Nano research in India

Subbiah Arunachalam, Thulasi Krishna Rao, Subbiah Gunasekaran, B Viswanathan

Writing in *Frontline* about two years ago, India's award-winning science writer *Bajji* R Ramachandran began his article on the status of nanoscience research in India with these words:

"THE government okayed a five-year national nano science and technology mission recently with a Rs.1,000-crore funding. Where are we in the field today and where do we go from here?

India missed the microelectronic revolution of the 1970s and the 1980s. It also failed to invest sufficiently in the rapidly advancing materials sciences and technology and, as a result, today it lags well behind in these fields of economic importance. As science progressed into the 1990s, the importance of the emerging area of nanotechnology was becoming quite apparent to the Indian scientific community. But policy initiatives for a publicly funded national programme were slow in coming. One had to wait until October 2001, when the Nano Science and Technology Initiative (NSTI) was launched by the Department of Science and Technology (DST), largely owing to the drive of C.N.R. Rao, the well-known materials sciences expert at the Jawaharlal Nehru Centre for Advanced Scientific Research (JNCASR) in Bangalore and a pioneer in nano science in the country."

It is not as if Indian scientists had not worked in nano science before NSTI. To quote Ramachandran again, "isolated research work was happening even almost three decades ago. In the late 1970s the Tata Institute of Fundamental Research (TIFR) of the Department of Atomic Energy (DAE) was carrying out studies in the application of fine-grained nano-crystalline materials in microwave and piezoelectric devices. In the 1980s, the Indian Institute of Technology (IIT) at Kharagpur was synthesising ceramic oxide nanoparticles. The researchers attempted industrial application of magnesium and aluminium oxide nanopowders in the cement industry.

During the same period, A.N. Maitra of Delhi University's Chemistry Department was engaged in the preparation of inorganic nanoparticles in the aqueous core of reverse

micelle droplets. According to Maitra, these are nanoscale droplets and nanoparticles formed in their core also have narrow size distribution. Nanoparticles of copper oxalate, yttrium oxalate and barium oxalate were produced in this way so that they could be sintered at much lower temperatures to yield the compound yttrium-barium-copper oxide for high-temperature superconductivity studies."

But certainly NSTI gave a fillip to the field. In this short paper, we have made a quick analysis of India's contribution to nano research as seen from *Web of Science*, 2006 and 2007.

Results

Let us begin with nano research in the world as a whole. A search for nano science papers in the *Web of Science* using the search strategy [PY = 2006 OR 2007 and Topic Words = nano* NOT(NaNO2 OR NaNO3 OR nanosecond OR nanovolt OR nanoampere OR nanogram OR nanonewton)] retrieved 42,761 papers with a publication date in 2006 and 45,522 papers with a publication date in 2007.Table 1 lists countries that are most active in this field. Twenty-five countries have published more than 600 papers each in the two-year period, and 19 countries have published more than a thousand papers. USA leads the field accounting for one quarter of all nano science papers indexed in

Table 1 - Leading countries contributing papers in nanoscience research
[Data from *Web of Science*, as on 23 March 2008]

Country	Record Count	% of 88283		Country	Record Count	% of 88283
USA	22630	25.63		AUSTRALIA	1601	1.81
PEOPLES R CHINA	17851	20.22		SINGAPORE	1555	1.76
JAPAN	8350	9.46		SWITZERLAND	1360	1.54
GERMANY	7000	7.93		NETHERLANDS	1217	1.38
SOUTH KOREA	5036	5.70		POLAND	1203	1.36
FRANCE	4818	5.46		BRAZIL	1196	1.35
ENGLAND	3535	4.00		SWEDEN	990	1.12
INDIA	3395	3.85		BELGIUM	887	1.00
ITALY	2937	3.33		ISRAEL	860	0.97
TAIWAN	2788	3.16		AUSTRIA	645	0.73
RUSSIA	2640	2.99		UKRAINE	610	0.69
SPAIN	2574	2.92		GREECE	602	0.68
CANADA	2373	2.69				

Web of Science in the two years considered. Till a few years ago, China and South Korea were way behind some of the OECD countries such as Japan, Germany, UK and France, but now China is second only to USA and accounts for over one fifth of the world's papers, and South Korea occupies the fifth position. India occupies the eighth position with less than 4% of the world output of papers. Table 2 lists institutions contributing a very large number of research papers in this field. Here again the dominance of Chinese institutions is evident. At least there are eight Chinese institutions in the list of 25 institutions publishing the largest number of papers in nano science. The lone entry from India, viz. Indian Institute of Technology, is indeed made up of seven institutions.

