Indian Council of World Affairs

EMERGING TECHNOLOGIES AND INDIAN DIPLOMACY

ARTIFICIAL INTELLIGENCE

SEMICONDUCTORS

NANOTECHNOLOGY

INDIAN COUNCIL OF WORLD AFFAIRS
SAPRU HOUSE, NEW DELHI
2024

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January 2024

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Foreword

During his state visit to the United States in June 2023, Prime Minister Narendra Modi underscored that "Our goal is to make this decade a tech decade." Overtime, India has embraced technology as a core element of its diplomacy and foreign policy. In contemporary times, emerging technologies have become critical for India's economic development and national security, thus, India is aiming to clinch its tech moment. India is crafting its diplomatic outreach around emerging technology and its applications like Artificial Intelligence, Nanotechnology, Semiconductors, Fintech (DPIs) etc. through various strategic bilateral and multilateral partnerships like iCET (India-US initiative on critical and emerging technology), India-EU Trade and Technology Council, QUAD Tech Network, Global Partnership on Artificial Intelligence (GPAI), etc.

India is complementing its diplomatic outreach with the integration of technology with its domestic governance. Various national missions such as India Semiconductor Mission (2021), Nano Mission (2007), India AI strategy (2018) and soon to be launched AI mission resonate with India's will to integrate emerging tech with diplomacy to advance its economic and geopolitical interests. Ministry of External Affairs has also undertaken structural changes such as the creation of technically specialized divisions like Cyber Diplomacy Division, New Emerging and Strategic Technologies Division (NEST), etc.

This Special Publication explores and examines how emerging technologies have become a new frontier of India's diplomatic outreach to promote its national interests. It includes papers by three distinguished Indian experts. The first paper by Shashi Shekhar Vempati, former CEO of Prasar Bharti titled 'India's Opportunity to Show the Way on AI for Greater Global Good' covers AI's role in redefining power structures, global interdependence, & societal frameworks and India's vital role in advocating responsible and equitable AI for all through its various diplomatic channels like G20 Presidency. The second paper by Amb. Bhaskar Balakrishnan titled 'Semiconductor Industry and India's Role' argues about the foundational role semiconductors play in almost all industries (smartphones, computers, medical devices, etc.) and India's efforts in developing its own semiconductor industry via its diplomatic cooperation with various countries such as US, Japan, RoK, Taiwan, etc. in addition to domestic efforts.

The third paper by Prof. Parameswar Krishnan Iyer titled 'Indian Diplomacy and India's Nano Mission' focuses on multi-disciplinary nature of nanoscience in promoting integration with other fields such as AI, Quantum, semiconductors etc. and the role played by India's nano mission in building strong domestic capabilities which is helping in forging deeper diplomatic engagements and international collaboration.

ICWA hopes this publication would be useful in enhancing understanding of how emerging technologies have become a new frontier of India's diplomatic outreach to promote its national interests and act as an impetus for further study on this subject.

Amb Vijay Thakur Singh

Director General
Indian Council of World Affairs

Sapru House
January 2023

INDIA'S OPPORTUNITY TO SHOW THE WAY ON ARTIFICIAL INTELLIGENCE FOR GREATER GLOBAL GOOD

Shashi Shekhar Vempati

Introduction

The interplay between technology and diplomacy is perhaps as old as civilization itself. Early examples of this would be the clay tablets that not only recorded conquests several thousands of years ago but also documented treaties between empires. It would not be an exaggeration to state that technology has continually redefined the diplomatic landscape be it the semaphores or the telegraph and today the internet. The 20th century is perhaps the period that witnessed the most rapid infusion of new technologies into the diplomatic landscape with the advent of new communication technologies from the telephone to the internet, and from social media to smartphones, all of which have had a revolutionary impact on how international relations are conducted. If the role played by the good old POTS (Plain Old Telephone System) rotary phones enabling International Hotlines between the U.S. and the Soviet Union during the Cold War, made for a number of Hollywood scripts, today Twitter/X is where reality emerges as stranger than fiction when global leaders and influencers spar with each other on geopolitical issues, unite over celebratory moments and are able to directly communicate their message transcending borders.

The rise of Digital Diplomacy over the internet has expedited correspondence, democratized access to information, and facilitated a new class of influencers and brand ambassadors empowered by technology. Creativity in the use of the internet and new communication technologies to achieve diplomatic objectives has meant that diplomats and world leaders are not only able to engage directly with the public, announce policies, or respond to global issues but more importantly are able to influence and shape public opinion across borders from electoral outcomes to street protests. The openness of the internet and the sophistication of digital communication technologies has made sovereign states both susceptible to such influences from across borders as well as empowered to exercise such influence in their own interests.

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From nuclear non-proliferation/disarmament to space collaboration, emerging technologies have shaped diplomatic agendas over the decades. Be it diplomatic initiatives like the Treaty on the Non-Proliferation of Nuclear Weapons (NPT), or the Outer Space Treaty of 1967, technology has been as much the focus of the diplomatic agenda as it has been an instrument of conducting diplomacy. Data privacy, cybersecurity and the flow of data across borders has emerged as another critical area where the interplay between technology and diplomacy has been both ways with the need for global collaboration in dealing with bad actors as well as deploying regulations as leverage against large technology platforms that operate across borders and jurisdictions. Technology as an instrument of State Policy through both overt and covert actors has emerged as an issue of paramount given the scale of misinformation and disinformation as has been evident during the recent conflict in Ukraine. Further the ability of large technology platforms to control the flow of information through social media in such conflict situations motivates the need for a multi-dimensional approach to the interplay between technology and diplomacy from a mere instrument to becoming a force multiplier.

Artificial Intelligence perhaps best exemplifies such an emerging technology with the potential for multi-dimensional interplay acting as both a force multiplier to diplomacy as well as a key focal point of diplomatic agenda-making. From a tool that can facilitate diplomatic practice to a significant agenda item for global diplomacy, AI's evolution at an unprecedented pace necessitates a keen understanding and adaptation to these changes within the diplomatic corps globally. This interplay of technology and diplomacy in the context of international

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relations thus merits a deeper analysis and broader elucidation.

While taking a close look at the AI landscape in India this paper explores AI's role within diplomacy. Further dwelling on India's AI agenda the paper draws lessons from recent global experiences to lay out opportunities for India to demonstrate techno-diplomatic leadership within the sphere of international relations.

India's AI Landscape

The Artificial Intelligence landscape in India has seen dramatic shifts over the past several years. Writing on India and the Artificial Intelligence Revolution in August of 2016, I found few early shoots of private investment in AI and several government funded research projects that were barely making an impact. Calling for an AI ecosystem to be developed in India the 2016 paper envisioned a national grand strategy driving public investment and augmenting national capacity. A follow up paper in 2019 on Artificial Intelligence Grand Challenges for India observed the impact of two specific efforts to kickstart an AI ecosystem in India – the National Strategy for AI authored by Niti Aaayog and the AI task force setup by the Ministry of Commerce that brought a national focus to AI. The setting up of the Wadhwani Institute of Artificial Intelligence underscored how privately funded AI research was starting to look at societal scale applications for AI in areas of public interest. The past five years have seen significant boost to AI efforts across India. Most notable amongst these is the AI for Bharat initiative of IIT Madras along-side the Bhashini effort of the Ministry of Information Technology, MeITY, focused on developing large language models for Indic Languages. The year 2022 was a significant mile-marker with India assuming the Presidency of the Global Partnership on Artificial Intelligence. The United Nations Industrial Organisation, UNIDO, released an index of Government AI Readiness in 2022 which found India at rank 32 globally while the Stanford

Institute for Human Centric Artificial Intelligence's AI Index report released in April 2023 ranked India fifth in terms of investments received by start-ups for AI based products and services. The index also found India at the top of the charts for AI skills penetration. To further track and measure AI penetration in India, the NASSCOM, an association of technology industries, has also launched an AI Adoption Index. India has since witnessed a broad-basing of the public discourse around with the evolution of new fora such as the AI for India forum, bringing together academia, think-thanks, start-ups and large enterprises to deliberate on the societal scale impact of AI in India and the policy responses needed in anticipation of the same.

AI in Diplomacy

Diplomacy on AI has been the focal point of several global geopolitical conversations with the recent advances in generative artificial intelligence capabilities raising concerns on the need for international norms on the development and deployment of large language AI models. Evolving such norms for AI becomes imperative given the interconnectedness of systems, platforms and applications transcending borders much like the internet. Further given the need for coordinated action by nations on issues ranging from climate action to international trade, trafficking to counter-terrorism, it is conceivable in the future that advancements in AI enable global networks to address the same bringing both benefits and new classes of challenges. While fears on rogue AI systems misinterpreting routine benign activities by one state as a military threat to another are perhaps exaggerated at this time, given the pace of evolution of autonomous systems and the intelligence powering them, such challenges are very much within the realm of possibility in the future. Pre-emptive defensive actions by AI powered autonomous systems in response to false

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alarms could impact interconnected systems such as power grids and energy distribution causing large scale disruptions across borders. Across both military and civil applications, it is quite likely that autonomous systems if not properly calibrated and coordinated, could inadvertently trigger international crises given the interconnectedness of systems and the interdependencies of economies. Further with the rapid pace at which generative artificial intelligence are able to hold human like conversations through digital personas we are entering a new age where AI powered agents are capable of conducting a swathe of human activities. An example closer to the world of diplomacy is real time translation in multiple languages as is commonly done in multilateral bodies such as the United Nations. It is entirely conceivable that multilingual AI personas designed to understand cultural nuances, historical contexts, while processing vast amounts of data to facilitate diplomatic conversations could pose new challenges in the absence of both human biases and emotions. If algorithms driven by logic and designed to maximise mutual benefit can bring speed and efficiency to conversations it is a matter of debate what implications the absence of political or emotional biases would have on such conversations.

This raises the question on the need for Trust and Transparency around Algorithms and Autonomous Systems powered by Artificial Intelligence that will likely be deployed in multilateral settings. Recent regulatory developments in China give adequate cause for concern on this front given how AI based systems are being mandated to necessarily incorporate nationalistic agendas. This also makes it imperative for multilateral use of technologies such as artificial intelligence to accurately reflect historical context with its varied nuances and subjectivities. Inclusivity in values, ethics, and oversight also become essential in the context of such hypothetical uses of artificial intelligence based systems.

Ultimately any such hypothetical role for AI in multilateral settings would need to make human oversight central and pivotal. Collaborative actions with human intervention would need to be based on a judicious mix of global values, ethics, and understandings. The language of diplomacy would need to evolve to blend the cold world of digital semantics with the timeless human art of negotiation.

India's AI Diplomatic Agenda

While hypothetical scenarios around bad actors and sentient systems may be further away in the future, in the immediate term there is a need for India to focus on Data Diplomacy in specific and Tech-plomacy in general. The recently promulgated legislation on personal data protection by the Indian Parliament offers a framework for India to establish trusted data flows across borders within the ambit of the new law. A key aspect of the law is the "negative list" of jurisdictions to which cross border data transfers cannot be undertaken. While the rules for operation of the law are yet to be framed it is entirely conceivable that future data diplomacy by India in the context of free trade agreements could entail both the flow of human talent and related personal data to facilitate workforce mobility. Tech-plomacy has in recent years gained significance with the efforts to secure global supply chains and the development of critical technologies. The QUAD alliance between India, United States, Japan and Australia is an illustrative example of how tech-plomacy is shaping geopolitics. The understanding between India and the United States for collaboration on critical emerging technologies from semiconductors to open radio networks underscores the extensive role tech-plomacy is poised to play in the years to come. The complexity of issues surrounding both bilateral and multilateral tech-plomacy would require new interdisciplinary roles such as tech ambassadors and related interdisciplinary studies for India to effectively leverage its global position as an emerging technology leader and frugal innovator.

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India's presidency of the Global Partnership on AI is an opportunity for India to play a key influential role in AI ethics. The fast-expanding capacity of the Indian I.T. industry in AI related capabilities and services makes for significant leverage in bilateral and multilateral relations. As the voice of the Global South, India can carve a niche for itself in its advocacy of global AI governance. With the rapid pace at which the backbone of economies, underpinning healthcare, finance, defense, and education is being impacted by AI a stark divide is emerging between nations that have harnessed AI's full potential and those that are still grappling with basic digital infrastructures. In this disparity is a role for Indian Diplomacy on AI. While developed nations have a head-start on integrating AI into their societal fabric, developing nations lag behind, even as societies grapple with the question of likely job losses due to AI-driven automation without the attendant benefits of AI's efficiencies. Unlike earlier waves of technology, the exponential pace of AI advancement can widen these disparities at an unmanageable pace to potentially threaten global stability, economic balances, and perhaps even trigger potential geopolitical tensions.

As the voice of the Global South, India could advocate for an Index of AI Development that goes beyond technological readiness of a country in AI but also it assesses the ethical standards that AI is being held up to within those nations apart from the extent to which AI education was broad-based and the scale at which AI is impacting economic output of the nation. Such an index with a developmental focus could set the stage for Indian diplomacy to lead discussions, negotiations, and potential interventions from the standpoint of the Global South. With concerns over data sovereignty, cyber espionage, and the potential for creating digital colonies assuming significance, the global south would also look to India for transparent and equitable partnerships for global collaboration on AI. The successful push by India in putting Digital Public Goods on the global developmental agenda could offer a template for such a co-operation around AI that puts the interests of the Global South on an

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equitable footing with the opportunities for the developed economies.

