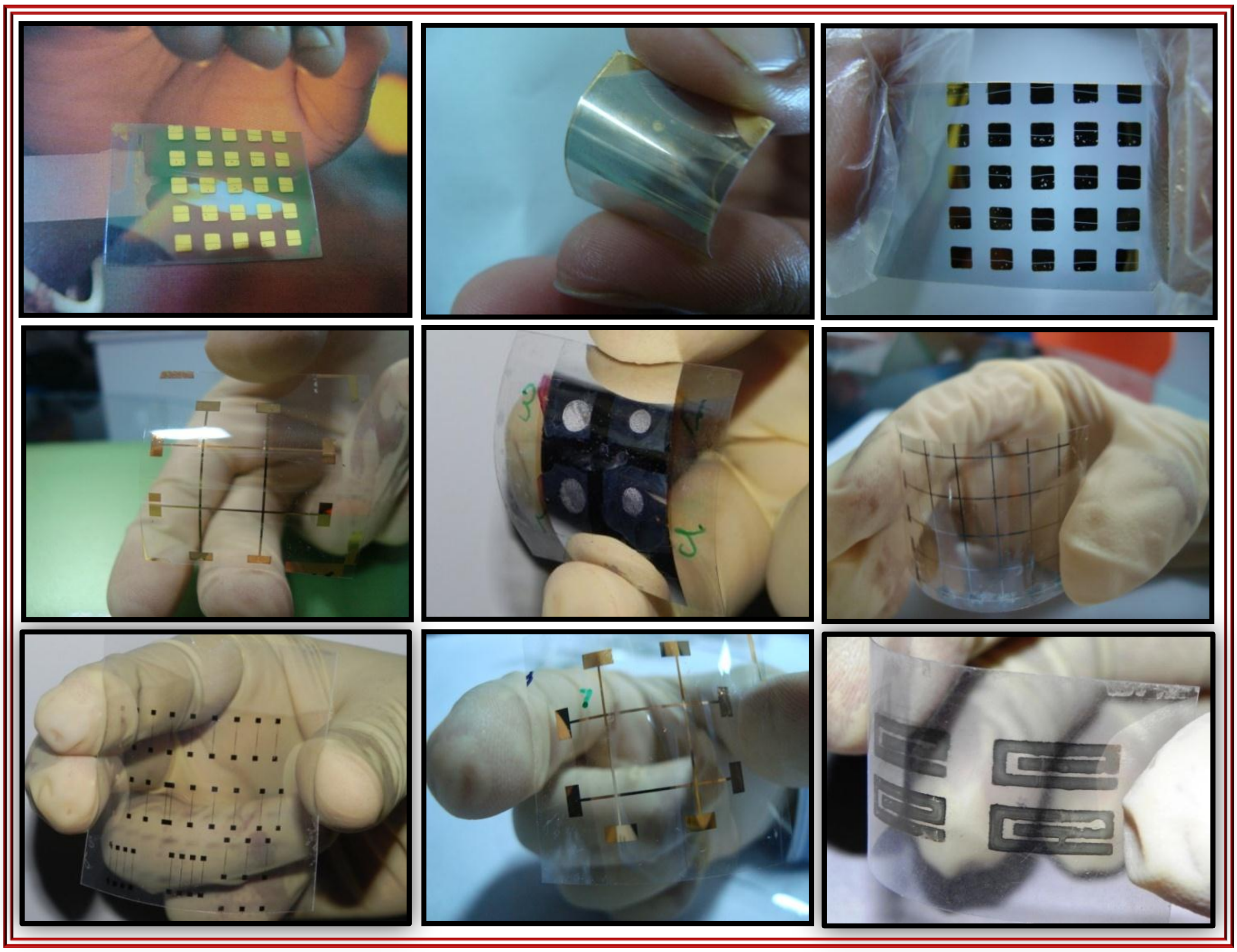
Detailed Project Report

for establishing a

Centre for Large Area Flexible Electronics

at

Indian Institute of Technology Kanpur



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Executive Summary

Large area electronics is a segment of electronics which is based on the monolithic integration of electronic components on amorphous substrates which typically results in products that are large in size with length scales ranging from a few centimeters as in sensors, to a few decimeters as in displays and lighting, to several meters as in organic solar cell based panels. This is in contrast to conventional microelectronics where integrated circuits (ICs) are fabricated on crystalline substrates and length scales are typically only a few millimeters.

Large area electronics is on the threshold of an imminent revolution that is driven by innovative applications made possible at a much lower cost than conventional methods of manufacturing. At the heart of this revolution lie two significant capabilities: designing products that are flexible and form fitting, and their manufacturing by printing based processes. The combination of the two may lead to roll-to-roll, large volume and high throughput manufacturing.

This revolution is being driven by use of new materials and methods of manufacturing. Hence, a break from the past has provided an opportunity to those who missed the "microelectronic bus" earlier. In other words, there are no well established players in flexible electronics at the moment and even those who are actively involved have been in it for a relatively short period. The Indian industry must make use of this opportunity to get a foothold in the emerging market for large area flexible electronics.

The electronics emerging from this would be fabricated on substrates that are plastics, paper, textiles or metal foils. The circuits will be printed roll-to-roll by fast manufacturing processes, much the same way as newspapers are printed. The products will be much more affordable and if required, even disposable. They find applications in several sectors of industry and technology. To name a few, distributed energy production through organic solar cells on windows and roofs, disposable sensors for air and water quality management or lab-on-a-chip for health monitoring, security packaging of medicines to check circulation of fake drugs, wearable and lightweight electronics on textiles as a soldier's gear, airport baggage handling, labeling of books in libraries or answer scripts in a large scale examination, flexible displays and lighting. Clearly, the examples span a large number of industrial sectors, and point to the widely held belief that only imagination is the limit to possible applications.

According to global industry sources, the flexible electronics market in 2011 was USD 1.8 billion and projected to be USD 19 billion in 2018. Much of the activity today is concentrated in the USA in North America; Germany, Finland and Denmark in Europe; and Korea, Taiwan and Japan in East Asia. In these locations, the development has accompanied emergence of several large sized strategic alliances and centres of excellence. A number of industry dominated conferences in flexible electronics have begun to see participation in excess of 1500 persons. The time is ripe for the Indian industry to take note of this rapidly emerging technology.

Since the domain of large area electronics today is still research driven, academic leadership is a must. However, in the Indian context, in order to reduce time to market, it is necessary to have simultaneous industrial participation. Further, the strategy for the development of manufacturing in flexible electronics in India should jointly emerge from a tripartite participation of industry, academia and government. Such issues should be addressed through a centre for excellence in flexible electronics. An interdisciplinary team of researchers at IIT Kanpur who have the required experience and expertise in the area propose to set up such a centre.

The vision of the centre is to conduct research and development in large area flexible electronics that serves as a foundation for development of domestic industry in this field. To achieve the vision, the objectives are to simultaneously conduct basic studies in the academia and develop products with (and also for) the industry. Further, one of the important objectives of the centre will be to facilitate up-front interaction of all segments of the industry - product, materials and equipment - during the development cycle itself, in accordance to a mutually shared road map for commercialization. In addition, the centre will promote small scale entrepreneurship, build national and international linkages and raise human resources in flexible electronics.

To realize these objectives, a centre, named as FlexE Centre, has been conceptualized as a platform having state of the art infrastructure and a competent team, named FlexE Team, entrusted with functions of generating knowledge, demonstrating proof of concept and build prototypes. The FlexE Team will serve as the link between the knowledge generation activity of academic partners and prototype and product building activities of industrial partners.

The model proposed for rapid development is a foundry-like structure. A flexible electronics based product is likely to have one or more of elements, such as transistors, memories, diodes, passive components, sensors, actuators (displays, LEDs, loudspeakers), power generation sources (photovoltaics) and energy storage elements (batteries). The centre will identify the state-of-art in these components, establish the component specifications and realize the components of these specifications. The industry will design products of their choice and rapidly build prototypes with these components. Wherever modifications and improvements of the specifications are required, the FlexE Team and industry will develop them together. New innovations and paradigm shifts in component technology will be the joint responsibility of academic partners and the FlexE Team.

Clearly, the FlexE team constitutes the heart of the FlexE Centre and therefore, it is imperative that the team should be of appropriate quality and size. To attract quality manpower, we propose to use industry participation and deputation of its personnel to the FlexE Team with attractive options to acquire higher educational degrees. The team would need a variety of expertise such as in device development, systems integration, electronics prototyping, materials and equipment support. Accordingly, the size of the team determined is approximately 60 persons, led by professionals of considerable experience and specifically hired to operate the centre.

Finally, it is critical that the FlexE Centre is supported with adequate funds in the initial stages to help spawn entities spanning the whole manufacturing eco-system thereby enabling the large area electronics technology to take root in India. The detailed project proposal is laid out with all its components including deliverables, estimated costs of establishing the centre and time schedules.

Table of Contents

1. Large Area Electronics

Electronics includes a wide gamut of products and applications, the foundation of which is the high-tech and high-value microelectronics industry.

Microelectronics normally conjures up an image of integrated circuits (ICs) and silicon wafers and industry names such as Intel and AMD. This technology is implemented on single crystal silicon wafers. Over time, conventional crystalline silicon based microelectronic manufacturing has followed the concept of decreasing feature size (from microns to nanometers) and increasing substrate size (from 2” wafers in the 1960s to 12” today) to develop increasing complex ICs at competitive prices. Unfortunately, in the commercial sector, manufacturing in this segment of industry in our country is nearly non-existent.

However, there is another set of products within microelectronics that are built not on crystalline silicon, but on glass and are equally large both by production volume and revenue. These, for example, include displays/television, lighting and photovoltaic modules. A television screen is made of pixels that are only tens of micrometers; thus making of a television is in the domain of microelectronics. However, the sizes in which a consumer may want the televisions are in excess of 40-60 inches. Further, to achieve lower costs, several screens of television are made simultaneously on a single glass plate. Thus, the size scale on which this segment of microelectronic industry works is in meters. Similarly, photovoltaic panels based on thin film of amorphous or polycrystalline forms of silicon are made in sizes that are in meters. Thus, these applications represent microelectronics on large area substrates leading to the terminology, *Large Area Electronics*.

The limitations faced in the scaling up of substrate size in the manufacturing of these traditional large area electronic systems can be overcome by printing organic and inorganic materials on flexible substrates. The flexible substrate based manufacturing platforms would not only lead to lower production costs, but also benefit applications that derive value from the larger size of the systems.

We first illustrate the new possibilities in applications and the potential low cost of such devices and then establish that the emergence of this field in the commercial sector is imminent.