Table 2 - Nano research in the world – Leading institutions
[Data from *Web of Science*, as on 23 March 2008]

Institution	Record Count	% of 88283
CHINESE ACAD SCI	3764	4.26
RUSSIAN ACAD SCI	1346	1.52
CNRS	984	1.11
TSING HUA UNIV	974	1.10
NATL UNIV SINGAPORE	850	0.96
UNIV SCI & TECHNOL CHINA	778	0.88
TOHOKU UNIV	771	0.87
ZHEJIANG UNIV	728	0.82
CSIC	721	0.82
OSAKA UNIV	711	0.81
UNIV TOKYO	710	0.80
INDIAN INSTITUTE OF TECHNOLOGY*	709	0.80
SEOUL NATL UNIV	675	0.76
CNR	673	0.76
MIT	661	0.75
UNIV TEXAS	660	0.75
UNIV ILLINOIS	650	0.74
NANJING UNIV	639	0.72
UNIV CALIF BERKELEY	638	0.72
GEORGIA INST TECHNOL	605	0.69
SHANGHAI JIAO TONG UNIV	586	0.66
KYOTO UNIV	567	0.64
FUDAN UNIV	562	0.64
NANYANG TECHNOL UNIV	544	0.62
JILIN UNIV	543	0.62

* Includes all seven Indian Institutes of Technology

Table 3 - Nano research in India – Leading institutions

[Data from *Web of Science* 2006-2007 as on 20 April 2008]

Institution	No. of papers	% of 3505
Indian Institute of Science	249	7.10
Indian Institute of Technology Kharagpur	245	6.99
Indian Association for Cultivation of Science	236	6.73
National Chemical Laboratory	158	4.50
Bhabha Atomic Research Centre	156	4.45
Indian Institute of Technology Madras	145	4.14
Indian Institute of Technology Delhi	130	3.71
Indian Institute of Technology Bombay	115	3.28
National Physical Laboratory	98	2.80
University of Delhi	96	2.74
JNCASR, Bangalore	95	2.71
Indian Institute of Chemical Technology	91	2.60
Indian Institute of Technology Kanpur	90	2.57
Jadavpur University	81	2.31
Alagappa University	70	2.00
University of Poona	62	1.77
Institute of Physics	58	1.65
Anna University	54	1.54
University of Hyderabad	52	1.48
Saha Institute of Nuclear Physics	51	1.46
Central Electrochemical Research Institute	50	1.43

In Table 4, we list the journals often used by nano science researchers to publish their findings. Although new journals have emerged to cater specifically to nano science research, researchers in this field publish their work in selected physics, physical chemistry and materials science journals.

Among the prolific authors from India in this field are S Chaudhri of Indian Association for the Cultivation of Science, Calcutta, C N R Rao of JNCASR, Bangalore, and D K Avasthi of Inter University Accelerator Centre, Delhi. We have already looked at the work and impact of C N R Rao. Here we present some results on our study on the nano research of Kamanio Chattopadhyay and A K Sood, both of Indian Institute of Science.

Table 4 - Journals most often used by nanoscience researchers

[Data from *Web of Science*, as on 23 March 2008]