From UPI (Unified Payments Interface) and Aadhaar, India's Digital Public Goods have demonstrated the potential for societal-scale digital transformation through open architectures and interoperability. Taking a similar approach to Artificial Intelligence (AI), India can carve a unique space in AI diplomacy, positioning an open AI stack as a digital public good. The India Stack of Digital Public Goods have demonstrated India's commitment to creating scalable, secure, and inclusive digital systems. The Aadhaar, universal-id, has enrolled more than a billion people, revolutionizing service delivery and financial inclusion while UPI has transformed digital payments through inclusiveness that has seen the smallest of vendors participate in the digital economy. Translating the principles of open standards, open APIs, and interoperable systems India can advocate for an 'Open AI Stack' as a layered framework, with standardized protocols, ensuring seamless integration and interoperability of AI systems. An open AI stack that can democratize access to AI can pave the way for societal scale benefits with modest investments. India can lead the charge in global forums to position AI as a digital public good through a universally accessible AI framework that can ensure that no country, regardless of its economic or developmental standing, is left behind in an AI powered future. To alleviate common concerns around opacity, biases, and potential misuse by championing a collaborative approach, a shared AI ecosystem, can lend a positive trajectory to global competition on AI by fostering mutual growth making it a win-win proposition.

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> With its massive investment in AI development, China's integration into the global high-tech supply chain poses multi-dimensional risks. India's tech-plomacy will be tested on creative ways of coping with these risks by both engaging with China and countering potential harm from its actions.

India's advocacy for an open AI stack as a public good can form the centerpiece of its AI diplomacy strategy to bridge the AI divide between technologically advanced nations and those still striving to find their footing. By taking the lead in promoting open, transparent, and inclusive AI, India can position itself as a thought leader in the ethical AI discourse, influencing global AI norms and governance. Offering the open AI stack as a resource for collaboration can foster deeper ties with nations, echoing the soft-power diplomacy historically seen with India's IT and software prowess. Such an approach can spur a new wave of innovation, with start-ups and enterprises building solutions on this stack, propelling economic growth and positioning India as an AI hub.

A co-operation pact around AI could emerge as a rallying point for nations of the Global South to achieve the above outcomes. Such a pact would also have to strive to prevent the weaponization of AI, ensuring that AI isn't used for mass surveillance, espionage, or in autonomous weapons. It would however require techno-intensive diplomacy on definitions, enforcement mechanisms, and verification protocols. Bringing together ethicists, technocrats, and diplomats, an appropriate universal code for AI development and deployment, emphasizing human rights, privacy, and fairness could be the center-piece of these co-operation efforts. A desirable outcome of these efforts would be a global pledge to democratize AI, commitments on sharing AI resources, training and skilling in less developed countries, and ensuring that AI-driven solutions address global challenges, from climate change to healthcare disparities. Simultaneously these co-operation efforts would also need to put in place transparent systems wherein the algorithms and data that feed AI are accessible and can be audited. Prevention of AI-Powered Disinformation is an immediate goal given how large and open democracies are vulnerable to such organised efforts. Cooperation in identifying, mitigating, and countering AI-driven disinformation campaigns becomes critical.

From its use of AI for mass surveillance to its regulatory diktats on generative AI models, China's approach to Artificial Intelligence (AI) has significant implications for the world. With its massive investment in AI development, China's integration into the global high-tech supply chain, poses multi-dimensional risks. India's tech-plomacy will be tested on creative ways of coping with these risks by both engaging with China and countering potential harm from its actions. China's rise as a formidable player in AI and its ambition to emerge as the foremost global innovator in AI is evident from its extensive use of AI across various sectors. With use of AI for mass surveillance using facial recognition, censorship that routinely scrubs the Chinese internet of information inconvenient to the communist regime, integrating China into any global framework for AI ethics will be a complex task. The current trajectory of the developed west to isolate China from the global high-tech supply chain is spurring a renewed effort on its part to accelerate AI innovation. Given these complexities, a thoughtful approach to engage with China from an AI perspective will have to be evolved as India mulls a diplomatic agenda around AI. Given the intertwined nature of the global economy, and the multi-faceted challenges and opportunities that China's AI rise presents, the approach should ideally involve international cooperation, healthy competition, and strategic containment. How Indian Diplomacy navigates this complex landscape at the intersection of technology and geopolitics will shape the future of AI and its impact on global society and economy.

Conclusion

Artificial Intelligence is one of the most transformative technologies poised to shape the future of humankind in a profound manner. To realise its benefits universally while ensuring that no

To realise its benefits universally while ensuring that no community, society, or nation is left behind calls for an interplay between technology and diplomacy with the belief that AI's potential should be harnessed for the collective welfare of all.

community, society, or nation is left behind calls for an interplay between technology and diplomacy with the belief that AI's potential should be harnessed for the collective welfare of all. Empowering every nation and community with the knowledge and tools to harness AI calls for the development of resources for both AI education and skilling with the technology itself creating avenues to overcome barriers of culture and language. The thrust of AI Diplomacy will be to ensure every country, irrespective of its economic status, can deploy and benefit from AI. This would require both financial measures such as creation of global funds to assist nations in building necessary AI infrastructure and developmental measures such as shared AI cloud resources and collaborative research facilities. AI diplomatic efforts to ensure highest ethical standards and respect for human rights and freedoms will likely face complex challenges pitting China versus the rest. Protecting societies against misuse and harm from surveillance, unauthorized data harvesting, and manipulative AI technologies will require immediate action given the exponential pace at which these technologies are advancing. Diplomacy cannot also lose sight of the environmental implications from large scale high performance computing facilities as data centres and the widespread proliferation of AI-driven processes. A sustainable development agenda for AI facilitated by global diplomacy could focus on promotion of green AI research, energy-efficient algorithms and hardware and a transition to renewable energy for AI infrastructure. From China's regulatory moves imposing political norms on generative AI models to western beliefs and values biasing models there is an acute need for AI diplomacy to prioritise inclusivity and respect for indigenous cultures and diversity of local values in the manner in which these models are trained and developed. The ultimate test of effectiveness of these efforts would be when access to AI is equitable, the gap between nations is narrowed and universal accessibility is achieved. This will require a continuous commitment to greater good, collective aspirations to benefit all of humanity. Indian philosophy offers a rich tapestry of thoughts, values, and principles that can guide on the ethical use and development of AI for greater global good. The adoption of Vasudhaiva Kutumbakam (The World is One Family) from the Upanishads during India's Presidency of G20 is a good example of how Indian Diplomacy drawing on indic

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values can provide global leadership. An ethically grounded, inclusive framework for AI that is centered around the holistic welfare of humanity will not just serve India, but has the potential to emerge as a beacon for global common good, demonstrating how ancient wisdom can guide modern innovation to be both harmonious and beneficial. By 2047, when Independent India turns ahead with the culmination of Amrit Kaal, it is expected that Diplomacy on AI becomes as crucial as traditional diplomacy once was for peace, trade, and alliances. As Artificial Intelligence redefines power structures, global interdependence, and societal frameworks, the task is cut out for diplomacy to negotiate not just for national interests, but aspire for a balanced, equitable and harmonious AI-driven global order.

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SEMICONDUCTOR INDUSTRY AND INDIA'S ROLE

Bhaskar Balakrishnan

Introduction

This article examines the recent changes in the global semiconductor industry and technology. The role of major players is examined as well as issues related to supply chains. The recent developments in India's semiconductor policy and industry spaces and the various external engagements of India with major semiconductor industrial countries are examined. The impact of new technology and novel materials, and rare earths and the interconnections with renewable energy is assessed.

Context

Semiconductors are materials which have a conductivity between that of a conductor, such as copper, and an insulator, such as glass. Its resistivity falls as its temperature rises in contrast to metals which behave in the opposite way (1). Its conducting properties may be altered in useful ways by introducing impurities ("doping") into the crystal structure. When two differently doped regions exist in the same crystal, a semiconductor junction is created which is the basis of diodes, transistors, and most modern electronics. A large number of elements and compounds have semiconducting properties such as silicon and germanium; binary compounds, such as gallium arsenide, silicon carbide; and organic semiconductors, made of organic compounds; and semiconducting metal–organic frameworks. After silicon, gallium arsenide is the second-most common semiconductor. Silicon is a critical element for fabricating most electronic circuits. Semiconductors are widely used in electronic devices having replaced the older vacuum tube technology. Semiconductors are a key enabling technology. They are essential ingredients of other emerging technologies, such as artificial intelligence, autonomous systems, 5G communications, and quantum computing. Growth in semiconductor capabilities and performance, along with cost reductions, can drive economic output and productivity and enable new products, services, and industries (2). The semiconductor industry and the industrial activities and systems it enables is the basis of technological and industrial competitiveness and national security.

Background of the Industry

Semiconductor devices (also known as integrated circuits, microelectronic chips, or computer chips) are tiny electronic

From 2012 to 2022, global sales of semiconductor chips doubled to $602 billion. Improving semiconductor performance is critical and the industry seeks to improve the performance and energy efficiency of different types of chips.

devices (based primarily on silicon or germanium) composed of billions of components that can process, store, sense, and move data or signals. Semiconductor chips can have different functions - logic chips, memory chips, analog chips, and Optoelectronics, Sensors, Discretes (OSD). Each requires specialized design and manufacturing processes. From 2012 to 2022, global sales of semiconductor chips doubled to $602 billion. Improving semiconductor performance is critical and the industry seeks to improve the performance and energy efficiency of different types of chips, including creating chips with denser circuits, new architectures, and new materials.

Technology node generally represents the size of key electronics on chips measured in nanometers (nm), or 1 billionth of a meter. Over time, the size of these features has been continuously reduced, enabling higher performance by allowing more components on the same chip. Generally, the smaller the node size, the more advanced the semiconductor technology. A wide range of nodes is currently in production. For logic chips, these range from the most advanced 3 nm node, which began production in 2022, to mature generation nodes over 250 nm. In 2021, 84% of global semiconductor production capacity was for nodes over 16 nm. These mature generations of semiconductors are still in high demand.

Semiconductor Manufacturing Technology

Manufacture of semiconductor devices involves several technical challenges. To create an ideal semiconducting material, high chemical purity is essential as well as high degree of crystalline perfection. The larger the crystal, the more difficult it is to achieve the necessary perfection. Current mass production processes use crystal ingots between 100 and 300 mm in diameter, grown as cylinders and sliced into wafers.

Several processes are used to convert Silicon semiconductor wafers into commercial devices.The first step is thermal oxidation, which forms silicon dioxide on the surface of the silicon.and use of photomasks and photolithography to create the patterns on the circuit in the integrated circuit. The next process is etching which removes the part of the silicon that was not covered by the photoresist layer from the previous step. The last process is called diffusion or doping. To get the impure atoms embedded in the silicon wafer, the wafer is first put in a 1,100 degree Celsius chamber. The atoms are injected in and eventually diffuse with the silicon. After the process is completed, the semiconducting material is ready to be used in an integrated circuit.

Semiconductor Supply Chains

The semiconductor ecosystem and supply chain is complex and involves several sectors. These include (1) Research and development which advances all sectors of the supply chain. (2) Production which has three major steps: design, fabrication, and assembly, testing, and packaging (ATP). These steps either occur in a single firm—an integrated device manufacturer (IDM) that sells the chip—or in separate firms, where a fabless firm designs and sells the chip and purchases fabrication services from a foundry and ATP services from an outsourced semiconductor assembly and test (OSAT) firm. Production requires several inputs: materials, semiconductor manufacturing equipment (SME), electronic design automation (EDA), and core intellectual property (IP). (3) Design involves specification, logic design, physical design, and validation and verification. EDA is software used to design chips due to their increased complexity. Core IP consists of reusable modular portions of designs, allowing design firms to license and incorporate them in their designs. (4) Fabrication which converts designs into chips, relying on various SME and materials. First, a furnace forms a cylinder of silicon (or other semiconducting materials),which is then cut into disc-shaped wafers. Semiconductor fabrication facilities (“fabs”) make chips in these wafers. (5) Assembly, testing, and packaging starts with cutting a finished wafer—which contains dozens of chips in a grid pattern after fabrication. Each

The semiconductor ecosystem and supply chain is complex and involves several sectors.

> Taken together, the United States and its allies are internationally competitive in every segment in the semiconductor supply chain.

chip is mounted on a frame with wires that connect the chip to external devices, and enclosed in a protective casing.The chip is also tested to ensure it operates as intended. ATP also requires various SME and materials.

Each individual step is highly complex, requiring several sub-steps. The atomic precision of the fabrication process requires clean rooms clear of dust particles, which can interfere with chip fabrication. End use involves distribution of chips for integration into products such as smartphones, laptops, servers, communications equipment, and automobiles, among others. Table 1 is an estimate of the contribution to semiconductor value of each supply chain segment.