2. Flexible Electronics: The Way Forward

The electronic functions of control, logic, sensing, and information transmission brings intelligence to all the products. The prospect of bringing this intelligence to all objects without restricting it to electronic instruments which use high performance integrated circuits has given rise to the potential for a complete range of new applications – literally bringing the functionalities 'out of the box'. The winning combination of features that characterize this pervasive electronic based intelligence, also referred to as 'electronics everywhere and for everybody', are:

a) flexible substrates such as plastic, paper, textiles and metal foils for all possible forms,

b) printable circuits in large area possibly in roll-to-roll fast manufacturing processes similar to mass printing of newspapers,

c) affordable, i.e., low cost functionalities with performance just enough and appropriate for a particular application,

d) disposable after its designated duration of usage with possibility of recycling of components

Large area flexible and printable electronics essentially implies the manufacturing of electronic devices on a flexible substrate by employing printing techniques. High throughput methods such as roll-to-roll processes ensure large volume production - and coupled with the fact that a single line of machinery would be required in most cases - low cost and less energy-intensive end products. From the environmental perspective, flexible electronic products have the potential to be environment-friendly and biodegradable. In addition, lower power consumption and light weight make them attractive candidates for military, space and transport sectors. A technological revolution of sorts is in the making since it is going to touch almost all aspects of our lives – in ways that we may not be able to fully imagine at this point of time. We cite, as examples, some of the current developments and its progress within the grand challenge areas of energy, health, environment, defence, communication, transport and education.

It should be emphasized that this technology is truly relevant to India, both from the point of view of potential applications as well as developing new paradigm for electronics manufacturing. In contrast to conventional electronics, which involves capital intensive and complex fabrication facilities, manufacturing in flexible electronics is likely to need less capital and will be much simpler – which is ideal for distributed production. Hence, the advent of this technology offers a level playing field and newer opportunities in many sectors. Some of these are summarized below.

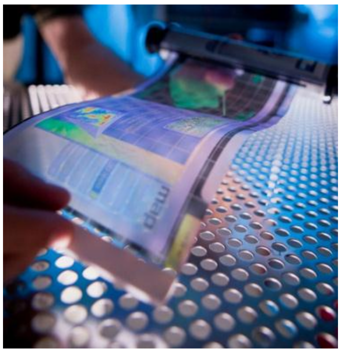
1	**Energy**	Distributed energy production through organic solar cells on windows, roofs, and indoor objects to harvest light within the buildings. Efficient indoor lighting panels on walls and ceilings integrated with the architecture of the building.
2	**Environment**	Disposable sensors and electronics for environmental monitoring, e.g. for air and water quality. Large scale distribution of sensors and their deployment at the point of use.
3	**Health**	Disposable lab-on chip for testing. Packaging of medicines. User controlled diagnostics.
4	**Defence & Security**	Wearable electronics in soldier's gear. Defence inventory control. Light weight large area probes and sensors for unmanned mission.
5	**Communication & Transport**	Railways inventory, ticketing and listing of passengers and parcels, component monitoring. Airport baggage handling and locating objects within a large set.
6	**Education**	Plastic electronics for volume documents, books, notebooks, magazines. Labelling of books in libraries, answer scripts in large scale examinations. Design of innovative test formats using printable electronics. Security printing of certificates.

2.1 Major Applications of Large Area Flexible Electronics

The new emerging technology would spawn its own new areas of applications. A myriad such applications have already been demonstrated and some of these have been marketed also. Fields of displays PV, lighting, healthcare and transport are going to be revolutionized in the next 5-10 years due to the adoption of printable and flexible electronics.

2.1.1 Displays

Displays are poised to be the largest share of flexible electronics products. It is expected that while glass size may limit the dimensions of displays on glass, printed displays on plastics will not have such restrictions. Roll-to-roll processes may increase the volume of production and the prices can be controlled. The flexibility and the thin form factor may add to the appeal of such displays from a consumer's perspective. Both industrial and academic groups are active in flexible display development. For instance, the flexible display centre at Arizona state university recently demonstrated the largest flexible OLED display.



Flexible OLED display(Fraunhofer Institute, Germany)

Flexible cell phone display (Samsung)

2.1.2 Photovoltaic applications

Large area flexible electronics on substrates such as steel are especially attractive in countries such as India where many shelters and godowns use corrugated steel as roofs. Integration of solar cell modules on the outer surface as power generation source and white light emitting diodes on the inner surface for lighting is attractive for building and also adds significant value to the roof. The picture on the right shows a 144W building integrated photovoltaic (BIPV) flexible solar panel.(http://imagesen.busytrade.com/176131800/144w-Flexible-Solar-Panel-For-Bipv.jpg).

(http://www.konarka.com/)

Flexible photovoltaic modules can also find innovative applications as in the awning above car parks providing useful shade as well as generating valuable power. Their low weight and flexible nature make their deployment easier and less costly.

Integrating flexible electronics in fabric has potential for a large number of applications. One application is a battery charger integrated in clothes as seen on left (enfsolar.com). This is particularly useful for defence applications as well as for outdoor recreational activities. Many universities and research labs have been exploring integrating PV in fabric. For example, Colorado State University (CSU) is trying to develop a natural fibre for outdoor clothing that can charge portable devices.

2.1.3 Printed batteries

Smart objects such as RFIDs, stand-alone sensors, etc. require a power source which should be thin, flexible and congenial to design requirements. Printed batteries meet these challenges. In addition the common markets, they cater to the needs of niche markets, such as, anti-wrinkle plasters. They provide options for many practical and novel applications in combination with flexible photovoltaic modules.

2.1.4 Large Area Flexible sensors

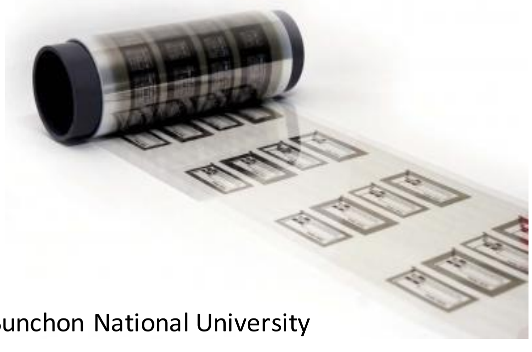
Flexible sensors will have applications in many areas including military, security enforcement, environmental monitoring, biomedical applications, robotics, packaging, etc. Many industrial competitors are active in this area. Sony, Agilent, VTT, Plastic logics, PARC, IMEC and Future Shape GMBH are some of the top players.

Sensors integrated with printed transistors on flexible sheets have been demonstrated as artificial skin for robots with ability to sense pressure, temperature and chemical environment.

2.1.5 Packaging tags

electronics-eetimes.com

A temperature sensor integrated with a timer can be used for monitoring perishable goods and pharmaceutical products. This smart packaging can collect data and wirelessly communicate to a wider target audiance. Thin Film Electronics, Norway is developing these smart packaging to be commercialized by Bemis by 2014. Such smart packaging will allow the user to walk through with their trolley whilst a scanner reads the goods and totals the amount, charges it to the customer's account and adjusts the shop's inventory.


Sunchon National University

2.1.5 Smart Labels & Printed RFID

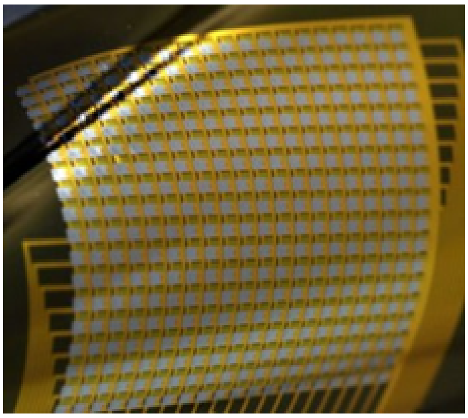
The area in which large area electronics has advanced the most at present is in applications involving smart labels for objects and identification. These include tens of thousands of items in retail stores, baggage sorting at airports, couriers, tickets, letters, perishable items such as milk, fruits and meat, etc. This has given rise to the concept termed as 'internet of things' in which objects made intelligent by fixing labels on them, allows them to be queried, sorted, sold or controlled during transportation.

Though RFID tags are routinely being used, to achieve their complete potential, more widespread use is essential. This can happen only if they come at a lower price and printing leads to a cheap manufacturing process. PolyIc (Germany) is the pioneer in this field.

2.2 Other Novel Applications

Apart from the applications described above, which are nearing commercialization, the characteristic features of flexible and printed electronics paves the way for conceptualizing of some truly innovative applications. Some examples are given below.

Example: Non-invasive recording of brain activity



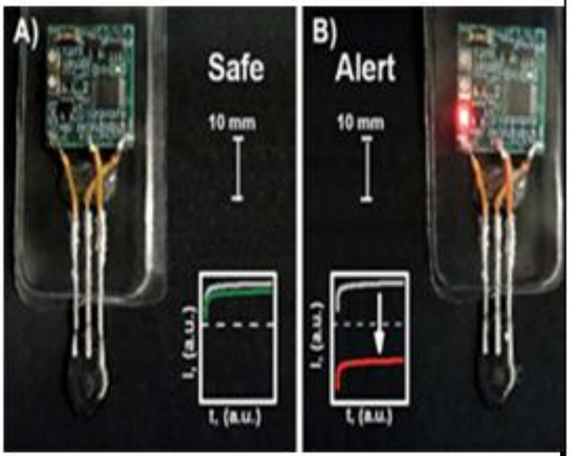
B. Litt, Univ. Penn.

Composed of 720 silicon nanomembrane transistors in a multiplexed 360-channel array, the newly designed **ultrathin, flexible, foldable** device can be positioned not only on the brain surface but also inside sulci (a depression or fissure in the surface of the brain) and other areas that are physically inaccessible to conventional rigid electrode arrays.

The multiplexed nanosensors of the new device can cover a much large brain area with high resolution, while using almost **ten times fewer wires** than current sensors.

Source: http://www.sciencedaily.com/releases/2011/11/111113141405.htm

Example :Detection of underwater hazards



J. Wang, UCSD

Printed thick-film electrochemical sensors directly on flexible wetsuit material has paved the way for nano devices to detect underwater explosives or ocean contamination. The electrochemical sensors are based on applying voltage to drive a reduction-oxidation (redox) reaction in a target threat or contaminant – which loses or gains electrons – then measuring the current output. The wearable microsystem provides a visual indication and alert if the levels of harmful contaminants or explosives exceed a pre-defined threshold. It does so by mixing different enzymes into the carbon ink layer before printing on the fabric.