Source Title	Record Count	% of 88283
APPLIED PHYSICS LETTERS	3438	3.89%
NANOTECHNOLOGY	2059	2.33%
PHYSICAL REVIEW B	1998	2.26%
JOURNAL OF APPLIED PHYSICS	1725	1.95%
JOURNAL OF PHYSICAL CHEMISTRY B	1447	1.64%
LANGMUIR	1428	1.62%
JOURNAL OF PHYSICAL CHEMISTRY C	1419	1.61%
JOURNAL OF THE AMERICAN CHEMICAL SOCIETY	1195	1.35%
NANO LETTERS	1134	1.28%
MATERIALS LETTERS	1072	1.21%
JOURNAL OF NANOSCIENCE AND NANOTECHNOLOGY	1054	1.19%
CHEMISTRY OF MATERIALS	931	1.05%
ABSTRACTS OF PAPERS OF THE AMERICAN CHEMICAL SOCIETY	881	1.00%
JOURNAL OF APPLIED POLYMER SCIENCE	835	0.95%
PHYSICAL REVIEW LETTERS	802	0.91%
ADVANCED MATERIALS	755	0.86%
THIN SOLID FILMS	738	0.84%
APPLIED SURFACE SCIENCE	693	0.79%
JOURNAL OF MATERIALS SCIENCE	639	0.72%
JOURNAL OF MAGNETISM AND MAGNETIC MATERIALS	635	0.72%
SURFACE & COATINGS TECHNOLOGY	631	0.71%
CARBON	601	0.68%
JOURNAL OF COLLOID AND INTERFACE SCIENCE	578	0.65%
MACROMOLECULES	574	0.65%
JAPANESE JOURNAL OF APPLIED PHYSICS PART 1-REGULAR PAPERS BRIEF COMMUNICATIONS & REVIEW PAPERS	563	0.64%

Kamanio Chattopadhyay of the Department of Materials Engineering, Indian Institute of Science, Bangalore, started publishing in this field in 1992 and has so far published eighty papers till 10April 2008. These have been cited 713 times for an average of 8.9 citations per paper. His h-index for nanoscience papers alone is 15. He has coauthored

papers with 83 researchers from 34 institutions in eight countries. He has collaborated with A Narayanaswamy in 19 papers, with N Ponpandian in 17 papers, with C N Chinnasamy in 12 papers, with R Goswami in 11 papers, and with V Bhattacharya in 10 papers. His nano science papers have appeared in 30 journals, and his preferred journals are *Materials Science and Engineering A* (17 papers), *Acta Materialia* (7), *Journal of Materials Research* and *Scripta Materilaia* (6 each).

A K Sood of the Department of Physics, Indian Institute of Science, Banglaore, started publishing in this field in 1994 and has so far published 54 papers till 10April 2008. These have been cited 601 times for an average of 11.1 citations per paper. His h-index for nanoscience papers alone is 13. He has coauthored papers with 32 researchers from 25 institutions in six countries. He has collaborated with C N R Rao in 25 papers, A Govindaraj (15), Y M Azhniuk (13), A V Gomonnai, V V Lopushansky and A Roy (11 each). . His nano science papers have appeared in 28 journals, and his preferred journals are *Chemical Physics Leters* and *Journal of Nanoscience and Nanotechnology* (6 papers each), *Physical Review B* and *Pramana* (5 each).

A detailed report on the nanoscience work of both Chattopadhyay and Sood including HistCite analysis will be prepared soon.

We have also looked at the work of P M Ajayan of Rice University (formerly at Rensselaer Polytechnic Institute). This non-resident Indian scientist has done extremely well. Starting from 1986 he has so far published 287 papers in all, all but 27 papers are in the field of nano science. His first paper in this field was in 1991. The 287 papers have been cited 14,326 times for an average of 49.91 citations per paper. His h-index is 56. In the seven years 2001-2007 Ajayan has averaged 27.5 papers a year. He has collaborated with 477 authors from 22 countries. His collaborators include S Iijima (14 papers, 1780 citations), T W Ebbesen (7 papers, 2411 citations), P Redlich (16 papers, 1297 citations), L S Schadler (16 papers, 1194 citations), C Colliex (10 papers, 1364 citations), O Stephan (8 papers, 1262 citations), P Bernier (12 papers, 1062 citations), B Q Wei (48 papers, 1727 citations), and R Vajtai (56 papers, 1196 citations). Ajayan's papers have appeared in 83 journals, and his preferred journals are *Applied Physics Letters* (30 papers,

927 citations), *Nano Letters* (22 papers, 812 citations), *Advanced Materials* (20 papers, 1091 citations), *Physical Review Letters* (17 papers, 1576 citations). Ajayan has published 14 papers in *Nature* (4061 citations) and 8 papers in *Science* (1239 citations). One of his reviews in *Chemical Reviews* has won 834 citations and another in *Reports on Progress in Physics* has won 222 citations. A detailed study of Ajayan's work is under preparation.

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