The United States is strong in most segments except for production of some fab tools such as lithography equipment and materials including wafers. Taken together, the United States and its allies are internationally competitive in every segment in the semiconductor supply chain.

Table 1: Semiconductor value add and market shares by segment and firm

	Segment value added	Market share						
		US	S Korea	Japan	Taiwan	Europe	China	Others
EDA	1.5%	96%	<1%	3%	0%	0%	<1%	0%
Core IP	0.9%	52%	0%	0%	1%	43%	2%	2%
Wafers	2.5%	0%	10%	56%	16%	14%	4%	0%
Fab tools	14.9%	44%	2%	29%	<1%	23%	1%	1%
ATP tools	2.4%	23%	9%	44%	3%	6%	9%	7%
Design	29.8%	47%	19%	10%	6%	10%	5%	3%
Fab	38.4%	33%	22%	10%	19%	8%	7%	1%
ATP	9.6%	28%	13%	7%	29%	5%	14%	4%
Total value added		**39%**	**16%**	**14%**	**12%**	**11%**	**6%**	**2%**

Semiconductor Markets

Logic Chips

Logic chips typically function as the "brains" of computing devices including microprocessors and microcontrollers. The use of custom-designed logic chips for special functions like analytics and machine intelligence—also called accelerators—is also expanding. The largest applications markets for logic chips include smartphones, high-performance computing, Internet of Things devices, and the automotive sector. Logic chips accounted for the largest share of total global semiconductor sales in 2021, at about 42% ($232 billion). In 2020, about 13% of global logic chip manufacturing capacity was physically located in the United States, others in Taiwan (35%) and China (23%). Most of the US owned logic chip manufacturing facilities (fabrication facilities or "fabs") are operated throughout the world by integrated device manufacturers (IDMs) such as Intel. More than 80% of the global capacity for producing logic chips is owned by contract manufacturers called foundries. For the logic chip foundry segment, U.S. capacity accounted for 7% of global foundry capacity in 2020. In 2022, TSMC (Taiwan) owned about half of the global logic chip foundry capacity. As of February 2023, two companies, TSMC and Samsung Foundries, had foundries capable of manufacturing the most advanced generations of logic chip technologies including 5 nanometer (nm) and 3 nm chips.

As technology has advanced down to 3 nm, the cost of designing logic chips has increased substantially. The United States has been the global leader in logic chip design, with U.S. headquartered firms accounting for 64% of revenues from logic chip sales in 2021. However, many of the US design firms do not have their own fabrication facilities and outsource production of their designs to foreign-owned foundries located outside

Logic chips accounted for the largest share of total global semiconductor sales in 2021, at about 42% ($232 billion). In 2020, about 13% of global logic chip manufacturing capacity was physically located in the United States, others in Taiwan (35%) and China (23%).

the United States. Only a few other logic chip manufacturers are capable of producing leading-edge chips, and those are a generation or two behind the 3 nm/5 nm nodes. Export restrictions in place on equipment and software to produce advanced nodes,may hamper China's SMIC in producing 7 nm chips at high quality or producing more advanced chips.

Memory Chips

Memory chips are used to store data and are of two types. Dynamic random-access memory (DRAM) holds short-term data while a device is powered on, while NAND flash provides long-term storage even after a device is powered off. Technology advances for NAND flash memory chips involve stacking layers of memory cells on top of one another. Further, 3D NAND can use an older process node between 30 nm and 50 nm, reducing the cost and complexity. The number of layers stacked in a device has increased from 24 layers in 2013 to more than 200 layers as of July 2022. Memory chips are more commoditized than logic chips, using designs that are less application-specific than those used for logic chip production.The largest applications markets for memory chips include mobile phones, data centers, and personal computing devices.

Memory chips accounted for about 28% of global semiconductor sales in 2021 ($154 billion). Most memory chips are commoditized products for broad commercial use and benefit from economies of scale, creating pressures and incentives for consolidation. For DRAM memory chip sales, Korean-headquartered Samsung and SK Hynix accounted for more than 70% of market share in 2021; U.S.-based Micron accounted for about 23%. For NAND flash memory sales, Korea-headquartered companies Samsung and SK Hynix and Japan-headquartered Kioxia accounted for about 53% of market share in 2021, and U.S.-headquartered Western Digital and Micron accounted for about 33% market share.Micron, Samsung, and SK Hynix are competing to mass produce 3D

> China's industrial policies have sought to establish key leaders in the memory chip segment. Since 2016, China's chipmaker Yangtze Memory Technologies Corporation (YMTC) has developed with $24 billion in subsidies from the PRC government.

NAND chips with the highest memory density by producing more than 200 layers per chip.

China's industrial policies have sought to establish key leaders in the memory chip segment. Since 2016, China's chipmaker Yangtze Memory Technologies Corporation (YMTC) has developed with $24 billion in subsidies from the PRC government. In November 2022, a reverse engineering firm claimed that YMTC had used a unique manufacturing approach to produce an advanced 3D NAND chip with 232 layers. However, with export restrictions and the addition of YMTC to the Entity List in December 2022, YMTC may face steep challenges in expanding manufacturing capacity market.

Analog Chips

Analog chips provide a wide range of functions, including working with sensors to convert and modify analog signals. They are used for power management, communications, and military detection and surveillance equipment. Globally, more than half of the analog chip market is for "application-specific" analog devices that are customized for specific end-users and produced in smaller batches. Next-generation power management and other chips are increasingly being fabricated on semiconducting materials (wide-gap) other than silicon, such as silicon carbide (SiC) and gallium nitride (GaN) to enable operation at higher temperatures and voltages. The growing production of electric vehicles, along with the need for increasingly sophisticated systems to integrate renewable power generation into the electric grid, are likely to increase demand for wide band-gap semiconductors over the coming years. GaN semiconductors are used in fast-charging applications for consumer electronics, as well as in aerospace and defense applications, where they show improved reliability in high-radiation environments compared with silicon-based devices.

Analog chips accounted for about 13% of global semiconductor sales in 2021 ($74 billion).The majority of top analog chip providers by revenue are IDMs that both design and manufacture their chips in-house. Analog chips typically require specialized designs for different end uses, producing relatively lower volumes of specialized products fabricated on mature generations of semiconductors. Since 2019, the semiconductor industry has invested more than $15 billion into the production of SiC semiconductors. The leading suppliers of SiC wafers globally are U.S.-based Wolfspeed and

> China's efforts to acquire foreign semiconductor firms (such as the Chinese company Nexperia's attempted bid for U.K. - headquartered Newport Wafer Fab, a transaction recently blocked by the U.K. government) have sought to advance China's capabilities in compound semiconductors with potential power and defense applications.

Coherent Corporation. Most GaN wafers are produced in Taiwan. In 2021, the three leading analog suppliers globally were U.S. firms: Texas Instruments, Analog Devices, and Skyworks Solutions. Collectively, these firms accounted for about 40% of the global market. Other analog suppliers include Europe-based Infineon and STMicroelectronics, as well as U.S.-based Qorvo, ON Semi, and Microchip. Analog suppliers use a combination of in-house and foundry services to produce their products.

Optoelectronics, Sensors, Discretes (OSD)

Optoelectronic semiconductors are used to interact with or produce light. Uses include light emitting diodes (LEDs); image sensors, such as those used in cameras; and laser diodes, such as those used in fiber optic communications. Other sensor applications include semiconductors designed to detect or control properties such as temperature, pressure, and acceleration. Sensors have a wide array of applications in consumer electronics. Discrete semiconductors typically perform a single electrical function. These types of semiconductors are typically produced using mature node technology.

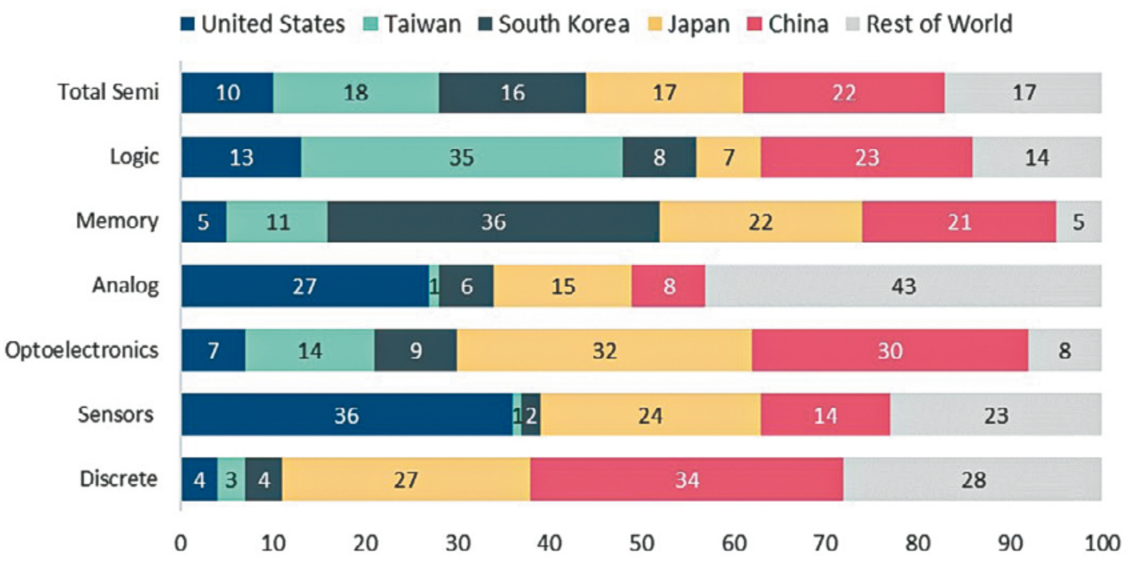
These types of semiconductors collectively accounted for about 17% of global semiconductor sales in 2021 ($96 billion). The market for these semiconductors is diverse, with many producers supporting a wide array of end applications. Producers include U.S.-based Diodes Inc., Vishay Intertechnology, Qorvo, dPix, and Cree. Other leading suppliers include Europe-headquartered companies ABB Ltd., Infineon Technologies, and STMicroelectronics, and Japan-headquartered Toshiba. China's industrial policies support national optoelectronic semiconductor champions such as San'an. China's efforts to acquire foreign semiconductor firms (such as the Chinese company Nexperia's attempted bid for U.K.-headquartered Newport Wafer Fab, a transaction recently blocked by the U.K. government) have sought to advance China's capabilities in compound semiconductors with potential power and defense applications.

Countries Dominant in Semiconductor Technology

The majority of global chip manufacturing capacity in 2020 was owned by firms in the United States (22%), South Korea (20%), Taiwan (19%), China (15%), and Japan (12%). These firms locate their manufacturing facilities mostly in the same set of countries, but the manufacturing share of different countries varies by chip type. (Table 2)

China lags behind overall, but is progressing in some segments. It excels in ATP, tools for assembly and packaging, and raw materials. It has moderate and growing capabilities in design, fabrication, CMP tools, and some etch and clean tools. China faces challenges in other segments, including most SME. Its greatest weaknesses are in EDA, core IP, some fab materials (especially photoresists), leading-edge logic fab capacity, and certain SME. These SME include lithography tools (most importantly, extreme ultraviolet scanners and argon fluoride immersion scanners), process control tools, testing tools, atomic layer etch, wafer and mask handling tools,

Table 2 : Wafer Manufacturing Capacity, by Fab Location and Chip Type, 2020



Source: CRS, adapted from SEMI, World Fab Forecast, November 2020. (2)

advanced deposition tools, and some ion implanters. These areas where China has low, minimal, or no capabilities are constraints which involve items necessary for advanced chip production exclusively produced by the United States and its allies.

Technology Advances

The semiconductor industry has witnessed technology advances over the decades. One has been by steadily reducing the dimensions of key electronic features printed on the chip, referred to as Moore's law. But there are fundamental limitations of reducing a chip's physical features. The cost to produce a 7 nm chip is four times that of a 45 nm chip, and the cost is expected to be much higher at more advanced nodes (e.g., 5 nm and 3 nm). Moreover, ever-shrinking transistors led to unsustainable power consumption As a result, to improve computing performance, the semiconductor industry began to invest in strategies beyond dimensional scaling, including multicore processors, specially designed chips (in contrast to generic, off-the-shelf chips), new materials and architectures, and advanced packaging techniques.

Advanced packaging includes many different innovative techniques to improve chip-to-chip communications and satisfy increasing demand for integrating more diverse functionalities into smaller device footprints. Advanced packaging strategies include placing chips close to each other with a "bridge" or stacking them on top of one another to achieve the shortest distance between interconnections while decreasing the spatial footprint in the end device. Advanced packaging accounted for 40% of the packaging market share in 2020 and is expected to increase to 60% by 2030.52 The United States accounted for nearly a quarter of global advanced packaging production capacity in 2020, led by Intel and Amkor. Taiwan leads in advanced packaging capacity, primarily due to capacity at firms ASE Group, TSMC, Chipbond, and ChipMOS.

Another tool to promote semiconductor innovation is the use of "chiplets." These

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integrate multiple elements of computing systems on a single piece of silicon, often referred to as a system on a chip (SoC). The chiplet fabrication process allows unique chiplets to be purchased from different vendors and packaged together to provide devices with enhanced functionality. An industry effort is under way to standardize chiplet design to improve the ability to mix-and-match in the market and to enable an "open chiplet ecosystem". Promoting the chiplet ecosystem can encourage innovation with lower costs. China's semiconductor industry has become increasingly interested in chiplets as a way to work around current U.S. export controls and address certain capability gaps.