Source: http://ucsdnews.ucsd.edu/archive/newsrel/general/20110707UnderwaterSensors.asp

Example : Sheet-Type Braille Displays

Takao Someya, University of Tokyo

An array of rectangular plastic actuators is processed from a perfluorinated polymer electrolyte membrane. The effective display size is 4 × 4 cm². Each letter consists of 3 × 2 Braille dots, and the total number of dots is 144; thus, 24 letters or 6 letters × 4 lines can be displayed. The Braille dots on one line are driven for 0.9 s. The total thickness and weight of the entire device are **1 mm and 5.3 g**, respectively. The present scheme will enable people with visual impairments to carry **the Braille sheet display in their pockets and read Braille e-books at any time.**

Source: http://www.ntech.t.u-tokyo.ac.jp/Archive/Archive_download/Archive_download_en.html

This scenario has been made possible by a unique combination of newly acquired capabilities over the last two decades. The key elements of such capabilities are:

i) functional design of molecules: a large set of material systems have been discovered and continuing to be improved at break-neck speed,

ii) nanoscale-engineered materials for macro-scale processes such as printing,

iii) low temperature processes for realizing complex hetero-structures of different types of materials from metals to semiconductors to dielectrics obtainable in thin film from,

iv) ability to design systems based on limited performance of components,

v) interdisciplinary expertise from diverse fields such as chemistry of materials and inks, physics of thin films, new directions in materials engineering, chemical engineering involving fluid dynamics of control of novel unit processes, electronics and electrical engineering of component and system development requiring notions different from the established microelectronics.

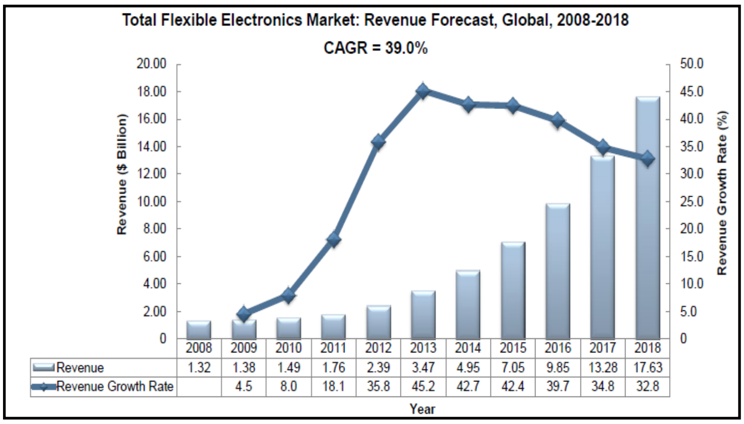
The various academic challenges stem from the issues listed above and one needs innovation at many levels by pushing the existing boundaries of each of the disciplines involved. Similarly developing applications whilst keeping the needs of different user agencies in perspective require innovative technology development models, as well as new business strategies.

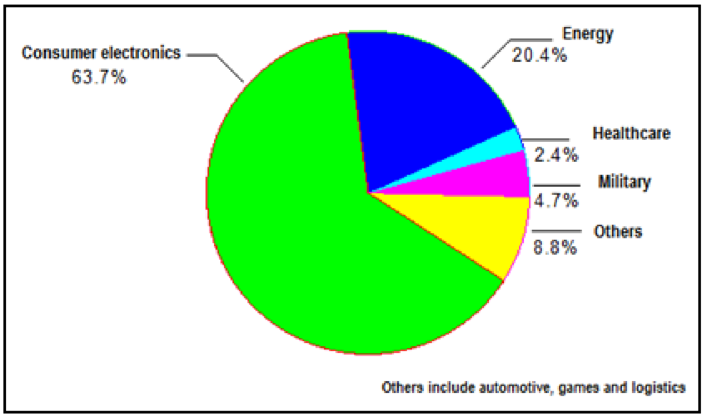
There have been seminal developments in the area, thanks to interdisciplinary academic groups who have contributed on the one hand to the core intellectual challenges involved, and on the other to nucleation of successful start-up companies sufficient to inspire confidence in commercial investors.

3. Flexible Electronics: Current Status and Projections

3.1 Global Market Scenario

The total flexible electronics market was USD 1.76 billion in 2011 and is projected to reach around USD 18 billion by 2018 (see figure[1] to the right). Close to 500 competitors are active in the market out of which 300 are located in North America, around 100 in Europe and 100 in the Asia-Pacific region. In North America, the flexible electronics market had revenue of USD 0.44 billion in 2011 which is projected to reach USD 3.94 billion by 2018. The European market is projected to grow from USD 0.58 billion to USD 5.46 billion during the same period. But the Asia-Pacific region will see phenomenal growth in this sector and the revenues will sore from USD 0.74 billion in 2011 to USD 8.23 billion in 2018 which is an annual compounded growth of 41.1%[1].

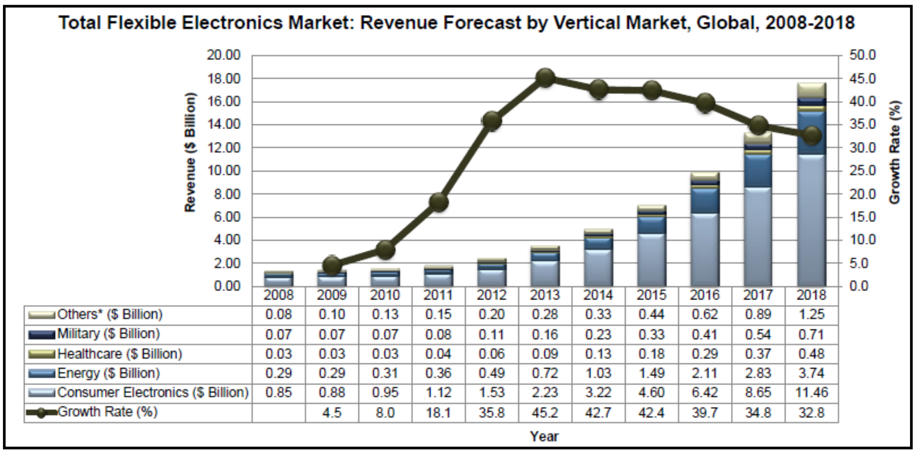




Major application areas are consumer electronics, healthcare, military, energy, games, logistics and automotive products. The division of the total flexible electronics market is shown in the figure[1] on the left. Huge demand for the consumer electronics products could be the driving factor for flexible electronics. There is a global demand for flexible and lighter products. The major flexible electronic products are flexible displays, flexible photovoltaic, flexible batteries, flexible sensors, flexible memories, and flexible radio-frequency identification devices (RFIDs). Major goals will be to achieve large volume and high quality production processes which ensure a stable and efficient end product.

A major share of 63.7 percent of the flexible electronics products currently is owned by the consumer electronics, which mainly includes the OLED-based display devices. Consumer electronics is supposed to retain this domination with the inclusion of other innovative products. Building integrated photovoltaic (BIPV) systems and portable devices may use printed solar cells. Other areas which will see a growth in the adoption of printable electronics are printed batteries, healthcare and transport.

Consumer electronics will continue to be the leader in generation of revenue as well, with a projected growth from USD 1.12 billion in 2011 to USD 11.46 billion in 2018(see figure[1] to the right). Other sectors like energy and military will also see considerable growth.

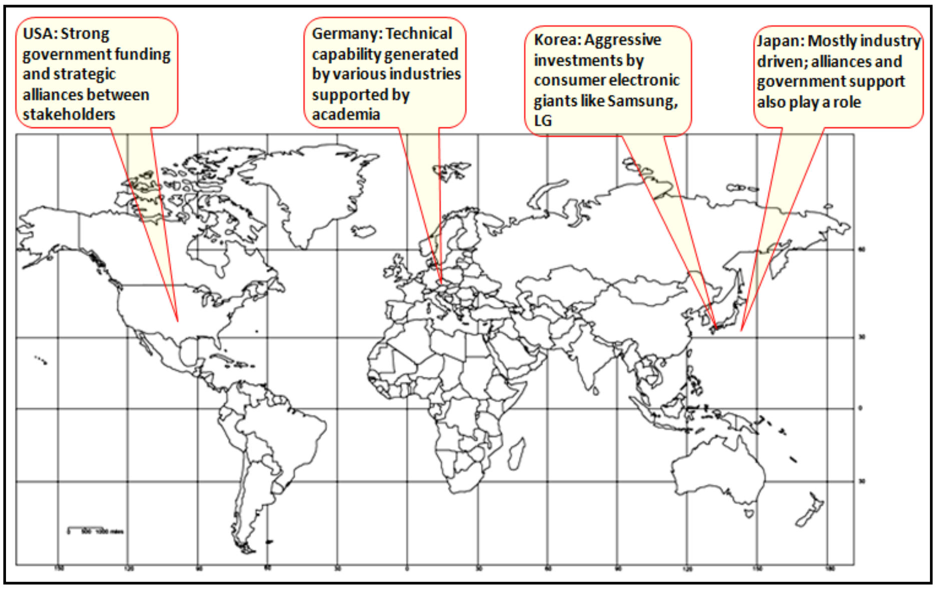


	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Others* ($ Billion)	0.08	0.10	0.13	0.15	0.20	0.28	0.33	0.44	0.62	0.89	1.25
Military ($ Billion)	0.07	0.07	0.07	0.08	0.11	0.16	0.23	0.33	0.41	0.54	0.71
Healthcare ($ Billion)	0.03	0.03	0.03	0.04	0.06	0.09	0.13	0.18	0.29	0.37	0.48
Energy ($ Billion)	0.29	0.29	0.31	0.36	0.49	0.72	1.03	1.49	2.11	2.83	3.74
Consumer Electronics ($ Billion)	0.85	0.88	0.95	1.12	1.53	2.23	3.22	4.60	6.42	8.65	11.46
Growth Rate (%)		4.5	8.0	18.1	35.8	45.2	42.7	42.4	39.7	34.8	32.8

3.2 Market drivers

There are a variety of drivers for flexible electronic market. Innovative products which were not even possible to have been imagined with traditional electronics define the major characteristic of flexible electronics. Printed solar panels, printed memory, flexible and printed displays and disposable printed batteries are some of the products being realized using flexible and printable electronics. Further the light weight and form factor of the products have enabled flexible electronics to penetrate into further innovative areas like smart textiles.

Ample government funding is another enabler for this technology. For example, in the USA, Department of Energy, National Science Foundation and the Defense Advanced Research Project Agency are all involved in funding extended research proposals in this area. Strategic alliances have played another important part in developing novel substrates, functional inks, materials, and innovative manufacturing techniques. The global hotspots in this field are depicted below[1].



It can be seen that three major factors contributed to the research and development of flexible and printable electronics wherever the activities flourished. They are 1) Strategic Alliances, 2) Centres of Excellence, and 3) Annual Conferences.

3.3 Strategic Alliances

Alliances have played an important role in bringing together all the stakeholders such as material manufacturers, equipment manufacturers, system integrators and academic players, under one umbrella. This has resulted in strengthening the existing know-how as well as exploring new applications. Some major alliances are given in the table below.

