foreign Collaborative Country Participation.**

Sl. No.	Name of collaborating country	ICP			%ICP			TC	CPP
		1996-08	2009-21	1996-21	1996-08	2009-21	1996-21		
1	USA	23	115	138	32.86	21.34	22.66	5080	36.81
2	Germany	12	73	85	17.14	13.54	13.96	2313	27.21
3	U.K.	14	48	62	20	8.91	10.18	2164	34.9
4	Canada	6	37	43	8.57	6.86	7.06	779	18.12
5	China	1	39	40	1.43	7.24	6.57	1319	32.98
6	Japan	5	34	39	7.14	6.31	6.4	1277	32.74
7	France	7	28	35	10	5.19	5.75	736	21.03
8	Poland	1	34	35	1.43	6.31	5.75	510	14.57
9	South Korea	4	29	33	5.71	5.38	5.42	314	9.52
10	Italy	4	25	29	5.71	4.64	4.76	1967	67.83
		70	539	609	100	100	100		

ICP=International Collaborative Papers; TC=Total Citations, CPP= Citation per Paper.



**Figure 1:** International Collaborating Countries Network of India with other Top Countries in the Quantum Optics.

Figure 1 shows the co-author's collaboration network map of India with other top countries in the quantum optics, and it is determined by the co-authorship of articles. The network is spread over 6 clusters. India is in the middle of the cluster that is linked with the most nodes and it is the largest community that evolved around various countries.

### Subject-Wise Distribution of Papers

India's publications on "Quantum Optics" may be classified under six major broad subjects as per the Scopus database classification. The largest contribution (75.24%) is made by Physics and Astronomy, followed by Materials Science (35.48%), Engineering (33.21%), Computer Science (19.64%), Chemistry (18.98%), and Mathematics (14.28%). Amongst these six broad subjects, Chemistry registered the highest citation impact per paper (16.30) and Computer Science the least (6.21) [Table 4].

**Table 4: Broad Subject-Wise Distribution of India's Papers on Quantum Optics.**

Sl. No.	Name of the subject	TP	TC	CPP	%TP
1	Physics and Astronomy	1586	21678	13.67	75.24
2	Materials Science	748	8027	10.73	35.48
3	Engineering	700	5881	8.40	33.21
4	Computer Science	414	2572	6.21	19.64
5	Chemistry	400	6519	16.30	18.98
6	Mathematics	301	2376	7.89	14.28
	India's total	2108	25958	12.31	100.00

### Significant Keywords

Table 5 shows the most frequent indexing keywords and their frequency of occurrence in India's "Quantum Optics" research. The keywords that appeared at least 28 times in 2108 publications were listed. Among the 12522 indexing keywords extracted from the dataset, 43 keywords met the threshold. The indexing keywords occurrence network map is displayed in Figure 2. The higher the co-occurrence frequency of the words, the closer the relationship between them, which is represented by the location of the two words. The size of the node represents the frequency of the keyword co-occurrence with other keywords.

A word cloud can visually illustrate the situation of keywords and highlight the keywords with a high frequency of occurrence. To clench the most prominent keywords in India's quantum optics research, word clouds are generated for the extracted index keywords. Figure 3 shows the word cloud of the index keywords.

### Profile of Top 30 Organizations

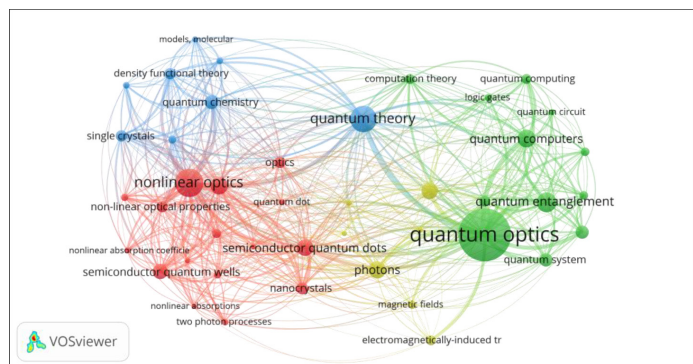
Overall, 455 organizations participated unevenly in Indian literature on "Quantum Optics", of which 282 organizations



