

Advancing Nanoelectronics Innovation in India: Outcomes of the Multi-Institutional NNetRA Research Program

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ABSTRACT

Nanoelectronics has emerged as a foundational technology enabling innovations across computing, communication systems, sensing platforms and biomedical diagnostics. Recognising the strategic importance of this field, the Nanoelectronics Network for Research and Applications (NNetRA) Program was launched to strengthen domestic research capabilities and accelerate technology development. Supported by the Department of Science and Technology (DST) and the Ministry of Electronics and Information Technology (MeitY), the Program established a collaborative research network among five premier institutions: IIT Bombay, IIT Delhi, IIT Kharagpur, IIT Madras and the Indian Institute of Science (IISc). The project proposals from these institutes were supported with a total budget of 294 crore, with joint funding by DST, MeitY, and the implementing institution on a 1:1:1 basis w.e.f. 2018. This report highlights the technological and scientific outcomes of the NNetRA Program through a comparative analysis of outputs across the participating institutions. Using institutional reports and Program documentation, the study presents indicators such as research publications, patents, technology prototypes, startup ventures, and trained workforce. The findings indicate that the Program significantly enhanced the nanoelectronics research ecosystem, facilitating interdisciplinary collaboration and technology translation across the country. The results demonstrate that mission-oriented collaborative research networks can play an important role in strengthening national innovation capabilities in strategic technology domains.

Keywords: Nanoelectronics, semiconductor research, innovation ecosystems, technology translation, research networks.

1. Introduction

Nanoelectronics represents one of the most transformative technological fields of the twenty-first century. By enabling electronic components at nanoscale dimensions, nanoelectronics technologies allow higher performance, lower energy consumption and enhanced functionality in modern electronic systems. These technologies underpin a wide range of applications, including high-performance computing, environmental sensing, medical diagnostics, advanced communication systems and power electronics.

Global competition in semiconductor and nanoelectronics technologies has intensified in recent years as countries seek to strengthen their technological sovereignty and industrial competitiveness. Governments worldwide have initiated strategic programs to enhance domestic research capabilities and develop innovation ecosystems that integrate academia, industry and government agencies.

India has recognised nanoelectronics as a critical domain for technological advancement and economic growth. To accelerate research and innovation in this area, the Government of India launched the Nanoelectronics Network for Research and Applications (NNetRA) Program. The initiative was designed to promote collaborative research among leading academic institutions and to encourage the development of technologies with practical industrial and societal applications.

The NNetRA Program represents an important step in building India's semiconductor research ecosystem. By supporting interdisciplinary research and facilitating technology translation, the Program aims to bridge the gap between fundamental scientific research and real-world technological solutions.

This report presents a comprehensive assessment of the outputs generated under the NNetRA initiative. The report focuses on five participating institutions, IIT Bombay, IIT Delhi, IIT Kharagpur, IIT Madras and IISc Bangalore, and examines their contributions to research productivity, innovation outcomes and technology development.

2. Overview of the NNetRA Program

The NNetRA Program was established as a national collaborative research network focused on nanoelectronics technologies. The Program sought to strengthen India's capabilities in semiconductor devices, nanosensors, photonics, biomedical electronics and related domains.

The initiative was jointly supported by:

- i. Department of Science and Technology (DST)
- ii. Ministry of Electronics and Information Technology (MeitY)

Five premier research institutions were selected as participating centres:

- i. Indian Institute of Technology Bombay
- ii. Indian Institute of Technology Delhi
- iii. Indian Institute of Technology Kharagpur
- iv. Indian Institute of Technology Madras
- v. Indian Institute of Science, Bangalore

Each institution implemented multiple research projects targeting different technological domains within nanoelectronics. The Program emphasised interdisciplinary collaboration and encouraged researchers to develop technologies that could progress toward prototype development and commercialisation.

In addition to scientific research, the initiative focused on several strategic objectives:

- i. Development of advanced semiconductor technologies
- ii. Creation of nanoscale sensing systems
- iii. Advancement of biomedical diagnostic technologies
- iv. Training of highly skilled researchers
- v. Promotion of technology translation and Startup formation

The distributed research network allowed institutions to leverage their unique strengths and infrastructure, thereby fostering a dynamic innovation ecosystem.

3. Methodology

This study adopts a qualitative and quantitative document analysis approach. Institutional project reports, program

summaries and technology outcome documents generated under the NNetRA initiative were examined to identify key indicators of research productivity and innovation outcomes.

The analysis focuses on several measurable indicators:

- i. Scientific publications in journals and conferences
- ii. Patents filed or granted
- iii. Startup ventures created from research outcomes
- iv. Human resource development (students and researchers trained)
- v. Technology prototypes and transfers to industry

A comparative institutional analysis was conducted to examine how different research groups contributed to the Program's overall objectives. In addition to quantitative metrics, qualitative descriptions of technological developments were analysed to understand the Program's broader impact.

4. Institutional Outputs

The five participating institutions generated significant research outputs across multiple nanoelectronics domains. Table 1 summarises the major quantitative outputs reported under the Program.

Table 1: Institutional Outputs under NNetRA

Institutions	Publication	Patents	Startups	Manpower Trained
IIT Bombay	25	7	3	53
IIT Delhi	172	21	3	115
IIT Kharagpur	81	10	3	70
IIT Madras	51	11	1	55
IISc Bangalore	106	11	2	173

The results indicate strong research productivity across the network, with IIT Delhi and IISc producing the largest number

of publications, while other institutions demonstrated strengths in device development and sensor technologies.