A list of major strategic alliances in the field of flexible and printable electronics

Alliances	Description
Organic-Electronic Association(O-EA)	• 192 members in 29 countries • Members are component and material suppliers, equipment and tool suppliers, system integrators, distributers, end users and research institutes
European Rotogravure Association (ERA)	• 130 members • International organization in gravure industry • Addresses issues related to publication, packaging, decorative printing sectors as well as paper and ink manufacturing, printing and finishing equipment
Flex Tech Alliance	• Offers expanded collaboration between and among industry, academia, and research organizations for advancing displays and flexible, printed electronics from R&D to commercialization. • Has funded over 100 projects in the display supply chain R&D, with a total public/private investment in excess of $220 million.
Printed Electronics Arena	• Creates sustainable long-term growth in the region around Norrkoping; since 1998 have been conducting R&D at Linkoping University and Acreo. • Members include the municipality, the university, and business community to work toward the regional development of operations based on printed electronics.
Japan Advanced Printed Electronics Technology Research Association (JAPERA)	• Established in 2011, aims at developing a manufacturing process of a high-performance TFT array on a flexible plastic film by continuous printing techniques with high reproducibility.
UK Technology Strategy Board (TSB)	• Linking technology providers in the sector to end users, business leaders, and creative designers to provide a joint understanding to ensure exploitation of market and product opportunities

3.4 Centres of Excellence

During the last few years several research centres focused on flexible and printable electronics sprouted in USA, Europe and the Far East. Most of them are government-funded and they provide a common platform for several industrial and academic players to work together. A representative list of such centres is given below.

Representative list of centres for R&D in flexible and printable electronics

Centre	Description
Flexible Display Center, Arizona State University (http://flexdisplay.asu.edu)	Main focus is on flexible OLED displays. Different levels of membership are offered to industrial partners. Currently having 23 industrial partners, 5 government partners and 3 academic partners. Has mass manufacturing capability.
Flexible Electronics Research Center, AIST, Japan (http://unit.aist.go.jp/flec/index_en.html)	Developing components, manufacturing technology and evaluation standards. Five functional teams are actively engaged in research.
Holst Centre, Netherlands (http://www.holstcentre.com)	Develops generic technologies for wireless autonomous sensor arrays. With 35 industrial partners the centre has shared roadmaps and programmes.
Centre for Plastic Electronics, Imperial College, UK	An interdisciplinary team from Imperial College London coordinates the activities. The doctoral training centre is an attraction for industrial partners. Aim is to ensure UK's dominant position in plastic electronics.
VTT Printed Intelligence, Finland (www.cpi.vtt.fi)	Vision is to employ low-cost and easy to use printed components for light emitting surfaces, sensing, energy foils, optical films etc. Facilities include various roll-to-roll fluid printing and coating labs and pilot scale equipments. Entrepreneurial activities also undertaken.
Institute for Print & Media Technology Chemnitz University of Technology (www.tu-chemnitz.de/pm)	Has developed multifunctional printing capabilities. Developing mass printing technologies for photovoltaic, sensor, communication segments.
Korea Printed Electronics Center(KPEC) (www.printedelectronicskorea.org)	Established by KETI. Establishing core technologies for printed electronics. Nurturing industrial cluster.
Printable Electronics Research Center, Suzhou, China (http://perc-sinano.com/en/)	Established by Chinese academy of Sciences. First research centre on printed electronics in China. Focuses on early stage product development and prototyping in PV, TFT and OLED

3.5 Conferences

Annual conferences play a vital role in arranging the venue for discussing the state-of-the-art technology, showcasing the prototypes and presenting the technology roadmaps. Some of the major annual conferences in the field of flexible and printable electronics are listed below. The number of conferences and participants in it are an indicator of worldwide interest.

Major annual conferences in the field of flexible and printable electronics.

Conference	Details
LOPE-C (Large area organic and printed electronics convention)	Annual conference organized by Organic and Printed Electronics Association(OE-A) and Messe Munchen International(Germany) In 2012, there were around 1500 participants from 46 countries
IDTechEx conferences Printed Electronics Asia Printed Electronics Europe	Many end-user application segments have their presence Main focus is on the commercialization of the technology
Flexible and printed electronics conference	Organized by Flextech alliance in USA More than 300 organizations present their technologies, roadmaps and forecasts
Printed Electronics, China	Organized by Chinese Academy of Sciences and the Ministry of Science and Technology

References

1. Future of semiconductors in flexible electronics market: Frost & Sullivan analysis, NAF-27, August 2012.

2. Printed organic and flexible electronics forecast: Players and opportunities, IDTechEx Report: 2009-2029.

4. Flexible Electronics: A Case for Academic Leadership

Manufacturing in microelectronics may be divided in two categories, (a) that on *single crystal* substrates, limited to a maximum size below 30 cm and (b) that on large area substrates, mostly with *amorphous or polycrystalline* materials, on meter scale or roll-to-roll .

As the innovations in applications suited for large area flexible electronics and current trends for it indicate, fortunately, we stand at a cusp in time, where the existing large area electronics industry is undergoing major changes. That provides renewed opportunities in India, at the levels of both innovation and manufacturing. The demand for better performance in existing products and new applications is being met by the introduction of new materials or innovative products. The consequences of these changes are illustrated below by two examples.

To date, the workhorse of the thin film transistor (TFT) industry for displays has been amorphous silicon. However, demand for better performance from displays is exceeding those that can be delivered by amorphous silicon. To meet the challenge, search for alternatives is leading to materials such as indium gallium zinc oxide. This represents an opportune time for India to enter into manufacturing, as the shift to new material represents a leveling of competitive landscape to a certain extent.

In addition to new materials, as we have shown in the previous sections, applications in the large area electronic segment are moving towards flexible and form fitting devices. This demand also forces new methods of processing, especially by introduction of printing as a means to fabricate electronic circuits. This impending change also offers India an opportunity to claim a portion of the manufacturing pie. An illustrative example is the field of LED lighting. While we are significantly behind in single crystal based LED lighting and international industry is well established, the emerging technology of organic light emitting diodes (OLED) on a large area and in a flexible form offers an opportunity to break the entry barrier to manufacturing in the LED based lighting segment.

These two examples clearly illustrate that the search for new materials and new methods of manufacturing are research driven and hence will require a leadership role from academia. Both academia and industry need to come together in a mission mode for ensuring manufacturing activities in the country.

The Flexible Way: Academic Leadership

Large area electronic manufacturing is in transition with new materials and methods of manufacturing. This transition offers us a window of opportunity. Further, as the transition is necessarily research driven, the role of academia is important. Hence, large area electronics in general and flexible electronics in particular, is an area ripe for academia driven academia-industry-government collaboration to usher in flexible electronics manufacturing in India.

Concurrently, it would serve us well to remain aware of other important areas in which technology is already mature and require industry leadership.

Industry Leadership

Country needs industry leadership in several manufacturing areas where academia can also be a partner. Some of these are

- ***Single crystal silicon microelectronics circuit manufacturing***
- ***Nitride based LEDs for lighting***
- ***Amorphous Si based photovoltaics***
- ***Amorphous Si based TFTs for displays and other applications***

Manufacturing on single crystal silicon substrates is mature and well established. We may have missed on this technology because that developed closer to our independence. Bringing this activity to India now will primarily depend on policy and industry.

However, shift in the lighting industry from light bulb/tube-light/CFLs to solid state LED based lighting is only recent. Solid state LED lighting is based on single crystals of gallium nitrides and associated compounds. The steps involved are growth of nitride layers, device fabrication, packaging and fixture assembly. The technology of growth of these layers is a critical step in realizing LED products and is well protected by the leading companies of the world. In this regard, manufacturing in India is being relegated only to packaging and fixture assembly. There is a need to introduce nitride layer growth process and LED device fabrication in India. However, this technology is also mature.

Similar is the case with large area technologies based on amorphous silicon, specifically, TFT arrays for LCD displays and solar cells. The TFT technology based on amorphous silicon is well established, especially in East-Asia. Unfortunately, to the best of our knowledge, manufacturing in this area does not exist in India. The consequence is that while the country produced CRT televisions from start to finish, because of lack of availability of TFT technology, our flat panel TV manufacturing is likely to be reduced to LCD module and set assembly. On the other hand, in solar cell manufacturing, the world leadership is still not defined and evolving. Thus the potential for manufacturing in India remains positive.

A likely reason that India could not take full advantage of many recent technologies (solid state lighting or those based on amorphous silicon) is that a concerted effort was perhaps not taken at the right time to put together an ecosystem required for establishing such technology intensive manufacturing.

Hence, it is critical that in large area flexible electronics, we address both technology development (applied research) and manufacturing potential (industry) simultaneously.

5. Vision and Objectives

Vision

Conduct research and development in large area flexible electronics that serves as a foundation for development of domestic industry in this field.

Objectives

R&D: Conduct basic studies and scientific investigations relevant to field of large area flexible electronics.

Manufacturing: Conduct research and development in large area flexible electronics by developing partnership with industry and with a view that potentially leads to manufacturing.

Ecosystems: Facilitate formation of industrial ecosystem by addressing various aspects, products, materials and machines and academic ecosystem by engaging with reputed centers internationally and individuals nationally.

Entrepreneurship: Incubate small scale industry related to flexible electronics

International Partnerships: Build strategic partnerships that hasten the development cycle.

Human Resources: Undertake human resource development in relevant area.