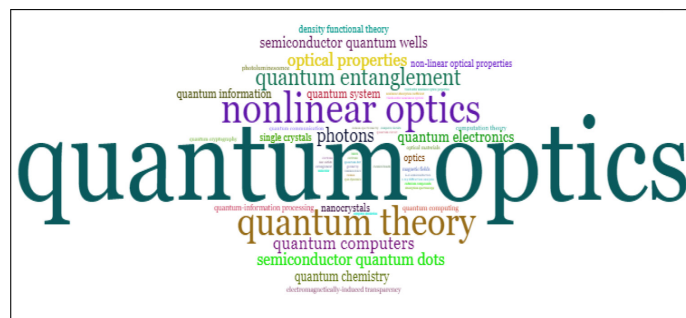
**Table 5: List of Top 43 Significant Keywords appearing in India' Literature on "Quantum Optics"**

Rank	Keyword	Frequency of Occurrences	TLS	Rank	Keyword	Frequency of Occurrences	TLS
1	quantum optics	1277	2075	23	photoluminescence	71	281
2	nonlinear optics	459	1489	24	quantum communication	65	211
3	quantum theory	399	1025	25	quantum cryptography	61	193
4	quantum entanglement	258	654	26	optical materials	58	265
5	quantum computers	216	701	27	magnetic fields	55	136
6	Photons	204	492	28	logic gates	47	166
7	optical properties	201	822	29	neodymium lasers	46	207
8	semiconductor quantum dots	188	649	30	optoelectronic devices	46	148
9	quantum electronics	181	464	31	two photon processes	44	173
10	semiconductor quantum wells	160	491	32	raman spectrometry	42	192
11	quantum chemistry	136	458	33	quantum chemical calculations	40	170
12	quantum information	130	351	34	quantum circuit	38	121
13	quantum system	129	294	35	quantum dot	36	121
14	Nanocrystals	110	417	36	models, molecular	34	164
15	non-linear optical properties	103	472	37	nonlinear absorption coefficient	33	145
16	Optics	102	201	38	electron optics	32	58
17	single crystals	99	416	39	thin films	31	110
18	density functional theory	98	420	40	Nanoparticles	30	109
19	quantum-information processing	91	246	41	nonlinear absorptions	30	120
20	electromagnetically-induced transparency	82	116	42	optical waveguides	28	81
21	quantum computing	82	267	43	Photonics	28	76
22	computation theory	78	305				

TLS=Total Link Strength



**Figure 2:** Indexing Keywords Co-occurrence Network Map.



**Figure 3:** Keywords Plus Cloud Map.

contributed 1-5 papers each, 91 organizations 6-10 papers each, 46 organizations 11-20 papers each, 23 organizations 21-50 papers each, and 13 organizations were 51-96 papers each.

A majority of the publications emerged from authors belonging to the top 30 organizations only and they together contributed 1443 papers and 6845 citations, constituting 68.45% share of Indian publications and 78.68% share of Indian citations.

On further analysis, it was observed that fourteen organizations contributed papers higher than the group average (48.10) of the top 30 organizations, with 96 publications emerging from the Indian Institute of Science, Bangalore, 80 publications from the University of Calcutta, Kolkata, 69 publications from Harish Chandra Institute, Allahabad, 68 publications from Tata Institute of Fundamental Research, Bombay, 66 publications from Physical Research Laboratory, Ahmedabad, 63 and 55 publications from IIT-Bombay and IIT-Kanpur, 54 publications each from Visva-Bharati University,

Shantiniketan, SN Bose National Centre for Basic Sciences, Kolkata, Indian Statistical Institute, Kolkata, IIT-Delhi and IIT-Madras, 51 publications from University of Hyderabad and 49 publications from Bhabha Atomic Research Centre, Bombay. Eight organizations had CPP and RCI above the group average (14.15 and 1.15) for the top 30 organizations and these included the Indian Association for Cultivation of Science (IACS), Kolkata (69.9 and 5.68), Physical Research Laboratory, Ahmedabad (23.23 and 1.89), Harish Chandra Institute, Allahabad (22.93 and 1.86), Tata Institute of Fundamental Research, Bombay (22.72 and 1.85), University of Hyderabad (22.72 and 1.85), IISER-Kolkata (17.46 and 1.42), Jaypee Institute of Information Technology, Noida (17.19 and 1.40) and Raman Research Institute, Bangalore (14.35 and 1.17) (Table 6).