Nanotechnology and Semiconductors

Nanotechnology is the manipulation of matter at the atomic and molecular scale. It has the potential to revolutionize a wide range of industries, including the semiconductor industry. Semiconductor devices are made up of tiny transistors, which are switches that control the flow of electricity. The smaller the transistors, the more powerful and efficient the semiconductor device can be. Nanotechnology can be used to create transistors that are much smaller than traditional transistors by using nanowires that are just a few nanometers in diameter. They can be made from a variety of materials, including silicon, germanium, and carbon nanotubes.Nanowires can be used to create transistors that are much smaller and faster than traditional transistors. Another way to use nanotechnology to create smaller transistors is to use quantum dots. Quantum dots are tiny semiconductors that are just a few nanometers in diameter. They have unique electronic properties that make them ideal for use in transistors. Quantum dots can be used to create transistors that are much smaller and more energy-efficient than traditional transistors. Nanotechnology has the potential to revolutionize the semiconductor industry by creating smaller and more efficient semiconductor devices, making electronics smaller, faster, and more energy-efficient.

Novel Semiconductors

Topological semiconductors are a class of novel semiconductor materials with unique electronic properties. They are characterized by the presence of topological surface states, which are electron states that are protected by the topology of the material's band structure. This makes topological semiconductors very promising for a variety of applications, including spintronics, quantum computing, and topological lasers. Some examples of topological semiconductors include bismuth selenide (Bi2Se3), bismuth telluride (Bi2Te3), and antimony selenide (Sb2Se3). These materials are typically III-V compound semiconductors. Topological semiconductors have the potential to revolutionize a variety of industries. In addition to topological semiconductors, there are a number of other novel semiconductor materials that are being developed for a variety of applications. These materials include - Wide bandgap semiconductors, Two-dimensional semiconductors, and Organic semiconductors. Graphene and boron nitride are two-dimensional (2D) materials with unique properties that make them promising for the development of new semiconductor devices like transistors, solar cells, nanosensors and nanomechanical devices. Many novel semiconductor materials are being developed that have the potential to revolutionize a wide range of industries, including electronics, energy, and healthcare. Advances in technology could well lead to major changes in the semiconductor industry, including manufacturing, and result in a more diverse range of semiconductor products at lower cost.

Renewable Energy and Semiconductors

Semiconductors are essential for the development of renewable energy technologies. They are used in a wide range of renewable energy devices, including solar panels, wind turbines, and batteries. Solar panels use semiconductors to convert sunlight into electricity. The most common semiconductor material used in solar panels is silicon. Silicon is a relatively inexpensive and abundant material. It is also very efficient at converting sunlight into electricity. Wind turbines use semiconductors to generate electricity from the wind. The most common

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semiconductor material used in wind turbines is silicon carbide. Silicon carbide is a very durable material that can withstand the harsh conditions of wind turbines. Semiconductors are also essential for the development of smart grid technologies.

Rare Earths and Semiconductors

Rare earth materials are a group of 17 elements that have similar chemical properties. They are relatively rare in nature, but they are used in a wide range of electronic devices, including lasers, magnets, and batteries. Rare earth materials are also used in the manufacturing of semiconductors. For example, cerium is used to polish silicon wafers, which are the basic building blocks of semiconductors. Neodymium and dysprosium are used to make magnets for hard disk drives. Rare earth materials such as Gallium are important for doping or making semiconductor materials. Disruption In supply chains for rare earths could disrupt the semiconductor industry.

India’s Semiconductor Development

India's semiconductor industry is in its early stages of development, but it is growing rapidly. The government has made significant investments in the sector, and several private companies are also expanding their operations. The Indian semiconductor

The Indian Government has launched several initiatives to promote the development of the semiconductor industry. These include the Semiconductor Mission, the National Policy on Electronics, and the Production Linked Incentive (PLI) scheme for semiconductors.

market is expected to grow from $15 billion in 2022 to $30 billion by 2026. This growth is being driven by the increasing demand for semiconductors in electronics, automotive, and industrial applications. The Indian Government has launched several initiatives to promote the development of the semiconductor industry. These include the Semiconductor Mission, the National Policy on Electronics, and the Production Linked Incentive (PLI) scheme for semiconductors.

The Semiconductor Mission is a government-funded initiative to support the development of the semiconductor industry in India (3). The mission provides financial assistance and other support to semiconductor companies. It was launched in December 2021 with a total financial outlay of ₹76,000 crore (US$9.5 billion). The Semiconductor Mission is led by a team of global experts in the semiconductor and display industry, and it serves as the nodal agency for the efficient, coherent, and smooth implementation of the Program for Development of Semiconductor and Display Ecosystem in consultation with the Government ministries/departments/agencies, industry, and academia.

The Semiconductor Mission has two main objectives: (a) To attract and facilitate investments in semiconductor manufacturing, packaging, and design in India. And (b) To develop a robust semiconductor ecosystem in India, including semiconductor design, manufacturing, and testing capabilities. The Semiconductor Mission offers a variety of financial and non-financial incentives to semiconductor companies that invest in India. These incentives include: (1) Financial support of up to 50% of the project cost for setting up semiconductor fabs in India; (2) Financial support of up to 50% of the project cost for setting up display fabs in India; (3) Fiscal support for the development of semiconductor design and testing capabilities in India; (4) Preferential market access to government contracts for semiconductor companies that invest in India; (5) Access to skilled manpower and research and development infrastructure in India. The Semiconductor Mission has already attracted significant interest from global semiconductor companies. Several companies, including Vedanta, Tata Group, and Reliance Industries, have announced plans to invest in semiconductor manufacturing in India. The mission is expected to attract $10 billion in investment in the semiconductor sector over the next five years. It is also working to develop a skilled workforce for the semiconductor industry.

The National Policy on Electronics (NPE) is a government policy that aims to promote the development of the electronics industry in India (4). It was first notified in 2012 and was revised in 2019. The NPE 2019 has a vision to make India a global hub for electronics manufacturing and design by 2025. It focuses on developing the entire electronics value chain, from core components to finished products. The policy also aims to increase the exports of electronics products from India.

The NPE 2019 provides a number of incentives to the electronics industry, including:

(1) Financial assistance for setting up new electronics manufacturing units and expanding existing units (2) Tax breaks and subsidies, (3) Preferential market access for domestically manufactured electronics products, (4) Support for research and development in the electronics sector, and (5) Development of skilled manpower for the electronics industry.

The NPE 2019 has had a positive impact on the development of the electronics industry in India. The electronics sector has grown at a CAGR of over 15% in the last five years. India is now the world's fifth-largest producer of electronics products. The NPE 2019 is playing a key role in the Indian government's efforts to make India a global hub for electronics manufacturing and design. The policy is expected to help India achieve its target of a $400 billion electronics industry by 2025.

The PLI scheme for semiconductors is a government scheme that provides financial incentives to semiconductor companies that invest in India for setting up semiconductor fabs, display fabs, compound semiconductors/silicon photonics/sensors (including MEMS)/discrete semiconductor fabs, semiconductor packaging (ATMP/OSAT), and semiconductor design (5). The incentives are linked to the production and sales of semiconductor products. The scheme was launched in December 2021 as part of the Semiconductor Mission with a total financial outlay of Rs 76,000 crore (approximately US$10 billion). The scheme is aimed at attracting investments in the semiconductor manufacturing, packaging and design ecosystem in India.

Under the PLI scheme, semiconductor companies can receive incentives of up to 50% of the project cost for setting up semiconductor fabs and display fabs in India. Companies can also receive incentives of up to 40% of the eligible expenditure for setting up semiconductor design and packaging units in India. The PLI scheme is expected to play a key role in the Indian Government's efforts to make India a global hub for

> The PLI scheme is expected to play a key role in the Indian Government's efforts to make India a global hub for semiconductor design, manufacturing and technology development.

semiconductor design, manufacturing and technology development. The scheme is also expected to help India reduce its dependence on imports of semiconductors and boost its electronics manufacturing sector.

The PLI scheme for semiconductors has already attracted a lot of interest from global and Indian semiconductor companies. For example, Vedanta-Foxconn has announced that it will invest $20 billion in a semiconductor manufacturing plant in Gujarat (6). Tata Group has also announced that it will invest $3 billion in a semiconductor fab in Tamil Nadu (7). Reliance Industries is planning to invest $10 billion in a semiconductor manufacturing plant in Maharashtra. Micron Technology will establish an ATMP (Assembly, Test, and Packaging) plant spanning 1.4 million square feet in Sanand, Gujarat along with Simmtech, a US-based chipmaker specializing in substrates (8). Rajasthan-based Sahasra Semiconductor will begin the commercial production of the first made-in-India memory chips at its Bhiwadi plant. Advanced Micro Devices (AMD), a major US semiconductor chip design company, has plans to invest up to US$400 million in India over the next five years, and set up its largest design facility in Bengaluru.

Semiconductors and Indian Diplomacy

Semiconductors are essential for the modern world, and their importance is going to grow in the future. They are used in a wide range of products, from smartphones and computers to cars and medical devices. India is a major importer of semiconductors, and it is keen to develop its own semiconductor industry. This is not only for economic reasons, but also for strategic reasons. Semiconductors are essential for national security, and India does not want to be dependent on other countries for its supply of semiconductors.

India's diplomacy to promote its semiconductor industry focuses on signing agreements with major countries

India's diplomacy to promote its semiconductor industry focuses on signing agreements with major countries to collaborate on semiconductor research and development. India is also working to attract foreign investment in its semiconductor industry.

to collaborate on semiconductor research and development. India is also working to attract foreign investment in its semiconductor industry. Some initiatives are focused on - (1) Quadrilateral Security Dialogue (Quad), on collaboration on semiconductor research and development and a more secure supply chain for semiconductors. (2) Bilateral agreements with countries, including the United States, Japan, and South Korea, and with Taiwan to collaborate on semiconductor research and development and to develop new semiconductor technologies and to improve its manufacturing capabilities.

The Quadrilateral Security Dialogue (Quad), also known as the Quad, is a strategic security dialogue between Australia, India, Japan, and the United States. It was established in 2007 and revived in 2017. The Quad has become increasingly important in recent years as a forum for cooperation on a range of issues, including security, trade, and technology. The Quad could consider collaboration on semiconductor research and development and could be well placed to develop its semiconductor collaboration initiatives under its Critical and Emerging Technologies programmes (9). In May 2022, the Quad leaders announced the formation of a new Quad Fellowship program to support the exchange of semiconductor researchers and engineers between the Quad countries. Quad cooperation in semiconductor development includes joint research projects to develop new gallium nitride semiconductors, new wide-bandgap semiconductors, development of new semiconductor manufacturing processes and equipment including next-generation lithography tools. The Quad countries have established a working group on critical and emerging technologies, which is focused on promoting cooperation on a range of technologies, including semiconductors.

India and the US

The United States has a long history of innovation and leadership in the semiconductor industry. Semiconductors were invented in the US in the 1950s, and US companies have been at the forefront of semiconductor development ever since. The US government has played a key role in supporting the development of the semiconductor industry. In the early days of the industry, the US government provided funding for semiconductor research and development. The government also supported the development of new semiconductor manufacturing technologies.

In recent years, the US government has become increasingly concerned about the decline of US semiconductor manufacturing capacity. In 2020, the US produced only 12% of the world's semiconductors, down from 37% in 1990. This decline is due to a number of factors, including the rising cost of manufacturing semiconductors in the US and the increasing competition from foreign companies. The US government is taking a number of steps to address the decline of US semiconductor manufacturing capacity. In 2022, Congress passed the CHIPS and Science Act, which provides $52 billion in funding for semiconductor manufacturing and research and development. The CHIPS Act also includes a 25% tax credit for semiconductor manufacturing investments. The US government's efforts to support the semiconductor industry are important since semiconductors are essential components in a wide range of electronic devices, from smartphones and computers to cars and medical equipment. Secondly, the semiconductor industry is a major driver of economic growth. Thirdly, the semiconductor industry is critical to US national security. The Biden administration has announced a number of initiatives to support the US semiconductor industry.

India and the United States are increasing cooperation in the semiconductor industry. In 2021, India and the United States signed a memorandum of understanding (MOU) on semiconductor corporations to

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strengthen cooperation between the two countries in semiconductor research, development, and manufacturing, and to promote investment and trade in the semiconductor sector between the two countries. For India, the MOU will help to attract investment in the semiconductor industry and to develop India's own semiconductor design and manufacturing capabilities. For the United States, the MOU will help to secure access to semiconductors from India and to strengthen its ties with India in the semiconductor sector. Some of the specific areas of cooperation that the MOU covers: (1) Research and development: The MOU encourages cooperation between Indian and US semiconductor companies on research and development projects.(2) Manufacturing: The MOU encourages investment in semiconductor manufacturing facilities in India.(3) Trade: The MOU aims to promote trade in semiconductor products between India and the United States.(4) Supply chain: The MOU aims to strengthen the semiconductor supply chain between India and the United States.