6. Realising the Vision: A Framework

To realise the vision and meet the objectives, the conceptual structure of the centre should include the following:

Salient Features

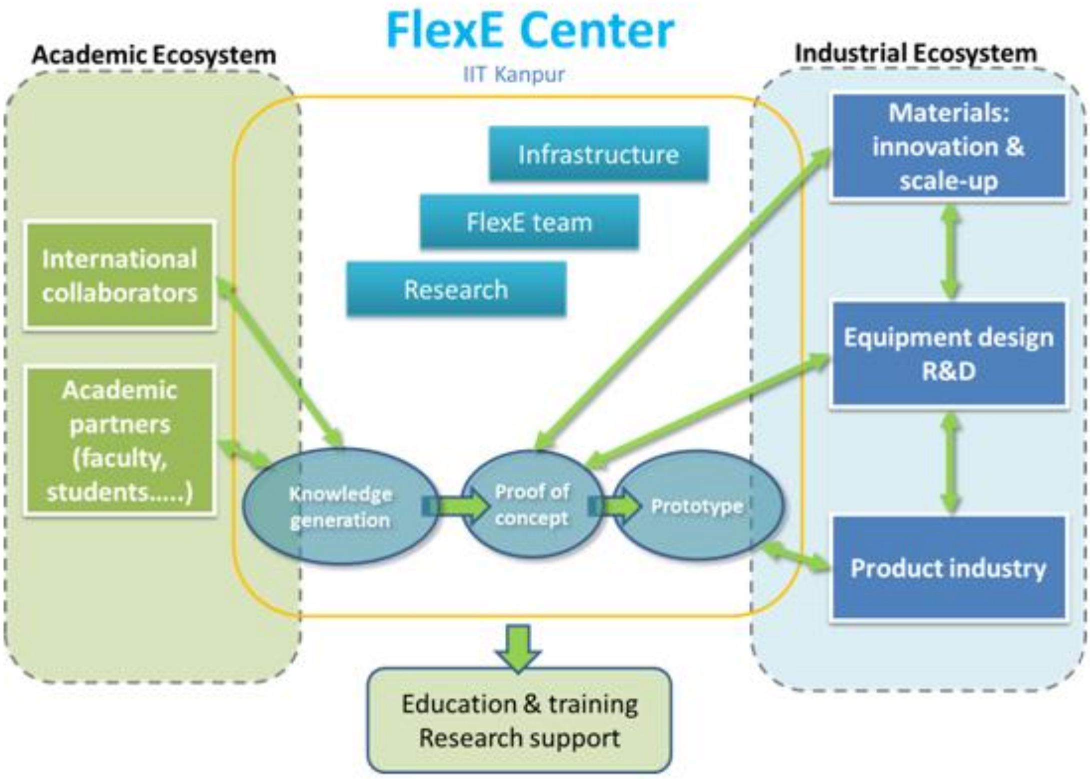
- an interdisciplinary team that advances the frontiers of research in large area flexible electronics.
- state-of-the-art processing facilities operated by trained staff, making it attractive to the industry for participation in developing products.
- a platform for a meaningful interaction between industry and academia.
- synergistic interaction among industries engaged in product development, materials and equipment manufacturing.

Around these core activities will be specific models for establishing strategic alliances with international partners for education and training.

Apart from physical and functional elements of the centre, it is also important to establish proper organizational structure and processes which promote the envisaged interaction between academia and industry and among industries, while maintaining proper checks and balances.

Based on the requirements described above, a concept of a centre has been visualized and shown in the figure on the following page. It is to be noted that there are two ecosystems. The first being an *Academic Ecosystem* comprising of *Academic Partners* and *International Collaborations* engaged in *Research, Education and Training*. The second ecosystem is an *Industrial Ecosystem* that brings together *Products*, *Materials* and *Equipment* industries in one physical location. An important aspect of this concept is a tight integration of all critical elements at one location to establish close Academia-Industry Collaboration for realizing the goal of high impact R&D, new manufacturing industry and entrepreneurship. As a consequence, the entity would necessitate the formation of a pan-Indian team of academic experts to deliver R&D solutions for rapid development of large area flexible electronic technologies.

The conceptual structure of the proposed centre is further elaborated in next few pages.


FlexE Center
IIT Kanpur
Academic Ecosystem
Industrial Ecosystem
Infrastructure
FlexE team
Research
International collaborators
Academic partners (faculty, students.....)
Knowledge generation
Proof of concept
Prototype
Materials: innovation & scale-up
Equipment design R&D
Product industry
Education & training
Research support

7. Functional Elements and their Role

7.1 Academic Ecosystem

The goals of the academic ecosystem conceived here in the context of developing flexible electronics, is to provide high quality research, provide education/training to generate human resource, build academic collaborations, national and international, and participate in strategic alliances. Accordingly, this ecosystem will be organized with the functional elements described in the following sub-sections.

7.1.1 The Facility and the Scientific Programme

In the concept diagram, this element is described as "FlexE Centre" which will be a state-of-the-art facility for flexible electronics. The role of IIT Kanpur will be to establish and nurture it. It will be led by a group of faculty members drawn from interdisciplinary areas; a brief profile of participating faculty is attached later in this document.

The equipment requirement in the centre will be derived from what is necessary to produce flexible OLED lighting, photovoltaic and sensor array prototypes. This approach will enable enough options to conceive other sets of product prototypes and fabricate them. The intent for following this approach is to make the FlexE Centre attractive for industry to take up prototyping activities.

The centre itself will be run by a competent staff. The scientific goal of this staff, organized as "*FlexE Team*," will be to establish processes to make good quality passive components, OLEDs, TFTs, solar cell, batteries, sensors and encapsulation of flexible substrates which can then be integrated to make product prototypes by the industry. Another role of the *FlexE Team* would be to provide electronic design and system integration. The capacity built by *FlexE Team* would also enable post-graduate research to flourish. Further, this research would be tailored, when necessary, to suit the industry requirements. Further details of the scientific programme are provided in the section: *Flexible Electronic (FlexE) Systems: The Scientific Programme*. In short, led by a group of faculty, the *FlexE Team* and the students from IIT Kanpur and other institutions across the country will produce original research and facilitate rapid prototype development with industry.

An important feature we wish to implement is with respect to deploying quality manpower in the *FlexE Team*. The normal mechanisms available are to employ scientific staff on established scales on short contracts, which either makes it unattractive for a competent engineer/scientist or the turnover of such staff too frequent. To overcome this problem, we intend to use the collaboration with industry as a means to deploy engineers on their payrolls (existing or especially recruited) as part of their contribution towards the partnership with the centre.

The core group of faculty at IIT Kanpur will evolve a policy for providing research support for other academic institutions in the country. The same team will be responsible to establish academic partners within country, international collaborations, training and education and policy for interaction with the industry.

7.1.2 Education and Training

Along with the development of flexible electronics, it will be necessary to produce trained manpower. As the centre is embedded in IIT Kanpur, the interested students will be offered courses in this area. In addition, the faculty associated with the centre will endeavour to attract large number of students to conduct research in flexible electronics as part of their M.Tech. and Ph.D. programme.

Additionally, there will be an annual short course and periodic workshops organized in large area and flexible electronics open to researchers and students from across the country.

An attractive feature will be provision of post graduate (M. Tech. or Ph.D.) degree for participants from the industry who work at the centre either as a part of *FlexE Team* or collaborative projects with the industry. This would help in attracting the best persons from industry to participate in the centre, while they retain their original employment status.

7.1.3 Collaborations: Academic Partners and International Collaborations

As part of academic outreach, we would leverage the services of best engineers/scientists in the country working in the area of flexible electronics by establishing partnerships with them and their institutions.

International Collaborations are important to provide visibility and also to learn the best practices. On the academic front, IIT Kanpur already has an ongoing collaboration with TU Chemnitz, Germany, for mass printable electronic products on paper and a leading government research lab CSIRO, Clayton in Australia, in organic photovoltaic technologies. Apart from that, there are several other centres with which opportunities of collaboration are being explored. To name a few, these are *Flexible Display Center*, Arizona, *Center for Organic Photonics and Electronics* (COPE), Georgia Tech, *Center for Hierarchical Manufacturing*, University of Massachusetts, Amherst, Microelectronics Center, UT Austin, and Microall in USA.

Further, there are a few strategic alliances forming between a group of industries and research centres. It is important to be a part of such alliances not only to gain access to technology, but also to play a role in the definition of *standards*.

7.1.4 Research Support to Academic Institutions

Wherever possible, the FlexE Team will provide assistance to individuals from other academic institutions for carrying out their research at the centre.

7.2 Industry Ecosystem: Products, Materials and Equipment

It will be natural for the centre to interact with industry that would be making final products, such as photovoltaic modules and OLED lighting sources. However, experience suggests that even when successful prototype development takes place, product manufactures are reluctant to commercialise the product due to the risks associated with the import of equipment and materials. In the absence of an existing domestic market, the equipment and materials companies, despite having the requisite skills also remain reluctant to invest.

Therefore, it is necessary to ensure simultaneous engagement with product, equipment and materials industries. This is best served by establishing a mechanism that brings their representatives together. As indicated in the concept diagram, the FlexE Centre intends to provide this much needed platform, and bring together the three types of industries to interact among themselves and with the academic part of the centre.

7.2.1 Product Industry

The centre through its FlexE Team would undertake development of critical set of components, such as resistor, capacitor, inductor, TFT, OLED, solar cell, etc. The product industry will interact with the centre as a *Partner* (described in section *Organizational Structure and Processes*) and execute projects with IIT Kanpur. The goal will be to build prototypes of commercial products using the components developed. The largest effort of the centre with respect to interaction with the industry will be focused here.

7.2.2 Equipment Industry

We will identify equipment makers who at a small scale have provided quality products for R&D in microelectronics and have them open a cell at IIT Kanpur within the centre. The objective will be to identify, among all the equipment needed, the ones that should be developed first. The decision will be based on capability, ease and requirements of the product industry.

Projects will be initiated to develop these equipments. The design will be researched at the centre, but fabrication activity will be external, according to the design developed at the centre. Thus laboratory facility required for this industry will be in form of a computer laboratory only. An important objective of including this activity will also be to initiate small scale enterprises by students in IIT Kanpur.

7.2.3 Materials Industry

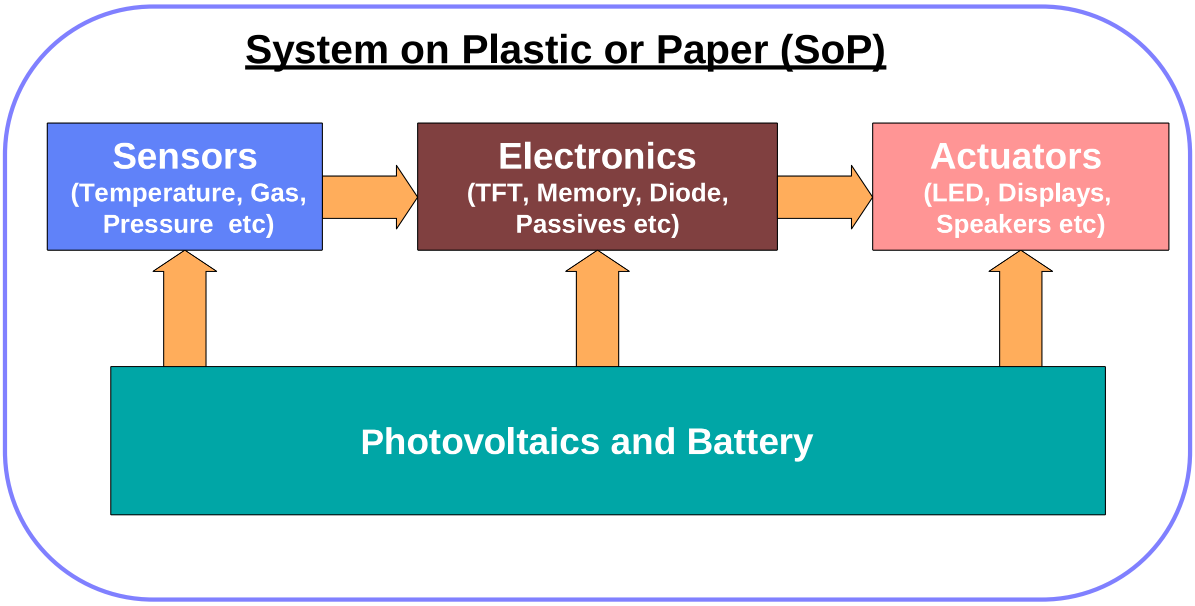
Two types of activities will be encouraged with materials industry. The first will be to facilitate kilogram or higher level production of established and proven materials, with due regards to applicable patents. Large batch experiments will have to be performed at the industry's home location. The centre's role will be to provide intellectual input for those experiments.