### Collaboration among Top 30 Organizations

The institute-to-institute collaboration network is shown in Figure 4. Table 7 depicts the top 20 strongest Indian institutional collaborative pairs. Among these institutions "University of Calcutta-Jadavpur University" and "HCRI-Allahabad – HBNI-Mumbai" collaborated in the highest publications ( $n=10$ ), followed by "University of Calcutta – ISI, Kolkata" collaboratively published 9 papers, "SNBNCBS, Kolkata – Bose Institute, Kolkata" and "SNBNCBS, Kolkata – ISI, Kolkata" collaboratively published 8 papers each.

### Profile of Top 30 Authors

Indian publications on "Quantum Optics" witnessed the participation of 635 authors, of which the majority (1479) of the authors contributed 1–5 papers each, 121 authors 6–10 papers each, 26 authors 11–20 papers each, and 9 authors 21–33 papers each. The top 30 authors individually contributed 12 to 33 papers each and together contributed to 544 papers and 7169 citations, constituting 25.81% share and 27.62% share of India's total publications and citations.

On further analysis, it was observed that nine authors contributed papers higher than their group average (18.13) of the top 30 authors: G.S. Agarwal (33 papers), A.K. Pati (32 papers), A. Pathak (31 papers), P.K. Panigrahi (29 papers), U. Sen and G. Vinitha (26 papers each), Arvind (23 papers), S. Banerjee (22 papers) and M. Ghosh (21 papers). Nine authors registered CPP and RCI above the group average (13.18 and 1.07) for the top 30 authors: G.S. Agarwal (40.82 and 3.32), P.K. Panigrahi (21.83 and 1.77), A.K. Pati (21.06 and 1.71), A. Pathak (19.87 and 1.61), K. Thapliyal (15.57 and 1.26), S. Banerjee (14.32 and 1.16), D. Sajjan (13.53 and 1.10), V.P.N. Nampoor (13.50 and 1.10) and C.Y. Panicker (13.50 and 1.10) (Table 8).

### Collaboration among Top 30 Authors

Figure 5 shows the most prolific author's co-authorship network. Of the total 635 authors, 43 authors who published 12 or more papers, met the threshold and found a 38 authors collaborations network. The collaboration map identified eight clusters, the size of the nodes, and the author represents the weights of the nodes. The bigger the node and author are, the larger the weight is. The distance between two nodes reflects the strength of the relation between two nodes. A shorter distance generally reveals a stronger relationship. The line between the two authors represents that they have appeared together. The thicker the line is, the more collaboration they have.

Among author-to-author linkages, the largest number of collaborative linkages (18) were between U. Sen – A. Sen, followed by Arvind – K. Dorai (16 linkages), A. Pathak – K. Thapliyal (14 linkages), S. Bhattacharyya – P.K. Panigrahi (7 linkages), etc. (Table 9).

### Profile of Top 30 Journals

Of the 2108 publications with one author from India, in the area of "Quantum Optics", 1751 are published in journals, 302 in conference proceedings, 39 in book series, 15 as books and 1 in trade journal. The 1751 journal papers were published in 299 journals, of which 245 journals published 1–5 papers each, 23 journals 6–10 papers each, 16 journals 11–20 papers, 10 journals 21–50 papers each, 3 journals 51–74 papers each and 2 journals 109–233 papers each.

The top 30 journals contributed 12 to 233 publications each and together published 1146 papers, constituting 65.45% share of India's total publications in journals. On further analysis it was found that: (i) the top 8 most productive journals were *Physical Review A* (233 papers), *Quantum Information Processing* (109 papers), *Physics Letters Section A* (74 papers), *Spectrochimica Acta Part A* (61 papers), *Optics Communications* (51 papers), *Journal of Molecular Structure* (49 papers), *Pramana Journal of Physics* (43 papers) and *Proceedings of SPIE The International Society For Optical Engineering* (42 papers). The top 8 journals in terms of CPP were *Physical Review Letters* (62.30), *Journal of Optics (United Kingdom)* (24.92), *Physical Review E* (19.07), *Journal of Optics B. Quantum and Semiclassical Optics* (18.85), *Journal of Physical Chemistry C* (18.58), *Journal of Applied Physics* (18.25), *Physical Review A* (17.24) and *Spectrochimica Acta Part A* (17.20) (Table 10).