In March 2022, the two countries signed a Memorandum of Understanding (MoU) to establish a semiconductor supply chain and innovation partnership to leverage the complementary strengths of both countries to facilitate commercial opportunities and develop semiconductor innovation ecosystems. In 2022, the US Department of Commerce announced that it would provide technical assistance to India's Semiconductor Mission. The US government is also working to encourage US semiconductor companies to invest in India. Specific examples of India-US cooperation in the semiconductor industry include (1) In 2022, Intel announced that it would invest $5 billion in a new research and development center in India; (2) In 2023, US semiconductor company Micron

> In 2022, the US Department of Commerce announced that it would provide technical assistance to India's Semiconductor Mission.

announced that it would invest $3 billion in a new manufacturing plant in India; (3) The US-India Semiconductor Research Initiative (USISRI) is a joint initiative between the US and Indian governments to promote semiconductor research and development. The growing cooperation between India and the US in the semiconductor industry has the potential to be a major driver of economic growth and technological innovation in both countries.

India and Japan

Japan was once the world's largest semiconductor producer, accounting for over 50% of global production in the late 1980s but its share of the market has since declined to around 9% in 2023. The Japanese government is committed to revitalizing the country's semiconductor industry. In 2021, the government announced a plan to invest over ¥1 trillion (US$7 billion) in the semiconductor industry over the next five years. This investment will be used to support the development of new semiconductor technologies and to build new semiconductor manufacturing plants.In addition Japanese semiconductor companies are also partnering with foreign companies to boost their competitiveness. In 2021, TSMC, the world's largest semiconductor foundry, announced that it would build a new semiconductor manufacturing plant in Japan in partnership with Sony and Denso. The Japanese government's initiatives include (1) Setting up the Leading-edge Semiconductor Technology Center (LSTC) in 2021. The LSTC is an R&D hub for scientists working on next-generation semiconductor technologies (2) Providing subsidies to companies that are building new semiconductor manufacturing plants in Japan.

India and Japan signed an agreement on semiconductor cooperation in 2022, covering a wide range of areas, including: semiconductor design, manufacturing, equipment research, talent development, strengthening of the semiconductor supply chain. The agreement also establishes a joint implementation

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committee to oversee the implementation of the agreement.

India and South Korea

The development of the semiconductor industry in South Korea can be traced back to the early 1960s. In the 1980s the industry began to take off with the South Korean government playing a key role, providing financial support and tax breaks to semiconductor companies, and also investing in research and development. The government also encouraged the formation of large conglomerates, or chaebols, such as Samsung Electronics and SK hynix that were able to invest heavily in the semiconductor industry and quickly became world leaders in the production of memory chips. Despite the challenges, including the Asian financial crisis and increased competition from other Asian countries, the industry has continued to grow. Today, South Korea is the world's second-largest producer of semiconductors, after Taiwan. It is also the world's leading producer of memory chips. South Korean semiconductor companies, such as Samsung Electronics and SK hynix, are at the forefront of technological innovation in the semiconductor industry. The South Korean semiconductor industry accounts for a significant share of the country's exports and GDP. The South Korean government continues to support the semiconductor industry. In 2019, the government announced

Today, South Korea is the world's second-largest producer of semiconductors, after Taiwan. It is also the world's leading producer of memory chips. South Korean semiconductor companies, such as Samsung Electronics and SK hynix, are at the forefront of technological innovation in the semiconductor industry.

a plan to invest KRW 50 trillion (USD 42 billion) in the semiconductor industry over the next decade. This investment is aimed at helping South Korea maintain its leadership position in the global semiconductor industry. The development of the semiconductor industry in South Korea is a remarkable success due to the government and industry partnership.

India and South Korea signed an agreement on semiconductor cooperation in 2023 covering a wide range of areas, including Semiconductor design, manufacturing, equipment research, talent development, strengthening of the semiconductor supply chain. The agreement also establishes a joint working group to oversee the implementation of the agreement.This is the first time that South Korea has signed a semiconductor cooperation agreement with a country other than the United States.

India and Taiwan

> India and Taiwan have a strong and growing relationship in the semiconductor industry. The two parties have signed a number of agreements to promote cooperation in the semiconductor industry.

The development of the semiconductor industry in Taiwan began in the early 1970s. In 1974, the Taiwanese government established the Industrial Technology Research Institute (ITRI) to promote the development of high-tech industries in Taiwan by providing funding and technical support to Taiwanese semiconductor companies. In 1976, the Taiwanese government convinced RCA, an American semiconductor company, to transfer semiconductor technology to Taiwan. This was a major turning point for the Taiwanese semiconductor industry. RCA's technology transfer helped Taiwanese semiconductor companies to develop their own manufacturing capabilities.In 1987, TSMC, the world's largest semiconductor foundry, was founded in Taiwan. TSMC pioneered the fabless foundry model, which allows chip design companies to outsource their manufacturing to dedicated foundries. This model revolutionized the semiconductor industry and helped

Taiwan to become a global leader in semiconductor manufacturing.

Today, Taiwan is the world's largest producer of semiconductors. Taiwanese semiconductor companies control over 50% of the global market share in semiconductor manufacturing. Taiwanese semiconductor companies are also leaders in semiconductor design. Some of the world's largest semiconductor companies, such as TSMC, MediaTek, and Qualcomm, are headquartered in Taiwan. The semiconductor industry is now Taiwan's largest export industry and accounts for a significant portion of Taiwan's GDP. Taiwan's dominance in the semiconductor industry gives it a significant advantage in the global economy. It also makes Taiwan a more important player in global geopolitics. The development of the semiconductor industry in Taiwan is a remarkable success story and a model for other countries.

India and Taiwan have a strong and growing relationship in the semiconductor industry. The two parties have signed a number of agreements to promote cooperation in the semiconductor industry. In 2019, they signed an MOU on cooperation in semiconductor research and development. In 2022, they signed an MOU on cooperation in semiconductor manufacturing. The two sides are also working together on a number of specific projects. Taiwan Semiconductor Manufacturing Company (TSMC), the world's largest semiconductor manufacturer, is considering setting up a manufacturing plant in India. In 2022, the Indian Semiconductor Mission and the Taiwan Semiconductor Industry Association (TSIA) signed a memorandum of understanding (MOU) to promote cooperation in the semiconductor industry. In 2023, the Indian government and the Taiwanese government announced a joint program to train Indian engineers in semiconductor manufacturing. Taiwanese semiconductor companies, such as TSMC and MediaTek, are investing in India's semiconductor industry. Indian semiconductor companies, such as Vedanta and Tata Group, are working with Taiwanese companies to develop new semiconductor products and technologies. In 2023, Taiwanese semiconductor company Foxconn announced that it would invest US$10 billion in a semiconductor manufacturing plant in Gujarat state. In 2023, Taiwanese semiconductor company MediaTek announced that it would set up a semiconductor design center in India. In 2023, the Indian government and the

> Indian semiconductor companies, such as Vedanta and Tata Group, are working with Taiwanese companies to develop new semiconductor products and technologies. In 2023, Taiwanese semiconductor company Foxconn announced that it would invest US$10 billion in a semiconductor manufacturing plant in Gujarat state.

Taiwanese government launched a joint research program on semiconductor materials and devices.

India and the Netherlands

India and the Netherlands signed an agreement in 2022 to promote collaboration in semiconductor research, development, manufacturing, and supply chain management. The agreement also establishes a joint working group to oversee the implementation of the agreement. In 2023, Dutch semiconductor company ASML announced that it would set up a semiconductor manufacturing equipment manufacturing plant in India. In 2023, Dutch semiconductor company NXP announced that it would expand its semiconductor manufacturing plant in India. In 2023, the Indian government and the Dutch government launched a joint research program on semiconductor materials and devices. Netherlands is a world leader in semiconductor manufacturing equipment. ASML, a Dutch company, is the world's only manufacturer of high resolution lithography machines, which are essential for manufacturing advanced semiconductors. ASML's investment in India is a significant development for the Indian semiconductor industry, as it will give Indian semiconductor companies access to the latest semiconductor manufacturing equipment.

The European Union

> In 2023, the Indian government and the Dutch government launched a joint research program on semiconductor materials and devices.

In recent years, the EU's share of the global semiconductor market has declined due to the high cost of semiconductor manufacturing and the increasing competition from Asia.

The European Union has a long history of semiconductor development and production. However, in recent years, the EU's share of the global semiconductor market has declined due to the high cost of semiconductor manufacturing and the increasing competition from Asia. In order to address these challenges, the EU has launched a number of initiatives, including (1) The European Chips Act, a €43 billion investment plan that aims to double the EU's global market share in semiconductors by 2030. (2) The European Semiconductor Alliance, a public-private partnership that brings together companies, universities, and research institutes to support the development and production of semiconductors in Europe; (3) The European Innovation Council, a funding program that supports startups and other innovative companies in the semiconductor sector. The EU's semiconductor policies aim to reduce the EU's reliance on imported semiconductors and to strengthen the EU's technological sovereignty. In addition the EU is also working to improve the regulatory environment for the semiconductor industry including revising its intellectual property laws to make it easier for semiconductor companies to protect their intellectual property.

India and the European Union are increasingly cooperating in the semiconductor sector. The cooperation seeks to exploit India's strong talent pool, especially in semiconductor design services. The EU has a number of leading semiconductor companies, such as ASML, Infineon, and NXP Semiconductors. Initiatives to promote

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cooperation between India and the EU in the semiconductor sector include: (1)The Trade and Technology Council (TTC) launched in 2020, which includes a working group on semiconductors; (2) The EU Chips Act (2021) provides funding for joint research and development projects with India; (3) A Memorandum of Understanding on cooperation in the semiconductor sector (2023), which provides a framework for cooperation in areas such as research and development, investment, and trade.

Specific areas of cooperation include (1) Joint research and development on developing new semiconductor materials and processes; (2) Investment in Indian semiconductor companies. For example, in 2022, NXP Semiconductors announced that it would invest $40 million in its Indian operations; (3) Increasing trade in semiconductors. For example, in 2022, the EU announced that it would reduce tariffs on imported semiconductors from India. The cooperation between India and the EU will help India to develop its semiconductor industry and reduce its reliance on China. It will also help the EU to secure its access to semiconductors and reduce its reliance on imports from Asia.

Technology Conflicts

The global semiconductor industry is worth hundreds of billions of dollars, and China is the world's largest producer of semiconductors. The United States and the European Union are also major players in the industry. In recent years, there has been growing technological and strategic competition between the US, China, and the EU especially in the semiconductor sector. The US has accused China of stealing its semiconductor technology and has imposed sanctions on Chinese semiconductor companies. The EU has also expressed concerns about China's dominance in the semiconductor industry.

The technological conflict between the US, China, and the EU has a number of implications for the global semiconductor industry. It is likely to lead to higher prices for semiconductors, delay the development of new semiconductor technologies and difficulties in operating in the global semiconductor market. Disruptions in the semiconductor industry could have a negative impact on the global economy as a whole. Specific examples of the technological conflict between the US and China include sanctions on Chinese semiconductor company ZTE (2018), US trade blacklist against Huawei (2019), and new rules restricting the export of semiconductor technology to China issued by the US Department of Commerce (2020). The technological conflict between

> The technological conflict between the US, China, and the EU is likely to continue in the coming years. This will have a significant impact on the global semiconductor industry and the global economy as a whole.

the US, China, and the EU is likely to continue in the coming years. This will have a significant impact on the global semiconductor industry and the global economy as a whole.

India's Role and Future Prospects

India has the potential to play a major role in the global semiconductor industry in the future. India is the world's most populous country, with a large and growing middle class. This makes India a huge market for semiconductors, which are used in a wide range of electronic devices. India also has a number of strengths that make it well-positioned to develop its own semiconductor industry. India has a large and growing pool of engineering talent. India also has a strong education system, which produces a large number of graduates in science and technology.

The Indian government is also committed to developing the semiconductor industry. The government has launched a number of initiatives to promote the industry, including the Semiconductor Mission, the National Policy on Electronics, and the PLI scheme for semiconductors. The Indian government is also working to attract foreign investment in the semiconductor sector. The government has signed a number of agreements with foreign countries, such as the United States, Japan, and South Korea, on semiconductor cooperation.

A number of global semiconductor companies are also investing in India. For example, Foxconn, ASML, and NXP have all announced investments in India in recent years. These factors suggest that India has the potential to become a major player in the global semiconductor industry in the future. India could become a major producer of semiconductors, a major market for semiconductors, and a major center for semiconductor research and development.

Some specific areas where India could play a major role in the semiconductor industry in the future are (1) Semiconductor design (2) Semiconductor manufacturing (3) Semiconductor supply chain. India is well-positioned to become a major hub for the semiconductor supply chain. India has a number of companies that specialize in semiconductor materials, equipment, and services. Indian companies are well-positioned to supply semiconductors and semiconductor-related products and services to companies around the world. Indian semiconductor design companies are well-positioned to design semiconductors for a variety of applications with access to a large pool of skilled engineers and technicians and latest semiconductor design tools and technologies.