The second activity will be development of new materials, in consultation with the research and industry persons engaged in developing products, so as to address applicable issues in product development. For this a chemistry laboratory will be a part of the centre.

It will be objective of the centre to promote small scale enterprises in this area too.

8. Flexible Electronic Systems: The Scientific Programme

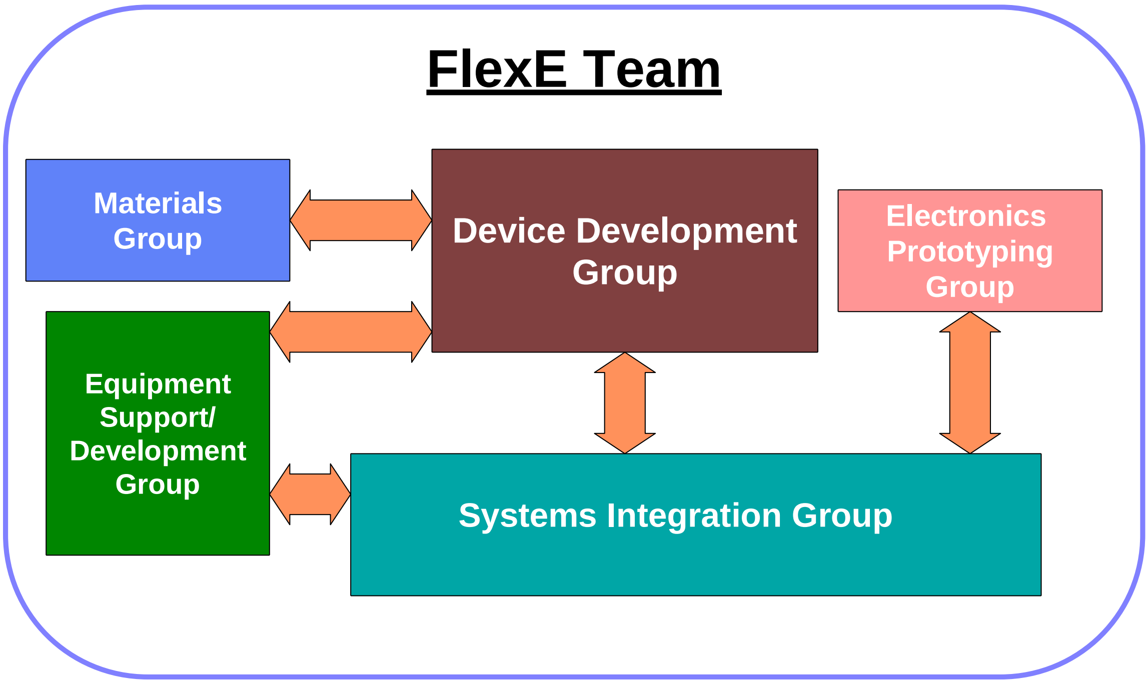
The goal of the centre is to produce flexible electronic systems, a generic block diagram of which is shown below.



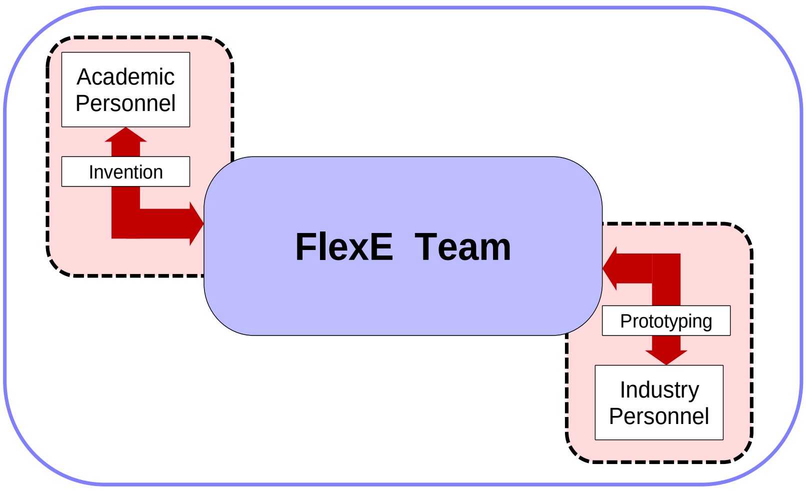
As an example, integration of TFTs with polymer actuators can be used to produce sheet type active-matrix Braille displays (see section *Flexible Electronics: The Way Forward*) or a TFT-temperature sensor array could be used to obtain a thermal map that can help in breast cancer detection. To increase the scope of interaction with a wider cross-section of industry, it is essential for the centre to develop a critical set of elements belonging to several or all the major blocks shown in the diagram above. The team at IIT Kanpur is at present engaged in development of sensors, photovoltaic (PV) cells, transistors, diodes, passive components such as resistors, capacitors and light emitting diodes. Most of the research and development work is at present on glass substrate. This existing expertise will be leveraged to develop components on flexible substrates.

To build a complete system on plastic, paper, textile or metal foils using low cost printing techniques, facilities for processing and characterization will have to be established. These include different types of printers such as screen, inkjet and gravure. In addition, when a process has reached maturity, a complete roll-to-roll process will have to be established where substrate in the form of a long sheet and wound on a roll is used. After a series of processing steps, the substrate is rewound on another roll. Characterization tools for each stage of processing ranging from instruments for measurement of roughness and porosity of paper, measurement of ink viscosity, microscopes (optical, electron etc) for examining film morphology and electrical and optical instruments for device characterization will have to be established. For efficient and proper use, these facilities need to be organized in close proximity of each other. It is envisaged that a new state-of-the-art flexible electronics laboratory will be setup to enable the vision of the centre.

In order to accelerate the process of trial-and error essential to the invention process, transforming promising ideas into proof-of-concept devices or fabrication of industrial-strength prototypes in collaboration with industry, it is envisaged that a dedicated team of researchers and engineers (FlexE Team) would undertake development of state-of-the-art technology of several critical components of FlexE system. A simplified conceptual figure of the FlexE Team for realizing these objectives is shown below.



The team includes a device group dedicated to development of critical components of FlexE systems. This is the largest group whose responsibilities include design/simulation, fabrication and characterization. The group would work with a materials group and will be assisted by the equipment support/development group. The systems integration group would have the responsibility of development of prototype systems involving integration of several device components. The group would work closely with partners from industries. A separate electronics prototype group would provide support to the integration group for interfacing of FlexE prototype systems with the external world.



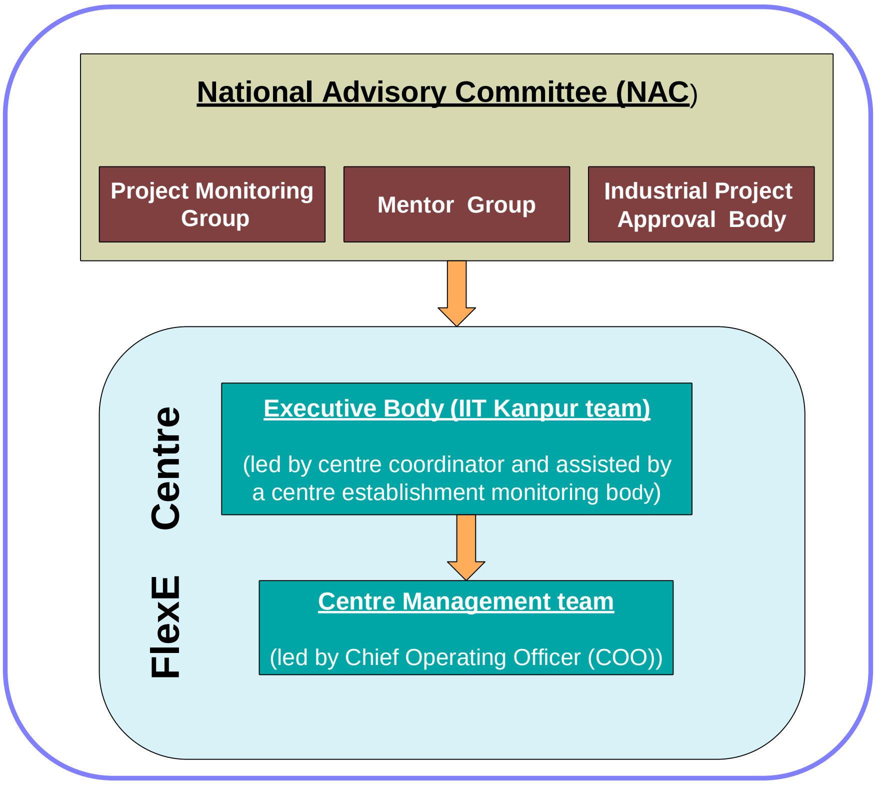
It is envisaged that although overlaps will exist with IIT Kanpur core team, the FlexE Team would be an entity that works closely with faculty and students from institutions from across the country, shown as Academic Personnel in the diagram on the left and also the industry to convert the ideas into products.

The Ph.D. and M.Tech. thesis work will be the engine for generation of new ideas. The FlexE Team will not only provide help in this process but also ensure that knowledge generated is not lost with the graduation of the student, rather the knowledge is incorporated in the technological products. The FlexE Team will also suggest topics where research and innovation is required and these problems will be addressed in thesis work. This will help to ensure that technology offered by the centre is unique and based on a portfolio of intellectual property developed in-house. As indicated in the figure above, the FlexE Team will work closely with personnel from industry, some of whom would be an integral part of it. The goal here will be harness the knowledge base of the centre to develop industrial-strength prototypes.

A major challenge in the whole endeavour is to recruit and retain high quality manpower so that the centre becomes an incubation centre for domestic industry in FlexE applications.

9. Organisational Structure and Processes

The organisational structure of the FlexE Centre is shown in the figure below. Each group, its constitution and functions are then described.



National Advisory Committee (NAC)

The centre will be guided by the *National Advisory Committee* (NAC), envisaged to be a high-powered body consisting of reputed individuals capable of giving technology directions to the FlexE Centre. The Director, IIT Kanpur will be its chairperson and other members will be representatives from DeitY, participating industries and the heads of R&D units of various government bodies and public sector undertakings.