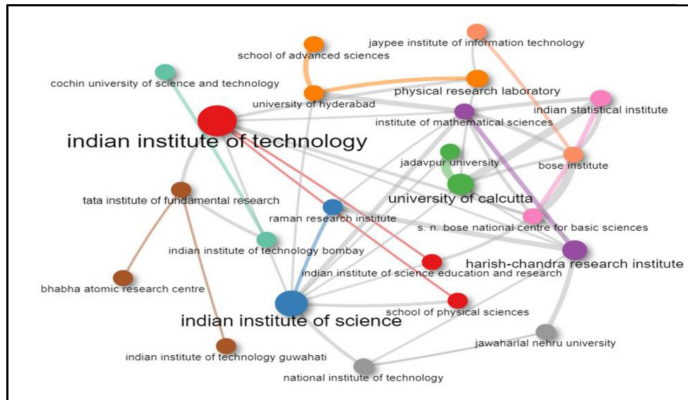
### High-Cited Papers

Of the 2108 papers, only 24 (1.14%) papers received 100 citations or more (assumed here as high-cited) and they together received 7156 citations, averaging 298.17 CPP. Of the 24 high-cited papers, 12 are in the citation range 100–198,

**Table 6: Top 8 Most Productive and Most Impactful Organizations on "Quantum Optics".**

Sl. No	Name of the Organization	TP	TC	CPP	HI	ICP	% ICP	RCI
<b>Top 8 Most Productive Organizations</b>								
1	Indian Institute of Science, Bangalore	96	1226	12.77	18	25	26.04	1.04
2	University of Calcutta, Kolkata	80	519	6.49	11	19	23.75	0.53
3	Harish Chandra Institute, Allahabad	69	1582	22.93	17	28	40.58	1.86
4	Tata Institute of Fundamental Research, Bombay	68	1545	22.72	20	29	42.65	1.85
5	Physical Research Laboratory, Ahmedabad	66	1533	23.23	19	22	33.33	1.89
6	Indian Institute of Technology, Bombay	63	539	8.56	15	29	46.03	0.70
7	Indian Institute of Technology, Kanpur	55	364	6.62	3	14	25.45	0.54
8	Visva-Bharati University	54	464	8.59	13	10	18.52	0.70
<b>Top 8 Most Impactful Organizations</b>								
1	Indian Association for Cultivation of Science, Kolkata	41	2866	69.90	14	15	36.59	5.68
2	Physical Research Laboratory, Ahmedabad	66	1533	23.23	19	22	33.33	1.89
3	Harish Chandra Institute, Allahabad	69	1582	22.93	17	28	40.58	1.86
4	Tata Institute of Fundamental Research, Bombay	68	1545	22.72	20	29	42.65	1.85
5	University of Hyderabad	51	1136	22.27	17	11	21.57	1.81
6	IISER-Kolkata	46	803	17.46	15	14	30.43	1.42
7	Jaypee Institute of Information Technology	37	636	17.19	15	17	45.95	1.40
8	Raman Research Institute, Bangalore	48	689	14.35	14	23	47.92	1.17

TP: Total Publications; TC: Total Citations; CPP: Citations per paper; HI: *h*-Index; RCI: Relative Citation Index; ICP: International Collaboration Papers; % ICP: Percentage of International Collaboration Papers.



**Figure 4:** Top 30 Prolific Indian Institutional Collaboration Map.

6 in the citation range 215–294, 5 in the citation range 315–589, and 1 received 1747 citations.

Of the 24 high-cited papers, the majority (15) were international collaborative papers, followed by 5 national collaborative and 4 zero collaborative. In terms of the type of publications, 21 of these 24 publications were articles and 3 were reviews.