Semiconductors and the Global South

The semiconductor industry is a global industry, but it is concentrated in a few developed countries, including the United States, South Korea, Taiwan, and Japan. These countries have the necessary infrastructure, technology, and skilled workforce to support a thriving semiconductor industry. The Global South is home to a number of developing countries that are trying to build their own semiconductor industries. These countries are motivated by a number of factors, including the desire to reduce their reliance on imported semiconductors, create jobs, and boost economic growth. However, there are a number of challenges that need to be addressed, such as the lack of infrastructure, technology, and skilled workforce, through investing in infrastructure: Governments need to invest in infrastructure, education and training, providing financial incentives, and creating partnerships with governments and businesses in developed countries to share technology and resources. India has offered to make its development experience available to the Global South and is well placed to support education and training in the semiconductor sector.

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Conclusion

Semiconductors and related supply and production chains will remain at the focus of attention of major players, such as the US, China, EU, Japan, South Korea, and Taiwan. The elements of competition, cooperation, and conflict especially involving China are likely to persist. In this scenario, Indian policy makers need to be agile, engage with all the key players with whom they have shared interests, and make the necessary policy changes to enable the complex semiconductor ecosystem to thrive in India. Given this India has a bright future in its semiconductor development and industry.

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INDIA'S NANO MISSION

Parameswar Krishnan Iyer

Introduction

Nanoscience and nanotechnology have emerged as an integral component of various day-to-day technologies which have been game-changers in several segments, whereas they are also termed to be highly disruptive. Nanotechnology has integrated all branches of basic sciences such as biology, chemistry, mathematics and physics in a seamless manner thereby dissolving the boundaries of these subjects. Nanoscience involves the study of materials properties in the nanoscale regime, changes which were perceived but not realized until few decades ago. Combined with the development and advancement in characterization tools of materials in the nanoscale regime the overall field has impacted the fundamental understanding of the intricate behavior of any material as its size is shrunk to a nanometer (10-9 meter) or which can be expressed as 0.000000001 m. Similarly, nanotechnology translates these unique properties of nanomaterials into various newer applications in the areas of electronics, healthcare, energy, catalysis, banking, transportation, manufacturing, defense, communication, agriculture, environment and advanced computing. Newer upcoming areas include technologies such as gene-editing, additive manufacturing (3-D printing), artificial intelligence, deep space technologies and quantum computing. With the advent of such technologies nanotechnology has to be utilized for social empowerment, uplift and empower the lives of millions of citizens and extend these technologies in crafting strong diplomatic engagements.

About Indian Nano Mission

The launch of any national technology mission by the Government of India is aimed at various societal aspects such as social empowerment, strategic lead, academic excellence, technology generation and industrialization aspects. Building upon these visionary points the major research and development initiatives in India included stimulating

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Nanotechnology has become an indispensable area of intervention in modern day human needs.

the academic strength of our scientists in fundamental sciences including those in interdisciplinary areas and several major academic promotional activities. These have been carried out as part of the Nano Science and Technology Initiative (NSTI) in several highly promising and competitive areas comprising multiple and interdisciplinary topics of basic sciences and engineering, with the Government of India launching a Mission on Nano Science and Technology (Nano Mission) in May 2007. The Department of Science and Technology, New Delhi was the nodal agency for implementing the Nano Mission. Since 2016, the Indian nano initiative has achieved a significant milestone by securing the third position in the global ranking via its contribution to Nanoscience and Nanotechnology publications specifically in areas such as:

(a) Agriculture

(b) Energy & Environment

(c) Quantum Materials in Nano Science and applications

Summary of State-of-Art

The fascinating world of mesoscopic objects was prophesized decades ago by Richard Feynman, imagining a world of miniaturization and laying the foundations of the now widely popular fields encompassing nanoscience and nanotechnology. This journey of nanotechnology has traversed a long way since Feynman's prophecy of "There's Plenty of Room at the Bottom" dating back to 1959. Nanotechnology is today a vast area that deals with simple to complex materials, mostly in the mesoscopic regime, manipulating their special properties probably in all domains of sciences and technology thereby influencing every possible application. Generally taken as being approximately 100 nanometers, nanosystems can be comprised of specific collection of atoms or molecules or maybe nanoscopic electronic components, for e.g., nano transistors inside CPUs. Any material having an external dimension in the nano regime can be considered as a nanomaterial. Size reduction in individual dimensions can give rise to different shapes of nanomaterials like nano sheets, nano dots, nano rods, etc. depending on the degree of confinement. The most fascinating observation about nanomaterials is that their physicochemical properties can be precisely tuned and be drastically different than their bulk counterparts, though having the same composition. Due to the quantum confinement effects imposed on the material as a result of dimension reduction, nanomaterials can possess very desirable optical, magnetic, electrical, electronic, chemical and biological properties which are otherwise inaccessible from their bulk forms. This has attracted many researchers all across the world, aiming at the utilization of these properties in the fields of healthcare, electronics, energy, agriculture, etc. Thus, nanotechnology has become an indispensable area of intervention in modern day human needs. Very high specific surface area, interesting electronic transport properties and optical characteristics make nanomaterials important objects for a plethora of multidisciplinary applications. Healthcare sectors are looking for target specific nanomaterials as carriers for directed drug delivery. Energy sector demands for more efficient nano catalysts for fuel cells, and newly emerging artificial photosynthesis-based fuel production systems. Nanotransistors, nanowires etc. find their uses in nanoelectronics based systems where a significant size reduction can lead to faster computing at greater speeds and accuracies. In the electronics sector, nanomaterials also have shown a way to dissipate thermal stress in microprocessors and chips, which is necessary for longer runtime and faster speed. In strategic areas such as the defence sector, nanomaterials have marked their presence quite strongly. Nanoceramics have found their uses in armours and as an abrasion resistant in the bores of cannons, in addition to their uses in coatings, imaging and communications. Nanocrystalline metals and composites are being researched as more efficient ballistic penetrators for hardened targets. Nanocrystalline aerogels are foam like structures which are extremely porous and they have found their uses as highly efficient thermal insulators. Keeping in mind the endless

> The main motto of the GoI Nano Mission is to promote basic research, develop infrastructure, develop technologies based on nanomaterials and nanosystems, to develop human resources and to promote international collaborations.

possibilities of nanomaterials and nanosystems, the Government of India decided to promote fundamental and developmental research in various aspects of nanotechnology.

The mission on Nano Science and Technology, also known as Nano Mission was introduced in May 2007 by Government of India. It was launched as an "umbrella capacity-building program", to promote research and development in the lucrative field of nano science and technology to lift India in the global nano market. The Department of Science and Technology (DST) under the Ministry of Science and Technology, Govt. of India promoted Nano Mission as a part of the Nano Science and Technology Initiative (NSTI). The main motto of the GoI Nano Mission is to promote basic research, develop infrastructure, develop technologies based on nanomaterials and nanosystems, to develop human resources and to promote international collaborations. It is to be noted that due to the steadfast efforts of the government, under the scheme of Nano Mission, India has enlisted itself within the top 5 positions across the globe, recently moving to the 3rd position in terms of scientific contributions in nanoscience and nanotechnology. It does not require any further proof to the fact that the Nano Mission has been a tremendous success, recognizing which, the Government of India has decided to continue the Phase – II of the project.

Nano Mission has supported various individual projects, technology development projects, industry-academia joint projects and inland infrastructure developments for research in nano science and technology. Many of the projects have realized grand success, in terms of both fundamental scientific discovery as well as fetching very high impact publications, resulting in portraying India's capabilities on the highly competitive global platform. These include notable contribution across academia, many of which are briefly highlighted. At a very early stage researchers from IIT Guwahati have been able to design metal nanoparticles-conducting polymers for redox reactions as well as atomically thin clay materials for oxidizing short chain alkanes on their atomically thin lateral dimensions, producing a plethora of oxygenated feedstocks. Our research group has demonstrated the development of organic nanoparticles for applications in light emitting diodes, photovoltaic devices, thin film transistors and biosensor applications. Solar based technologies are the future of sustainable energy, thus proper harnessing of sunlight is necessary. Nanomaterials with their distinct optical properties, are unique candidates for the same, and have been tuned for multiple optical applications at IIT Guwahati. Various target specific nanomaterials were developed by research group at Department of Chemical Engineering, IIT Kanpur as contrast agents for high precision multimodal bioimaging and allied applications. For the probing of metallic nanoarchitectures, multimodal nonlinear plasma optical microscopy workstation developed by IISER Pune has also been a great success. Developments made by Manipal College of Pharmaceutical sciences, Karnataka has shown an effective strategy for the treatment of drug resistant breast cancer, via the nanoformulation of siRNA and example of bionanotechnology. Metal organic frameworks have been studied widely as newer generation materials for applications requiring high porosities. Studies by CSIR-NCL on the isoreticulation, nanoparticle loading and growth dynamics of nano MOFs have paved a way for intentional tweaking of such structures as necessary. Not only healthcare, but also agriculture sector has found the use of nanomaterials as a controlled pesticide delivery nanovehicle. Copper and Graphene Oxide based such nanocarriers have been designed for the same intended purpose by INST Mohali (DST institute established in 2013) under the support of Nano Mission. Peptide based nanostructures are of special interest to the researchers worldwide. Under the support of Nano Mission, studies done by Bangalore University shows such possibilities of peptide based nanocatalysts for organic and peptidomimetic syntheses. A nano approach towards the targeting of pain neurones topically was studied with great success by Amrita Institute of Medical Sciences and Research Centre, Kochi. Nanomaterials as an active component in composites have been probed for quite a long time. Research carried out by NIT Rourkela revealed such possibilities of a nanocomposite-based scaffold with very high wet strength, for bone tissue engineering. Low dimensional materials like MWCNT and graphene has found their uses in various fields. Developments made by IIT Kharagpur researchers has revealed the effectiveness of these materials and their polymer nanocomposites in EMI shielding. New generation nanocatalysts embedded over carbon foam has shown remarkable performance in Lithium-Air type batteries as researched by SSN College of Engineering Chennai. Nanomaterials are also interesting candidates for thermoelectric power generation from thermal systems. Magnesium silicide based thermoelectric nanomaterials have been developed to be very effective for this purpose under the Nano Mission at NIT Tiruchirapalli. As discussed earlier, peptide-based therapeutics are very promising in the healthcare sector. A joint Nano Mission Project between Bose Institute Kolkata, IICB Kolkata and JNCASR Bangalore has been fruitful towards the development of nano delivery carriers for peptide therapeutics. Similar to that, rationally designed nanozymes developed by IISc Bangalore has been successfully effective against the amyloid beta aggregation which leads to several neurodegenerative diseases. In energy sector nanomaterials have always been promising materials, as studied by IIEST Shibpur. Quantum dot decorated nano titania composites have been very effective in dye sensitized solar cells and related systems. High surface area of nanoparticles renders them a very suitable candidates for sensor and similar applications. Researchers at BITS Pilani have been able to develop a multimodal sensing, imaging and therapeutic platform based on lanthanide doped hydroxyapatite nanomaterials. Researchers from IACS Kolkata, were successful in this regard, architecting such hetero nanostructures which can harvest visible-NIR light from solar spectrum. Not only healthcare, energy etc. but also nanomaterials are extremely important for catalysis, owing to their extremely high surface area. CSIR-NCL researchers have found great success utilizing nano catalysts for Fischer Tropsch type syntheses where syngas is converted into value added carbon fuels. Point of care technologies are extremely now a days for rapid detection and diagnosis of various health hazards as well as diseases. With the support of Nano Mission, researchers from IIT Ropar have been able to deliver such a POC system for rapid diagnosis of small cell lung cancer, utilizing a CNT as an electrochemical immunosensor. Not only energy generation, but also storage of the generated energy is equally important. Nanomaterials can play a crucial role in the same, as IISER Pune researchers came up with a method of producing supercapacitors from cheaper metal oxide/sulfide nanomaterials, which can prove to be very crucial in sustainable energy storage in very near future. Many nanomaterials based specific drug delivery cargo systems have been developed by researchers all across the country under the Nano Mission scheme. However, it is worth mentioning the developments made by South India Textile Research Association (SITRA) Tamilnadu, who have been able to develop nanofibrous membrane based wound healing patches for the controlled release of drugs on the wound. Another important field where nanomaterials have proven their worth is sensors. NISER Bhubaneswar researchers have strategically designed ferromagnetic semiconductors and their heterostructures for use as a magnetic field sensor. These types of small form factor sensors can prove to be very useful in low resource condition and remote applications. The field of nanotechnology is not only limited to nanoscale particles of various organic or inorganic compositions, but also nanoaggregates / nanomicelles have come up to be very promising for many purposes. Such a multifunctional and stimulus responsive magnetic nano micellar system has been developed by researchers at Sastra University, Tamilnadu for the theranostics and treatment of breast cancer. Environmental remediation is another concerning field where critical attention must be given. With the rapid depletion of potable water, repurification of existent water sources to a potable extent becomes crucial. Nano Mission has supported such an approach to the researchers in Bharati Vidyapeeth University Pune, who have utilized a nanomembrane comprised of graphite nanoplatelets for ultrafiltration of contaminated water. Apart from remediation, environmentally friendly chemical processes are also highly sought after for a sustainable existence of mankind. Conversion of light alkanes into oxygenated feedstocks are basic building blocks of the chemical industry. However, in many cases classical materials and methods are often dangerous for the environment and also inefficient on the other hand. The method is not only environmentally friendly, but also more efficient. Battery electrodes made up of nanomaterials can prove themselves to be more long lasting and robust as compared to the classical counterparts. Developments made by IISc Bangalore researchers have shown the same, where nanostructured cathodes and interlayers have been proven to be more robust towards cyclic usage in Na-S and Mg-S battery set up.