4.1 IIT Bombay

IIT Bombay played an important role in the NNetRA program by focusing on advanced semiconductor device technologies and nanosensor systems. The institute developed gallium nitride (GaN) semiconductor technologies, which are widely used in high-power electronics due to their superior efficiency and thermal stability.

One of the key technological developments was the fabrication of infrared photodetectors compatible with CMOS technologies, enabling potential applications in space sensing and imaging systems. The institute also developed secure one-time programmable memory technologies that can support hardware-level encryption systems.

Another significant achievement was the development of soil monitoring nanosensor platforms for agricultural applications. These sensors measure soil moisture and electrical conductivity, enabling precision agriculture practices. The technologies were tested in collaboration with agricultural industry partners and demonstrated potential for commercialisation.

The translational impact of these technologies is reflected in the creation of several startups and technology transfer agreements with organisations such as ISRO and semiconductor fabrication facilities.

4.2 IIT Delhi

IIT Delhi emerged as one of the most productive institutions within the NNetRA network in terms of research publications and patents. The institute conducted extensive research in biosensors, nanophotonics, magnetic field sensors and microfluidic diagnostic systems.

Researchers developed lab-on-chip diagnostic platforms capable of detecting biological markers with high sensitivity. Such devices have potential applications in point-of-care medical diagnostics, enabling rapid and low-cost disease detection.

In addition, IIT Delhi researchers made significant contributions to nanophotonic sensing technologies that utilise the optical properties of nanostructures for highly sensitive detection of chemical and biological species.

The institute also demonstrated strong innovation outcomes through multiple patent filings and the creation of technology startups based on nano-biosensor technologies.

4.3 IIT Kharagpur

IIT Kharagpur focused on the development of environmental sensing systems and biomedical diagnostic technologies. Researchers developed advanced nanosensor platforms capable of detecting environmental pollutants and monitoring air quality.

Another important area of research involved nano-enabled drug delivery systems and biomedical diagnostic devices. These technologies have potential applications in healthcare diagnostics and therapeutic monitoring.

The institute also worked on developing portable diagnostic platforms for use in resource-limited settings. Such technologies are particularly relevant for public health applications in developing regions.

Through these initiatives, IIT Kharagpur contributed to expanding nanoelectronics applications beyond traditional semiconductor technologies.

4.4 IIT Madras

IIT Madras conducted research in several key nanoelectronics domains, including MEMS sensors, gallium nitride electronics and biomedical microfluidic systems. The institute developed microscale sensing devices capable of detecting physical and chemical parameters with high sensitivity.

One area of significant innovation was the development of microfluidic platforms for biomedical diagnostics. These systems enable precise manipulation of small volumes of biological samples, allowing rapid detection of disease markers.

Researchers also explored advanced semiconductor device structures that could improve the performance of electronic systems used in communication and sensing technologies.

The institute's research outputs include multiple patents and the development of prototype devices with potential industrial applications.

4.5 IISc Bangalore

The Indian Institute of Science made significant contributions to nanoelectronics research through work on power electronics, photonic sensors, and nanoscale robotics. IISc researchers developed advanced GaN-based power electronic devices designed for efficient energy conversion systems.

Another area of innovation involved nanophotonic sensing platforms, which utilise nanoscale optical structures to achieve highly sensitive detection capabilities. Such technologies can be used in environmental monitoring, healthcare diagnostics and industrial sensing applications. Technologies, viz., packaged GaN devices, compact PCR systems, high-power fibre laser, gas sensors, and transmitters, have already been transferred in the project.

The institute also explored emerging technologies such as nanoscale robotic systems for biomedical and materials science applications. These research activities resulted in significant publication output and contributed to the advancement of India's nanoelectronics research capabilities.

5. Technology Translation and Innovation Impact

One of the main objectives of the NNetRA Program was to encourage technology translation and commercialisation. Several projects progressed from laboratory research toward prototype development and industry collaboration.

Key technology areas with commercialisation potential include:

- i. Semiconductor power devices
- ii. Environmental monitoring sensors
- iii. Biomedical diagnostic platforms

- iv. Microfluidic lab-on-chip technologies
- v. Photonic sensing systems

Startup formation represents another important outcome of the Program. Several research teams established technology ventures to commercialise nanosensor and diagnostic technologies developed during the Program.

Industry collaborations also played a critical role in validating and deploying technology. Partnerships with organisations such as space research centres, semiconductor fabrication facilities and healthcare technology companies facilitated the translation of research outcomes into real-world applications.

6. Discussion

The findings highlight the effectiveness of collaborative research networks in advancing technological innovation. By connecting multiple institutions and encouraging interdisciplinary research, the NNetRA Program created a distributed innovation ecosystem.

Human resource development represents another major outcome of the initiative. Hundreds of students and researchers received training in advanced nanoelectronics technologies, contributing to the development of a skilled workforce for India's semiconductor sector.

Furthermore, the Program demonstrated that academic research can generate technologies with practical industrial applications. Through technology transfer and startup formation, several research outcomes progressed toward commercialisation.

7. Conclusion

The Nanoelectronics Network for Research and Applications (NNetRA) Program has played a significant role in strengthening India's nanoelectronics research ecosystem. Through collaborative research across five premier institutions, the Program generated substantial scientific outputs including publications, patents, technologies and startup ventures.

The case studies presented in this paper illustrate the diverse technological innovations emerging from the participating

institutions. From semiconductor devices and nanosensors to biomedical diagnostic platforms, the Program has contributed to multiple technological domains.

Mission-oriented collaborative research initiatives such as NNetRA provide an effective model for advancing strategic technologies and fostering innovation ecosystems. Continued investment in such programs will be critical for strengthening India's capabilities in semiconductor technologies and other emerging technological fields.

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