Among the participating countries, 5 papers are contributed by USA, 4 each by China and Germany, 2 each by France, Japan, and Israel, and 1 each by Argentina, Australia, Canada, Columbia, Finland, France, Ireland, Italy, Israel, Netherland, Oman, Qatar, Poland, Singapore, and Taiwan.

**Table 7: The Strongest Collaborative Indian Institutional Pairs in Quantum Optics.**

Sl. No	Institutional Pairs	TCL	S. No	Institutional Pairs	TCL
1	University of Calcutta-Jadavpur University	10	11	ISI, Kolkara – IMS, Chennai	6
2	HCRI-Allahabad – HBNI-Mumbai	10	12	SNBNCBS, Kolkata – IMS, Chennai	6
3	University of Calcutta-ISI, Kolkata	9	13	IMS, Chennai – ISI, Kolkata	6
4	SNBNCBS, Kolkata – Bose Institute, Kolkata	8	14	IISc, Bangalore – IMS, Chennai	5
5	SNBNCBS, Kolkata – ISI, Kolkata	8	15	HCRI-Allahabad – RRI, Bangalore	5
6	TIFR-Mumbai – IIT, Mumbai	7	16	University of Hyderabad – IMC, Chennai	5
7	PRL-Ahmedabad – IIT-Gandhinagar	7	17	IMS, Chennai-HBNI, Mumbai	5
8	BARC, Mumbai-HBNI, Mumbai	7	18	IISc, Bangalore – IACS, Kolkata	4
9	RR-CAT, Indore – HBNI-Mumbai	7	19	HCRI-Allahabad – IMS, Chennai	4
10	PRL-Ahmedabad – IISER, Kolkata	6	20	SNBNCBS, Kolkata – IMS, Chennai	4

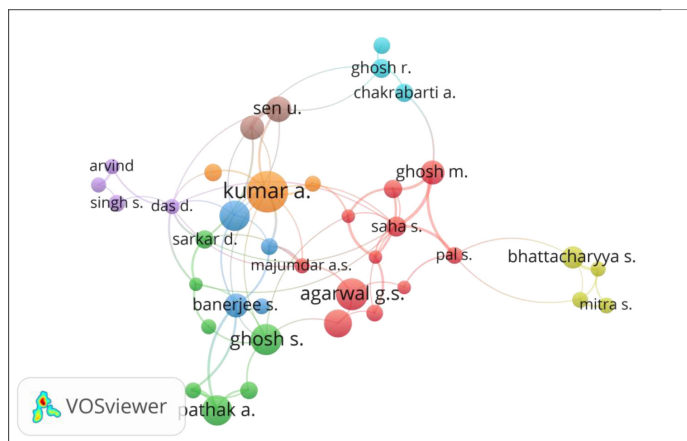
TCL=Total collaborative linkages.

The 24 high-cited papers involve 92 organizations (24 Indian) and 155 authors (38 Indian). Among the participating organizations from India, the largest number of papers (4) are contributed by IACS-Kolkata, followed by HCRI-Allahabad

**Table 8: Profile of Top 5 Most Productive and Most Impactful Authors on "Quantum Optics".**

Sl. No	Name of the author	Affiliation of the author	TP	TC	CPP	HI	ICP	%ICP	RCI
<b>Top 8 Most Productive Authors</b>									
1	G.S.Agarwal	PRL-Ahmedabad-	33	1347	40.82	18	16	48.48	3.32
2	A.K.Pati	HCRI-Allahabad	32	674	21.06	15	11	34.38	1.71
3	A. Pathak	Jaypee Institute of Information Technology	31	616	19.87	15	17	54.84	1.61
4	P.K. Panigrahi	IISER-Kolkata	29	633	21.83	12	7	24.14	1.77
5	U. Sen	HCRI-Allahabad	26	270	10.38	9	9	34.62	0.84
6	G. Vinitha	VIT-Chennai	26	298	11.46	11	4	15.38	0.93
7	Arvind	IISER-Mohali	23	176	7.65	9	3	13.04	0.62
8	S.Banerjee	IIT-Jodhpur	22	315	14.32	11	4	18.18	1.16
<b>Top 8 Most Impactful Authors</b>									
1	G.S.Agarwal	PRL-Ahmedabad-	33	1347	40.82	18	16	48.48	3.32
2	P.K. Panigrahi	IISER-Kolkata	29	633	21.83	12	7	24.14	1.77
3	A.K.Pati	HCRI-Allahabad	32	674	21.06	15	11	34.38	1.71
4	A. Pathak	Jaypee Institute of Information Technology	31	616	19.87	15	17	54.84	1.61
5	K. Thapliyal	Jaypee Institute of Information Technology	14	218	15.57	8	8	57.14	1.26
6	S.Banerjee	IIT-Jodhpur	22	315	14.32	11	4	18.18	1.16
7	D.Sajan	Bishop Moore College, Mavelinkkara	17	230	13.53	9	4	23.53	1.10
8	V.P.N.Nampoor	Cochin University of Sand	12	162	13.50	6	0	0.00	1.10