Not only research projects in academia, but Nano Mission has also provided active support for technology development projects, where a proof of concept has already been portrayed earlier and where prototyping or pilot scale production/ operations were necessary. CSIR NCL and CSIR CGCRI has been supported by DST for their technology developments on metal oxide/sulfide nanostructures-based charge storage devices and multiplexed detection of neurotransmitters on a lab on a chip setting using nanoparticle embellished graphene modified micro electrodes, respectively. CMR Institute of Technology and CSIR NCL have been supported for their developments of nanoplatforms for VOC detection and nano-heterojunction based quantum dot solar cells respectively. Diatom based solar panels for biofuel production has been generously supported at H.S. Gour Central University, Madhya Pradesh. A joint project run by IIT Delhi and Sastra University on multifunctional metal oxide modified textiles for UV filter applications has also been supported by Nano Mission. Nano devices on neuromorphic computing, AgNP-Graphene based anti-corrosion coatings and nanoporous ceramic sensor for moisture detection has been supported at IIT Bombay, IISc Bangalore and CSIR CGCRI respectively. Significant developments have been made on nanostructured multiferroic heterostructures for room temperature ME-RAM and magnetic sensor applications at IIT Roorkee under the Nano Mission project. Development of 2D nanomaterials based non-volatile memory devices have been supported at JNU Delhi, whereas bifunctional nano capsules for drug delivery has been developed under at IIT Kanpur. Support has been given to institutes like CSIR NEIST and NIT Mizoram for the developments of nano membranes for gas separation type applications. Graphene based nanoelectronics development has been supported at IIT Mandi, whereas silicon based nanophotonic systems have been supported to be developed at IIT Indore. Technology development projects in the field of advanced agriculture also has been supported generously by the government, like the production and evaluation of nano biochar based micro fertilizers for maize production in rainfed agro ecosystem in North Western Himalayas, conducted by Sher-e-Kashmir University of Agricultural Sciences and Technology, Jammu.

Nanoelectronics Network for Research and Applications-NNetRA (Inter-Ministerial program)

The network of nanoelectronics facilities at the Indian Institute of Science (IISc), Indian Institute of Technology Bombay (IITB), Indian Institute of Technology Delhi (IITD), Indian Institute of Technology Guwahati (IITG), Indian

Institute of Technology Kharagpur (IITKgp), Indian Institute of Technology Madras (IITM), were nucleated by the generous support of the MeitY (then DeitY), from 2006 to 2017. Indian Institute of Technology Hyderabad (IITH) started their activities in 2010 and established innovation hub for Nano-X in 2011 in their temporary campus and enhanced their capabilities regularly and finally shifted the facility to the permanent campus in the year 2021, with their internal funding and Japan International Collaboration Agency (JICA) funding. Overall, the facilities represent ₹950 Cr of cumulative investment.

These are comprehensive facilities for the design, fabrication, and characterization/testing of nanoscale devices and are intended to constitute the academic training and research pillars of the overall semiconductor/nanoelectronics ecosystem. The facilities have put India on the global R&D map, with academic output in all areas of current and future relevance. The areas align with national priorities, contributing to numerous national missions and technology frontiers, which help in placing India as a nation on strategically niche position. Despite the challenges the Centres have also focused heavily on technology development and translation, establishing a technology pipeline of multiple high-TRL technologies. The pipeline has led to over 3900 research papers, 721 PhDs, 397 patents, 57 technologies, 40 technology-transfers, and 15 start-ups in a short span of time.

As national facilities, the Centres bring an unprecedented openness to the Indian ecosystem, facilitating experimental semiconductor-based nanoelectronics across the nation through the INUP programs. The INUP program has generated an additional 800 publications, 600 PhD theses, and 45 patent, from 600 institutes, 96% of which are tier 2/3.

The Centres have become especially significant with the Government of India's (GoI) recent thrust in semiconductor manufacturing. This national centers thus presents a plan and a model to fund the Centres for the next 10-years, which will take our nation at the forefront of multiple technologies and a strong tool for diplomacy in frontier areas. The current funding models, which include both sustenance and research deliverable, are suboptimal. A new funding model (the "sustenance" model), where a certain base level of support is guaranteed, separate from R&D projects will strengthen all the activities from basic research to technology transfer. The sustenance model is based on a study of successful models with established semiconductor ecosystems like USA, Korea, Taiwan, Japan, Germany, and China. Nanotechnology has played a major role for social empowerment in countries across the world and with the widespread integration of IT and the Internet facilitates, access to essential services, particularly in underserved areas has tremendously grown. Telemedicine has enabled remote healthcare consultations, e-government services provide online access to government information and services, and digital banking allows individuals to manage their finances conveniently. Such access to nanotechnology based services can empower individuals, enhance their quality of life, and promote inclusivity.

Outlook

Nanoelectronics for Indian Semiconductor Mission

Integrated semiconductor technologies like electronics, photonics, and micro/nano-electromechanical systems are the building blocks of computing, communication, sensing, information display, and many forms of energy conversion. Semiconductor technologies underpin the growth drivers of e-commerce, e-banking, digital services, health, and transportation (including Railways).

India has little commercial semiconductor manufacturing, a lacuna that needs to be addressed immediately and has been pending since 1989 when the silicon foundry in the Semiconductor Complex Ltd. was destroyed in a fire accident. Global set-backs like the COVID-19 and integrated-chip (IC) shortage have brought an unprecedented focus on the need for India to develop semiconductor manufacturing and the timely development of chips and devices needed for several strategic areas. There is broad consensus that India must create a semiconductor manufacturing ecosystem, not just in the interest of strategic sectors of Defence, Aerospace and Atomic / Clean Energy, but also for 'smarter' civilian infrastructure that is built on data, communication, and distributed power. It was this need that led to the recently announced "Programme for Development of Semiconductors and Display Manufacturing Ecosystem in India". The "Manufacturing Programme" is a ₹ 76000 Cr GoI initiative to catalyse the semiconductor design and fabrication ecosystem in the country, through the newly constituted "Indian Semiconductor Mission".

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The Indian Government has launched the "Indian Semiconductor Mission" with an investment of $10B. The project is unprecedented in its scope, offering fiscal incentives to set up semiconductor fabs in India. To create a sustainable ecosystem, the Semiconductor Mission has earmarked 2.5% of the outlay towards "capacity building, training, partnerships, and R&D". These activities are exactly the mission and mandate of the Nanoelectronics Centres established by GoI under the Nano Mission.

The academic nanoelectronics Centres are vital to the ecosystem because:

- The academic nanoelectronics Centres focus on basic research and development. So, they serve as a knowledge repository to troubleshoot and refine processes at the commercial and prototype fabs.
- The toolset at the academic nanoelectronics Centres is flexible and redundant, so multiple devices and technologies can be processed simultaneously. This flexibility is not available to a prototype or commercial fab, so they depend on the academic Centres for proof-of-concepts.
- The academic Centres train the staff employed at commercial and prototype fabs.

The salient requirements are:

- Readymade infrastructure: The seven Centers in 6 IITs and IISc are large state-of-the-art R&D facilities

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with a cumulative investment of ₹1050 Cr spread over 60000 sq. ft. They are critical for India's future in semiconductors technologies. Training and research for ISM can only happen in these facilities.

- Training for ISM: The ISM projects a need for 5000 PhD and 30000 BTech/MTech over the next 5 years. Assuming a 50:50 split between fabrication and design, 2500 PhD and 15000 BTech/MTech must be trained in nanoelectronics fabrication. The Centres across IITs and IISc must be well-equipped to deliver ALL these requirements through a mix of internal students, external students, and certification programs.
- Semiconductor R&D: To sustain these facilities the Centres will raise an additional 23% from other sources to cater to ISM's R&D needs in the areas of computation, memory, automotive, and mobility.
- Industry support: The centres must serve as hubs that provide high-value services to the semiconductor industry, e.g., failure analysis, advanced characterisation, unit-process development, tool validation, leasing cleanroom space and consumable qualification.

Role of Centre for Nanotechnology (CFN) at IIT Guwahati in the Implementation of National Education Policy via Research, Innovation, Translation, and Entrepreneurship in the Key Areas of Semiconductor, Solar Cells, Healthcare and Green Hydrogen

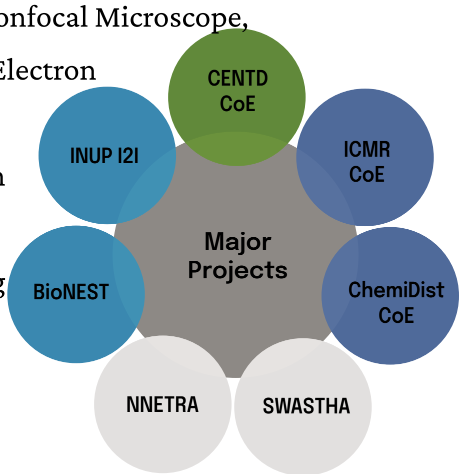
The Centre for Nanotechnology at Indian Institute of Technology Guwahati, established in 2004, with the Vision to Foster R&D in the interdisciplinary area of nanoelectroncis. Develop human resources for multidisciplinary areas of science and technology at the nanoscale and augment academic partnerships with industry. The Mission is to pursue excellence in teaching and research in nanoelectronics, develop state-of-art infrastructure in the North East Region, and collaborate with Industry & Academia.

The courses offered by the Centre are highly multidisciplinary. These include Nano Device: Fabrication, Production & Patent Writing, Nanotechnology Primer,

Quantum Mechanics and Spectroscopy, Practical Quantum Mechanics and its Applications, Recent Advances in Nanotechnology, Frontiers in Nanoscience & Nanotechnology, Nanobioscinceces, and Instrumentation for Nanotechnology.

In about a few decades, the Centre has incubated multiple Centres for Excellence in (I) Research and Development of Nanoelectronics Theranostic Devices and (II) Design and Development and Fabrication OLED, Organic Solar Cells & TFTs based on molecular, polymeric, and composite materials. The Centre also host an Incubator in the form of BioNEST. The Centre's research focus is to develop indigenous technologies and skilled human resources in Nanoelectronics, Health Care, Advanced Materials, Energy Harvesting, Nano-Biotechnology, Environmental Sciences, and Bio-Inspired Technologies. In addition, the development of low-cost indigenous devices to detect deadly diseases to cater to the needs of citizens in the North East region is the Centre's primary focus. The aims are in line with the National and International expectations related to Unnat Bharat, Skill India, Digital India, and Make in India initiatives of the Government of India.

Apart from the regular academic and research facilities, the Centre will host Class 100 and Class 1000 cleanroom facilities, with Atomic Force Microscopy, Super Resolution Confocal Microscope, Photolithography, Electron Beam Lithography, Oxidation Diffusion Furnaces, Probe Stations, Sputtering Units, Physical and Chemical Vapor Deposition



units, and state-of-art computational facilities, for cutting-edge fabrication and characterisation at the nanoscale. Presently, the Centre is among the leading academic and research excellence in India and Abroad. The Centre host a 300 sq. m cleanroom with class 1000 and class 100 bays. The cleanroom is supported by a utility building that houses the DI water plant, compressed dry air plant, chilled water plant, speciality gas tanks, UPS, air-handlers, electrical distribution panel, etc.

Over the last six years, the CFN-IITG facility has provided access to state-of-the-art facilities to over 530 participants across the NE region. Further, more than 30 research groups of IITG utilise the facility for their research. Nearly 60 PhD thesis and more than 100 MTech and 100 BTech projects have been benefitted from the facilities so far. The multidisciplinary workforce involved with the Centre has published more than 350 research articles in International Journals with a good number of citations and about 50 patents. This facility is perhaps the only existing in the NE region of the country.