This body will guide the Centre, annually review its performance, and be responsible for any policy direction of the centre. An important role of the NAC will also be to approve specific proposals to form partnerships with industry and academia.

NAC (constituted in consultation with DeitY)
- Guides the Centre
- Gives technology directions
- Makes policies for the Centre
- Approves collaborations with academia and industry
- Reviews the Centre performance

The NAC will also organize periodic reviews of the proposed centre by a team comprising of experts drawn from across the world, as is also the practice in the international centres of repute in flexible electronics.

In addition, to expedite decision making, the NAC would perform its functions through the following smaller sub-groups: *Mentor Group* – 4 to 5 member scientific/technical group, *Projects Monitoring Group* – a subset of the NAC and *Industrial Projects Approval Body* – a group formed in consultation with DeitY for approving industrial projects. Each is described further.

Mentor Group

This will be a group of 4-5 eminent members, drawn both from academia and industry. The constitution of this group may be done on the advice of the Executive Body. Although, the chair of the mentor group will be an NAC member, the body may have members outside of NAC as well. The role of the Mentor Group will be to advise the Executive Body on its strategic direction and help in developing a national and international network both in academia and industry.

Mentor Group
- Advise Executive Body and NAC
- Help develop national and international networks

Projects Monitoring Group

Although, the overall performance of the centre will be reviewed by NAC annually, a detailed project by project review is also necessary. It is envisaged that a smaller sub-group of NAC will conduct these detailed reviews and provide feedback to NAC. It is important for the success of the centre that it should be nimble enough in its approach so that as new developments take place, new academic partners join in or specific partnerships with industry are approved, appropriate timely changes in approach can be made. For example, changes may be required in altering the specifications of the equipment as new or higher priority needs are discovered. These changes proposed by the Executive Body may be approved by Projects Monitoring Group which will have the authority to take decisions as long as they are within the approved budget.

Projects Monitoring Group
- Conduct detailed project reviews
- Approve changes to the proposal within approved budget

Industry Projects Approval Body

An important feature of activities of the centre is to engage the industry in a meaningful way that leads to manufacturing in the country. It is envisaged that at the time of approval of the proposed centre, a few participating industries will be identified and an expression of interest will be sought from them. We propose that a fraction of the total project funds be reserved (as *Prototype Development Fund*) to finance these proposals. The processes used to sanction these joint proposals will be kept the same as that followed by DeitY. Thus, an *Industry Projects Approval Body* will be established. This body will be responsible for sanction of the projects against the *Prototype Development Fund*. A subset of NAC, the *Projects Monitoring Group*, as mentioned before, will perform the project monitoring function. The financial audit at the time of sanction of the project will be performed by *Audit Department* of IIT Kanpur.

Industry Projects Approval Body

- Evaluates and approves joint projects proposals from industry
- Manages *Prototype Development Funds*

This proposed mechanism is expected to ensure speedy approval of projects, with same due diligence as practiced in DeitY. Further, by reserving a fund for projects leading to product development, we may be able to leverage it for obtaining *matching grants* from elsewhere.

Executive Body

The responsibility of project execution and management of the centre will lie with IIT Kanpur through the team of faculty members at the Samtel Centre for Display Technologies, IIT Kanpur. The Chief Operating Officer (COO) of the centre will be a part of this core team. The coordinator of the Samtel Centre for Display Technologies, IIT Kanpur, appointed by the Director of the institute, will be the ex-officio coordinator of the FlexE Centre. The COO and other staff of the Centre will report to the Coordinator.

The role of this body will be to execute mandates of the centre as approved by the *NAC*, which includes the following:

- establish the centre
- make policies for day to day functioning of the centre and be responsible to execute them
- hire project manpower for the centre, as per prior approval, through IIT Kanpur processes
- execute the scientific programme of the centre, as per the approved projects

Executive Body (the Team at IIT Kanpur)

- Executes the functions of the centre
- Prepares policies for engagement with academic and industry ecosystem
- Responsible for the scientific programme at the centre
- Identifies industry partners and executes projects with them
- Coordinate development of roadmap for flexible electronics

- prepare policy documents for engagement with academic ecosystem
- prepare policy documents for engagement with Industrial ecosystem
- identify industry partners and execute projects with them, with the intent for manufacturing in future
- Coordinate development of roadmap for flexible electronics

Centre Establishment Monitoring Body

This is a subset of the Executive Team having 2-3 persons. This structure is created only for the first phase when substantial infrastructure development will be required. The role of this sub-group will be to vigorously drive the time-lines for the establishment of the centre.

Processes

Engagement within Academic Ecosystem

The *Executive Body* will identify international collaborators and establish MOUs with them, after approval from the NAC. The object of this collaboration will be to accelerate project execution and sharpen project objectives by identifying partners with complementary strengths. The mechanism of interaction will include joint workshops and exchange of research students.

A similar arrangement will be sought with partners within the country. However, the centre will also provide *Research Support* to individuals in the country for a limited period. The decision making for this activity will remain with the *Executive Body*.

Engagement with Industry Ecosystem

The interaction with the industry will also be through MOUs.

To deepen the engagement with the industry, the MOUs will provide for deployment of their manpower at the centre for execution of specific projects and also for joint activities in the centre. Their status in IIT Kanpur will be the same as that of project staff that works in the IIT. This will allow access to the institute's central facilities

An important feature will be encouragement to participating employees of the industry to obtain post graduate degrees with the research performed at the centre, provided the candidates fulfill the admission criteria and the other graduating requirements.

Levels of Engagements with Industry

Specific means for engagement with the industry will be evolved by the NAC. At this point we are making one such suggestion which is given below.

Centre ***Partners*** will pay a fee determined by the *NAC* for establishing a partnership with the centre. The *Partner* will be able to jointly write projects with IIT Kanpur team members and apply for funding. Part of the financial requirement, will be contributed by the industry. The Partners will be able to post personnel at IIT Kanpur and jointly share IP developed in relation to the project executed with them.

Observer status will be granted by the NAC by paying a predetermined fee, lower than that for a partner, under a MOU. The *Observers* will be able to place their personnel at IIT Kanpur to work on the ongoing works at the centre. However, the *Observers* will not be able to submit their project proposals to access Prototype Development Fund. The *Observers* will have no claim to IP.

Work Packages will be developed jointly by industry and the team at IIT Kanpur. These will typically be short term projects, fully funded by the industry. The IP will be jointly owned.

Role of MOUs

All engagements with bodies outside IIT Kanpur, except with respect to IP protection and work packages will be through a MOU with IIT Kanpur. IP protection will be governed with separate agreement and work packages will be executed within the framework already in practice at IIT Kanpur.

IP Protection

Prior to partnership with academic or industry partners, the centre through IIT Kanpur will enter in an IP protection agreement.

10. The Programme of Activities

The team at IIT Kanpur submitted to DeitY (GOI) a concept paper for initiating activities in flexible electronics, with due justification also given in this document. Following that, a workshop to consider the concept paper was organized on 15 March, 2013. The recommendations of the workshop are attached as **Annexure I.** The proposal below has been prepared taking these recommendations into account**.**

10.1 Research and Development

This section briefly describes different works that would be carried out at the proposed centre. The work will be broadly divided into two parts, namely "research" and "development" with the FlexE Team in the middle enabling research on one end and working towards component and prototype development on the other.

In the following, we provide activities which are envisaged at the start. However, we emphasize that the list provided is an indicator; the activities would be added and some directions changed as new knowledge becomes available and industry and academic partners come on board. The process of managing this change has already been elaborated in the section on "Organizational Structure and Processes".

10.1.1 Research

Active research would be a key part of the centre where the core team will establish a research programme to further the frontiers in flexible electronics and also research activities that would lead to development of a component library. Basic engineering oriented research would be carried out at the centre by post graduate students leading to Ph.D. and M. Tech. degrees in accordance with the vision of the centre. Though the outlook of the research would be futuristic, the FlexE Team would also suggest relevant research topics essential for the development of components and prototypes. The research programme at the centre would seek strategic collaboration with academic partners nationally and internationally to augment existing research activities. Some of the research activities that would start in the centre at its inception are enclosed as **Annexure IIA**. Details of initial collaborations for research with Indian and foreign academic institutes and national laboratories are enclosed as **Annexure IIB.** Increased collaborations would be the the outcome of roadmap development workshops organised periodically. Annexures IIA and IIB only give a glimpse of the kind of research activities that would start at this centre. These would evolve with the centre, keeping the needs of industry in focus.

10.1.2 Development

Development of a component library with specifications tuned to product industry will be the key task of the FlexE Team. This activity will be mentored by the core team with various research inputs feeding into continuing development of the component library. The specifications of the components will be decided in consultations with industry partners and will be upgraded periodically. Development programme for some of the key enabling components is enclosed as **Annexure IIC**. The specifications for components listed in Annexure IIC are the initial targets that the FlexE Team strive to achieve. The target specifications will be revised in light of the requirements of prototypes to be developed in collaboration with industry partners. Besides component development, the FlexE Team will also engage in prototype development with industry. The industry partners will be eligible to write joint proposal for prototype development. These proposals will be reviewed and approved by the "Industry Projects Approval Body" and, upon approval, these joint projects will be able to utilize funds from "Prototype Development Funds" kept aside for this specific purpose under PPP (Public-Private Partnership) model. The core team has been in discussions with several industry partners and some of the application areas in which first prototype development activity will start are outlined in **Annexure IID**.

Apart from enabling "Research" and "Development" activities as outlined above, the centre would also engage in outreach activities. The key deliverables of the centre are enumerated below. (*Note: The deliverables of individual research and development activities are provided separately*)

10.2 Deliverables

1. Establish the infrastructure of the centre.
   (A major activity in the initial years would be to develop the space for the centre, develop arrangements for accommodation of participants and populate high-tech equipment in the centre.)

2. Establish a research programme to engage in leading edge research in the area of flexible electronics and build strategic academic collaborations.

3. Establish a research programme which leads to development of a critical set of components suitable for rapid development of products.
   (The proposed strategy is to build core competence in developing essential components for a variety of applications, as elaborated in section "Flexible Electronic (FlexE) Systems: The Scientific Programme." Accordingly, the centre will identify the device components, prepare their specifications and develop them in participation with academic and research collaborators nationally and internationally. An effort would also be made to involve the wider research community in this process.)

4. Develop prototypes in collaboration with industry for commercialization.
   (As part of the recommendation of the workshop held to discuss the concept paper, it was decided that the products that are to be developed at the centre should be decided with the participating industry. As a strategy, we will select one that is relatively easier to achieve and hence can be commercialized by the appropriate industrial partner in a shorter period, and the other more challenging and thus likely to take longer to commercialize.)