TP=Total Publications; TC=Total Citations; CPP=Citations per Paper; HI=h-Index; RCI=Relative Citation Index; ICP=International collaboration papers; % ICP=Percentage of International Collaboration Papers



**Figure 5:** Top 38 Most Prolific Co-authorship Visualization Network.

(3 papers), Bharathiar University, Coimbatore, IISER-Kolkata, PRL-Ahmedabad, and TIFR-Mumbai (2 papers each) and BARC-Mumbai, Bharathidasan University, Tiruchirapalli, BHU-IMS-Varanasi, BHI-IT, Varanasi, BITS-Goa, IISER-Trivandrum, IIT-Patna, JNU-New Delhi, Jamia Millia Islamia, Delhi, Kerala University, Loyola College, Chennai, NIT-Rourkela, Pondicherry University, Raman Research Institute, Bangalore, SASTRA University, Thanjavur, TIFR-Bangalore, University of Hyderabad, VECC-Kolkata, etc (1 paper each).

**Table 9: The Strongest Collaborative Indian Author Pairs in Quantum Optics.**

Sl. No	Author Pairs	TCL	S. No	Author Pairs	TCL
1	U. Sen - A. Sen	18	8	S. Banerjee - K. Thapliyal	4
2	Arvind - K. Dorai	16	9	S. Adhikari - A. Kumar	4
3	A. Pathak - K. Thapliyal	14	10	A.S.Majumdar - S. Adhikari	4
4	S. Bhattacharyya - P.K. Panigrahi	7	11	A. Kumar - U. Sen	4
5	D. Vinitha - D. Sajan	6	12	S. Adhikari - S. Banerjee	3
6	A. Pathak - S. Banerjee	5	13	S. Mondal - A. Pathak	3
7	R. Philip - D. Sajan	5			

TCL=Total Collaborative Linkages.

The 24 high-cited papers were published in 15 journals, of which 5 papers are published in *Physical Review Letters*, 4 papers in *Physical Review A*, 2 papers each in *Review of Modern Physics* and *Physical Review E*, and 1 paper each in *Analytical and Bioanalytical Chemistry*, *Advances in Colloid and Interface Science*, *Biomaterials Research*, *Journal of Optics (United Kingdom)*, *Laser and Photonics Review*, *Nature Materials*, *Nature Nanotechnology*, *Nature Physics*, *Nanomedicine*, *Optica* and *Spectrochimica Acta Part A*.