Focal Areas

Semiconductor Applications	One of the significant challenges of North East India has been the lack of facilities despite its rich bio-diversity and quality human resources suitable for high-end research, engineering, and translation. One of the thrust objectives of the National Education Policy – NEP 2020 is to formulate digital certification programs for advanced research and translational trainings for capacity building with particular emphasis on the hands-on components. In this direction, the last decade has witnessed the phenomenal success of Centre for Nanotechnology (CFN) at IIT Guwahati in establishing a state-of-art infrastructure required for micro/nanoelectronics R&D and translational research in the North-East (NE) region of the country. One of the major highlights of CFN has been the setting up of a pilot-scale clean room targeting state-of-art fabrication, characterization, and testing of the modern micro/nanoscale electronic devices at IITG, which is perhaps among the first of its kinds in the North East India. Following this benchmark set by MeitY, a natural extension has been the upskilling of a larger span of human resources from the NITs, IIITs, and Universities of North East region by providing access to these state-of-art facilities in inculcating micro/nanoscale electronic research and translation. Gratifyingly, in the past few years, under the auspices of MeitY various programs such as NWNTD – National Workshop on NEMS/MEMS Theranostic Devices, and INUP-I2I – Indian Nano Users Program has been implemented by CFN to train more than 700 bright participants in the fabrication, characterization, testing, and simulations of nanoscale devices. In addition, CFN is also upskilling 100 paramedics per year certified by NSDC with the support from MeitY. CFN has been able to disseminate

	the state-of-art facilities established at IITG to researchers across academia, R&D centers, and industry from various parts of the country with a particular emphasis on NE. The facilities have been useful in various instances through programs like INUP-I2I to train bright students and faculty members from 7 NITs, 3 IIITs, 70 Central and Private Universities, and a number of Research Institutes of NE India in semiconductor devices which is in line with the GoI initiative of "Indian Semiconductor Mission". In addition, one of the major foci has been to upskill R&D personnel who can lead Start-ups/SMEs/MSMEs to inculcate translational semiconductor research in the country. The pilot-scale fabrication can also be utilized as a National Centre for the complementary trainings associated with recent Mega-Fab MeitY initiative.
Wearable Electronics and PoC devices for Healthcare Applications	Indian Institute of Technology Guwahati in collaboration with the Ministry of Electronic and Information Technology – MeitY, GoI has envisioned to establish a state-of-art Academic cum Research Nano-Fabrication facility in the form of "Centre for Excellence in Research and Development of Nanoelectronic Theranostic Devices" and "Smart Wearable Advanced nanoSensing Technologies in Healthcare ASICs" Over the past decade, under this initiative, IIT Guwahati and MeitY has collectively planned and delivered the following scientific and technological items with a major target towards the developing of cutting-edge indigenous devices under the mission of 'Atmanirbhar Bharat', 1. Establishment of a brand-new Centre for Nanotechnology building of 10,000 sq. m. area equipped with ISO 5 and 6 clean rooms and 23 state-of-art laboratories having cutting-edge fabrication – Lithography, CVD and PVD reactors, oxidation and diffusion furnaces, and printers, characterization – confocal and electron microscopes, UV-Vis spectroscopy, and AFM-Raman-TERS and testing – IV-CV analyzer, AC/DC/RF probe stations, network analyzer facilities, for the first time in the North-East India. 2. Development of an array of healthcare devices to detect liver/kidney/pancreatic health, detect pathogens and cancer markers with immense commercial potential. In the process, 7 transfer-of-technologies and more than 280 publications in the high impact international journals, more than 40 Patents, 30 prototypes, 50 PhD students, and manpower training. 3. Development of an array of SAW, FET, microfluidic, MEMS, and NWFET devices integrated with indigenous nanobiosensors, at the level of from TRL 2 to 5, in which some of them are translated into a product by startups,

	ready to hit the market. In particular, frugal and low-cost point-of-care healthcare devices have been developed to detect liver/kidney/pancreatic health, detect pathogens (e.g. UTI) and cancer markers (cervical, liver, and others), among others. 4. Handholding of multiple startups in the area related to materials and nanoelectronics such as M/S Primary Healthtech Pvt. Ltd., M/S Bioaptagen Pvt. Ltd. and M/S JSV Innovations Pvt. Ltd. Establishing fruitful partnership with industry such as M/S Vivocon Pvt. Ltd., M/S Chemidist Pvt. Ltd. 5. Utility of the established facility towards a number of future activities such as INUP-I2I, SWASTHA, and other CoEs sponsored by the funding agencies in particular MeitY.
Solar Cell Devices	Affordable green energy and photovoltaics have been major focus areas of research at the Centre for Nanotechnology (CFN), I.I.T. Guwahati. Solar cells are being designed and developed using solution-processible materials such as semiconducting polymers and organic-inorganic hybrid semiconductors. In the last few years, halide perovskites have attracted large attention with their efficiencies nearly matching that of silicon. At CFN, single junction solar cells are being developed using various perovskites such as 3D MAPbI3, double cation perovskites, mixed-halide perovskites, 2D/3D mixed-dimensional perovskites, 3D and lower-dimensional lead-free tin perovskites etc. Devices with one of the highest-reported power conversion efficiencies (PCE) have been achieved using unique interface and additive engineering strategies. The stability of these devices has been improved by defect and surface passivation. The physics of such solar cells is investigated using advanced characterization techniques such as impedance and deep level transient spectroscopies. Extensive simulation is done using in-house developed and patented MATLAB algorithms, and also by industry-standard 2D and 3D TCAD software such as Sentaurus - Atlas, Silvaco – Victory, and Lumerical. Three distinct algorithms for optical modelling have been developed for improving the performance of tandem and triple junction PSCs by lowering reflection losses and increasing the carrier generation rate in the active layers. Predictions for the monthly energy densities have been made for such devices by studying the angle-dependent efficiencies. The role of plasmonics, light trapping design, and bifacial applications in single junction and tandem PSCs have been developed. Environmental and life cycle assessment are done for the devices by estimating parameters such as energy payback time (EPBT) and greenhouse gas emission factor (GEF).

Nano-Catalysis for Specialty Chemicals, Fertilizers and Green Hydrogen	The rapid depletion of fossil fuels, anthropogenic emissions and ever-increasing energy consumption has triggered an increasing interest in the future energy system based on renewable resources. The use of abundant and readily-available feedstock and energy storage that do not contribute to carbon footprint are two global challenges that have caught the attention of researchers world-wide. Aligning with the priorities of G20 Summit being hosted by India in 2023, IIT Guwahati is working towards developing affordable, high-performance and environment-friendly energy storage and production systems that are also sustainable. This will be the institute's major contribution in building a sustainable future. The development of inexpensive, high-performance, sustainable, and environmentally friendly energy storage and production systems is of utmost importance in the current scenario where energy demand is ever-increasing. In this context, multiple efforts are underway at IIT Guwahati towards achieving Sustainable Goals of Green Hydrogen Generation and Carbon Dioxide Sequestration. These include: 1. Development of Perovskite Oxide based Catalysts for generation of Green Hydrogen 2. Formulation of efficient Catalytic systems that transform industrial / biomass wastes into hydrogen. 3. Development of photocatalysts to convert solar energy to Green Hydrogen. 4. Development of inexpensive, less toxic and efficient catalysts to mimic Artificial Photosynthesis Along with this, IIT Guwahati has also established a ChemDist Centre of Excellence for Industrial Nanotech Innovations (CD-CoE) with an aim to develop and commercialize new-generation technologies and products related to ethanol manufacturing from agro-based feedstock apart from development of efficient protocols for conversion of Ammonia into green Hydrogen.

National Benefit and Beyond

Our nation can reap rich benefits in leaning into India's scientific prowess to "more confidently assert Indian national interest on the world stage," if research policies are driven for the larger benefit of the nation. These policies are crucial and deciding factors for a developing nation, where niche technologies such as the semiconductors that rely heavily on nanoscience and nanotechnology aspects and multiple allied industries dependent on this rapidly evolving multidisciplinary sector that not only impacts the social empowerment, but are collectively a major source of revenue generation and the top sectors having massive export potential. Such niche sectors are the primary

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foundation that allows a nation or a core business group to develop a long-term strategy and allow any nation a strong basis for diplomatic engagement. Besides, it would benefit the masses, uplift their standard of living and elevate them from poverty by providing access to multiple technology sectors, and direct resources toward national security, energy, space exploration, communications and remote sensing, skilling and training.

By evolving a strategic national plan of research in nanoscience and nanotechnology and prioritizing allied areas of technology development and additive manufacturing coupled with Artificial Intelligence (AI), our nation can become self-reliant in several domains of knowledge generation, trained manpower and ready for several hi-tech sectors. Thus, developing a systematic action plan of utilizing nanoscience and technology, its combination with robotics, quantum technology, and the integration of Artificial Intelligence (AI) will provide great technological advancements, and their long-term implementation as a national mission will lead to establishment of national centers of excellence. This will drive the knowledge ecosystem and propel the manufacturing sector thereby enabling several national goals to be achieved, and offer more options to the government for global engagement and help in positioning itself at a much stronger level at the international stage.

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ABOUT THE CONTRIBUTORS

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A Technocrat, Columnist, Policy Thinker and now Author, Shashi has served in various Leadership roles in the Indian Technology, Media and Public Policy space. He currently serves as the Chairperson of the Advisory Committee to oversee Science and Technology Communication, Govt of India. He was CEO of Prasar Bharati (2017-2022), CEO of Rajya Sabha TV(2017-2019), CEO of Niti Digital(2014-2016), Vice President of Asia Pacific Broadcast Union(2021-2022), Vice President of Indian Broadcasting and Digital Foundation(2019-2022), Member of Board of Broadcast Audience Research Council of India(2017-2022), Chairperson of External Experts Group at the University Grants Commission of India (UGC)(2023), Member of Board of the AJK Mass Communication and Media Research Center(2023-2026), Member of ICWA Council.

Dr. Bhaskar Balakrishnan

Dr. Bhaskar Balakrishnan has been a diplomat from 1974-2007 and served as Ambassador of India to Greece, Cuba, Haiti and the Dominican Republic, and has worked in Sudan, Syria, Zambia and Austria. He has worked for over ten years with various UN organizations in Geneva and Vienna, including three years as Special Assistant to the Director General, UNIDO.

He headed the Investment & Technology Promotion Division of the Ministry of External Affairs concerned with promotion of foreign investment and technology flows, economic reforms, energy, and transportation, and the Communications and Vigilance Division of the Ministry. He represented the Ministry in several inter-Ministerial bodies such as the Foreign Investment Promotion Board, the Genetic Engineering Approval Committee, Steering Committee on Biomedical Research, and the Task Force on Information Security.
He was educated at Indian Institute of Technology, Kharagpur (B.Sc Hons), Delhi University (M.Sc), and Stonybrook University, New York, USA (Ph.D in Physics). He has taught at Stonybrook University, and Panjab University, Chandigarh.

He has been a Member of the National Security Advisory Board during 2013-14. He has been conducting training courses for Indian and foreign diplomats for the Foreign Service Institute of India, and has participated as expert on national television programmes. He is an adjunct faculty member at JSS University, Mysore. He is presently Science Diplomacy Fellow, Research and Information Systems (RIS), New Delhi (since 2018)

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Professor Parameswar Krishnan Iyer received his Ph.D. in Chemistry from the CSIR-CSMCRI (Central Salt and Marine Chemicals Research Institute), Bhavnagar, India, in 1999. He was awarded the Lady Davis and Goldsmith Foundation Post-Doctoral Fellowship at Technion, Israel, (1999-2001), Dupont Post-Doctoral Fellowship at University of California at Santa Barbara, USA, (2001-2003), and US-Army Research Associate Fellowship at Case Western Reserve University, Cleveland, USA, (2003-2004). In 2004, he joined as a Faculty at IIT Guwahati, and is currently a Professor at the Department of Chemistry and Centre for Nanotechnology since 2013. His research interests include the design and development of functional materials and their applications in optoelectronic devices such as photovoltaics, LED, transistors, memory, sensors based nanodevice fabrication and in therapeutics.

For his contributions in research and development he has been recognized with several national and International awards and recognitions some of which include Fellow of the Royal Society of Chemistry (Leaders in the field), MRSI Medal, CRSI Bronze Medal, International Association of Advanced Materials Scientist Award, INSA Medal for Young Scientist in Chemical Sciences, Max-Planck India Fellowship, etc.

Prof. Iyer has guided 35 PhD students, several masters and bachelors students and postdoctoral researchers. He has more than 240 International Journal Publications (Including in Nature), 20 Books / Book chapters, ~40 Patents and is involved in a multinational startup company, two national start-up company and transferred several technologies to industries. He is an Associate Editor of prestigious journals ACS Applied Bio Materials, Nature Scientific Reports and Frontiers in Medical Technology. He also serves as an Editorial board member of ACS Sensors, CCS Chemistry, ACS Applied Nano Materials, and RSC Material Chemistry Frontiers. He also serves as an expert member in various national and international scientific and technical bodies, council member and advisor member. He is very passionate about teaching and research and is extensively involved in enhancing the quality of STEM education in schools and colleges in northeast India, major skilling initiatives, entrepreneurship and executive education programs. He has been serving as the Dean of Public Relations, Branding and Ranking at IIT Guwahati since July 2019 and Officiating Director at IIT Guwahati from December 2022 to November 2023.

About ICWA

The Indian Council of World Affairs (ICWA) was established in 1943 by a group of eminent intellectuals led by Sir Tej Bahadur Sapru and Dr. H.N. Kunzru. Its principal objective was to create an Indian perspective on international relations and act as a repository of knowledge and thinking on foreign policy issues. The Council today conducts policy research through an in-house faculty as well as through external experts. It regularly organizes an array of intellectual activities including conferences, seminars, roundtable discussions, lectures and brings out a range of publications. It has a well-stocked library, an active website, and publishes the journal India Quarterly. ICWA has over 50 MoUs with international think tanks and research institutions to promote better understanding on international issues and develop areas of mutual cooperation. The Council also has partnerships with leading research institutions, think tanks and universities in India.

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