**Table 10: Bibliometric Profile of Top 30 Journals.**

Sl. No	Name of the journal	TP	TC	CPP
1	Physical Review A	233	4016	17.24
2	Quantum Information Processing	109	938	8.61
3	Physics Letters Section A	74	946	12.78
4	Spectrochimica Acta Part A	61	1049	17.20
5	Optics Communications	51	833	16.33
6	Journal of Molecular Structure	49	647	13.20
7	Pramana Journal of Physics	43	244	5.67
8	Proceedings of SPIE The International Society For Optical Engineering	42	28	0.67
9	Journal of Physics B. Atomic, Molecular and Optical Physics	39	312	8.00
10	Optical Materials	39	609	15.62
11	Optik	36	140	3.89
12	Physical Review Letters	33	2056	62.30
13	European Physical Journal D	31	165	5.32
14	Journal of Modern Optics	29	235	8.10
15	Journal of Optical Society of America B. Optical Physics	23	109	4.74
16	Physical Review E	44	839	19.07
17	Journal of Optics B. Quantum and Semiclassical Optics	20	377	18.85
18	Journal of Physics Conference Series	19	21	1.11
19	Physica B. Condensed Matter	18	124	6.89
20	Journal of Materials Science Materials in Electronics	16	99	6.19
21	Optics Express	16	259	16.19
22	New Journal of Physics	15	252	16.80
23	Optics and Laser Technology	15	203	13.53
24	Physica Scripta	15	89	5.93
25	Superlattices and Microstructures	14	99	7.07
26	Journal of Optics. United Kingdom	13	324	24.92
27	Optical and Quantum Optics	13	49	3.77
28	Journal of Applied Physics	12	219	18.25
29	Journal of Optics India	12	9	0.75
30	Journal of Physical Chemistry C	12	223	18.58
	Total of 20 journals	1146	15513	13.54
	India's total journal papers	1751		
	Share of top 20 journals in India's output	65.45		

TP=Total Publications; TC=Total Citations; CPP=Citations per Paper

## DISCUSSION

Quantum optics have witnessed significant developments over the last few years, which helped to trigger, both directly and indirectly, the birth of quantum technologies, whose aim is to harness non-classical quantum effects in applications. Accordingly, this paper analyzes the Indian research output on the topic of "Quantum Optics" using a bibliometric method.

Globally, 67274 publications were published on "Quantum Optics" during 1996-2021 as indexed in the Scopus database. Of the global publications, 97.42% of publication share emerged from the top 15 countries. USA (17300 publications, 25.72% share) contributed the largest share to global output,

followed by China (11775 publications and 17.50% share), Germany (8370 publications and 12.44% share), U.K. (5865 publications and 8.72% share), etc.

Our findings suggest that a 3.13% share of global research output with 12<sup>th</sup> rank on the topic, emerged from India during 1996-21, with an average citation impact of 12.31 CPP. Of the 2108 publications with one of the authors from India, 30.03% and 28.89% were published with external funding support and as international collaborative publications.

The most frequently used keywords in this area of research, besides quantum optics, included nonlinear optics (459), quantum theory (399), quantum entanglement (258), quantum

computers (216), photons (204), semiconductor quantum dots (188), quantum electronics (181), etc. When one attempts to interpret closely the frequency of commonly used keywords, it is evident that the majority of the research on quantum technologies is somewhat related to quantum optics.

The present bibliometric study also suggests that the research from India was not limited to a few centers only. Overall, 455 organizations participated unevenly on this topic. Although a majority of the publications emerged from authors belonging to 30 organizations only, together contributed to 68.45% of publications and 78.68% share of citations. Another important aspect of the present bibliometric study is that it suggests that although the majority of the publications emerging from institutes like IISc-Bangalore, University of Calcutta, HCRI-Allahabad, TIFR-Mumbai, and PRL-Ahmedabad, in terms of CPP and RCI, authors from institutes like IACS-Kolkata, PRL-Ahmedabad, HCRI-Allahabad, TIFR—Mumbai, and the University of Hyderabad had the highest impact. These findings suggest that the present undoing mechanism has possibly contributed to change in the landscape of the Indian research and this may have a significant positive impact on the research output from India.

The present bibliometric study also suggests that the research from India was not limited to a few authors only. Overall, 635 authors participated unevenly on this topic. The majority of the publications emerged from authors belonging to the top 30 organizations only and they together contributed 544 papers and 7169 citations, constituting 25.81% and 727,62% respective share of Indian publications and citations suggesting that the research output of various authors was heterogeneous and there is a need to improve the research capacity across the country. The majority of the papers were published in journals, with a maximum number of publications in the *Physical Review A* (233 papers), followed by *Quantum Information Processing* (109 papers), *Physics Letters Section A* (74 papers), *Spectrochimica Acta Part A* (61 papers), *Optics Communications* (51 papers), *Journal of Molecular Structure* (49

papers), *Pramana Journal of Physics* (43 papers), etc.<sup>16</sup> Taken together, the present study suggests that the research base in India is becoming more wide-base in this field.

## CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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