5. Coordinate development of national technology roadmap every three years for flexible electronics.
   (Workshops will be held together with persons in research and manufacturing for this purpose; a national roadmap will be an outcome, relevant portions of which will be followed by the centre. This activity will be a means of expanding national and international academic.)

6. Establish standards for electronic products in the field of large area electronics.
   (The centre will participate in strategic alliances globally, where these standards are established.)

7. Coordinate outreach activities that lead to growth of R & D in flexible electronics by conducting at least **one workshop** and a short course every year.

8. Create at least **one spin-off commercial venture** based on work done at the centre.

9. Generate human resource.
   (Apart from graduating students with advanced degrees, the centre will also work with industry participants to impart and upgrade relevant skills periodically. In the duration of the project, we will produce at least ***10 Ph.D.s and 20 M. Tech.s****)*

The next section discusses the budget, timelines and milestones.

11. Budget

11.1 Budget

The budget is written in two parts. The first part represents ***establishment of the centre infrastructure*** in which the participating industry partners would contribute through manpower. The second part of the budget represents ***specific projects with industry*** to be operated in Public Private Partnership (PPP) mode.

DeitY Contribution (85% of the total below; 15% to be provided by IIT Kanpur)

		In Lakhs of Rs.					
A)	**Establishment of the Center**	**Total**	**Y1**	**Y2**	**Y3**	**Y4**	**Y5**
	Constructed Infrastructure						
	Laboratory Space	1606.25	661.33	944.92	0.00	0.00	0.00
	Accomodation for long term partners	580.99	290.50	290.49	0.00	0.00	0.00
	Capital Equipment	4200.00	2100.00	2100.00	0.00	0.00	0.00
	Consumable Stores	2765.00	203.00	416.00	591.00	734.00	821.00
	Manpower	1347.14	188.77	263.88	281.09	299.39	314.01
	Training and Travel	200.00	32.60	46.60	33.60	39.10	48.10
	Contingencies	100.00	20	20	20	20	20
	Overheads	500.00	100	100	100	100	100
	A) Sub-total	**11299.38**	3596.20	4181.89	1025.69	1192.49	1303.11
B)	**PPP Mode Industry Projects**						
	Prototype Development Fund	2000.00	100	200	800	600	300
	B) Sub-total	**2000.00**	100.00	200.00	800.00	600.00	300.00
	Grand Total (A+B)	**13299**	**3696**	**4382**	**1826**	**1792**	**1603**

11.1.1 Industry Contribution

Right from the beginning, partnering industries will demonstrate their commitment to the centre by providing manpower on their payroll for the FlexE Team located at the centre.

In 6-12 months from the start, as also indicated in the time line (next section), specific project proposals will be prepared with the partner industries. In this, industry will share project costs in PPP mode, also utilizing the *prototype development fund* established in the centre by DeitY funds.

In addition, industry participants will pay a partnership fee to the centre. Those industries which participate from the start will pay a lower partnership fee, to be decided by NAC.

11.1.2 IIT Kanpur Contribution

IIT Kanpur will contribute up to 15% of the total project cost towards constructed infrastructure and manpower. Further, IIT Kanpur will provide support by way of (a) faculty time, (b) use of its high-tech central laboratories, (c) workshop facilities and other infrastructures, (d) utilities for the laboratories, (e) maintenance support of the civil infrastructure and, (f) other support functions in form of project administration, purchases etc.

12. Potential Benefits to the Nation

With the successful establishment and functioning of this FlexE Centre, the nation should derive various technological, scientific and strategic benefits that will also result in wide-spread socio-economic benefits. The technological benefits will be in the form of expansion of domestic manufacturing industry and ecosystem. These should not just lower the cost of products and make them widely available, but will potentially benefit the rural and low income sectors of India by providing opportunities for manpower and skill development and job creation. In the following paragraphs, some of the key benefits are discussed.

1) Establish a nodal point for flexible electronics and create an ecosystem:

Flexible electronics is potentially going to change the way devices for various consumer applications are perceived. However, establishing a lab to develop such devices requires substantial financial support and infrastructure. Hence, there is a strong need to develop a state-of-the-art laboratory at one strategic location which can serve as a nodal point for brining India at par with the best in the world in this domain. Establishment of such a centre at IIT Kanpur will allow smooth transition and conversion of ideas developed in localized laboratories to actual devices and final product prototypes. The tangible benefits would be:

- the centre would provide a platform to both academic world and industries to test their ideas at the prototype level.
- the Indian industry does not need to individually establish such a laboratory; that means the centre serves as shared space for the Indian industry.
- the infrastructure would allow the creation of a knowledge platform that would attract international participation for contract R&D.
- the centre would play a pivotal role in bringing together various industrial players related to materials, equipments and devices thereby creating a much needed industrial ecosystem for large area flexible electronics in India.

2) Place India on the world roadmap of flexible electronics:

Historically India has not been able to establish itself as a leading player in technological product development. A timely setting-up of such a centre would help establish India as a significant player in the emerging field of flexible electronics. This would be important both from strategic as well as commercial point of view allowing significant savings in foreign exchange, as technology would not need to be imported to establish a product line.

3) Device development and commercialisation:

- One of the core aims of the centre is to develop devices that find use in practical systems. The partnership model of academia and industry would help building proof of concept devices and more importantly these flexible electronic devices are expected to find application in commercially viable products. These devices would be as per the requirements of products that are in tune with **India's need** and do not have to be a sub-optimal adoption or modification of device technology developed outside India.

- It is planned that the FlexE Centre will spin-off at least one company which would have the capability to commercially develop and manufacture devices based on flexible electronics that cater to the needs within India.

4) IP creation:

The focus of effort on the up-coming large area flexible electronic technology should help in the generation of core IP in the area. This is bound to have a wide range of benefits including followings:

- *savings in foreign exchange and revenue*, as many of these IP could be used as a cross-licensing tool with foreign companies/institutes to obtain permission to use other patents which might also be essential for the commercial manufacture of the final product.
- *revenue generation*, as the IP generated at the centre can be potentially licensed to both foreign as well as Indian companies (which won't have to look outside India for these licenses) working on this technology which can earn significant foreign exchange and revenue for India.

5) Strategic product development:

Product development in this centre does need not be limited to commercial activities alone, but may also be for strategic and social responsibility purposes. Very often, foreign sources of know-how or products are not reliable or even viable. Some examples are given below.

- *Defence applications* – special chemical sensors, light weight PV panels, etc.
- *Space applications* - thin film solar cells for space vehicles, radiation hardened electronics, etc. as many a times these technologies are not commercially available and labs outside India may not transfer it to our forces for strategic/security reasons.
- *Rural applications* – medical products for rural India that may not be sufficiently commercially viable for foreign entities to take up research and development.

6) Human resource and skill development

One of the major issues which the manufacturing industries, specifically the high-tech industries face in India, is the availability of trained manpower which can be productively employed right away without significant costs associated with training them. The FlexE Centre should alleviate this problem for the large area flexible electronic industry by:

- generation of human resource as Ph.D.s and M.Tech.s from IIT Kanpur and other partner academic institutions
- organisation of regular workshops and seminars on industry and academic related topics
- organisation specific workshops to address industry specific issues
- joint programmes with industry where personnel get trained being part of the process.

7) Driving the technology as per India's needs

- The FlexE Centre will help establish country specific standards for electronic products in the field of large area flexible electronics.
- The FlexE Centre will coordinate the definition of national technology roadmap every three years for flexible electronics with other stake holders. This will allow all the stake holders including the government agencies and the associated industries to direct their effort in a coherent and mutually beneficial manner. This is required for the country to be able to take a leading global role in large area and flexible electronics technology.

13. Biographical Sketch of IITK Team

Anshu Gaur
Assistant Professor, Materials Science and Engineering

Experience
Ph.D., Materials Science, University of Illinois at Urbana-Champaign, USA, 2008
Applied Materials Inc., USA

Research Interest
Electronic and opto-electronic materials, thin films, device physics, carbon based nanostructures

Ashish Garg
Associate Professor, Materials Science and Engineering

Experience
Ph.D., Materials Science, University of Cambridge, 2001
Infineon Technologies, IIT Kanpur

Research Interest
Printable Electronics, Organic Solar Cells and Multifunctional Materials

Ashish Gupta

Research Engineer, Samtel Centre

Ph.D.(Chemistry) University of Allahabad, India

Research Interest: *Conjugated Polymers & Nanomaterial Synthesis*

Baquer Mazhari
Professor, Electrical Engineering

Experience
Ph.D., Electrical Engineering, U. Illinois, Urbana-Champaign, 1993

Research Interest
Organic Semiconductors, Semiconductor device modelling and analog circuits

Deepak Gupta
Professor, Materials Science and Engineering

Experience
Ph.D., Materials Science and Engineering, UC Berkeley, 1993
Argonne National Laboratory,
Motorola,
Samtel Colour Ltd.
IIT Kanpur

Research Interest
Organic Semiconductors, Displays, Electronic and Optical Materials

S. Sundar Kumar Iyer
Professor, Electrical Engineering

Experience
Ph.D., Electrical Engineering, UC Berkeley, 1998
IBM Microelectronics (NY), IIT Kanpur

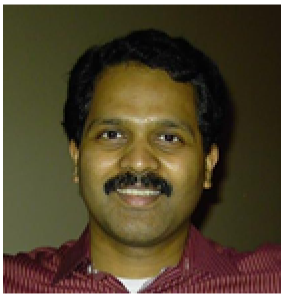
Research Interest
Organic solar cells, Photovoltaic systems, Printable electronics, VLSI technology, devices and circuits

Monica Katiyar
Professor, Materials Science and Engineering

Experience
Ph.D., Materials Science and Engineering, U. Illinois, Urbana-Champaign, 1994
Motorola, IIT Kanpur

Research Interest
Organic Electronics(OLED/OTFT),Printable Electronics
Thin Films, Material Characterization

Siddhartha Panda
Associate Professor, Chemical Engineering



Experience
Ph.D., Chemical Engineering, U. Houston, 1999
IBM Semiconductor R&D Center, IIT Kanpur

Research Interest
Chemical sensors, Lab-on-a-chip, Micro/nano fabrication, Microfluidics, Materials processing for microelectronic and display technologies

Y. N. Mohapatra
Professor, Physics and Materials Science Programme

Experience
Ph.D., IISc, 1988
IIT Kanpur

Research Interest
Semiconductors, electronic and photonic materials, OLED/PLED

Annexure List

Annexure I: Minutes of the workshop on "Centre of Excellence for Large Area Flexible Electronics" held at IIT Kanpur on March 15, 2013.

Annexure II: Programme of activities at the proposed centre

IIA: Research at the Centre

1. Development of carbon nanotubes and graphene based transparent electrodes for flexible electronics
2. Design and Fabrication of an Organic Diode-based Temperature Sensor Array
3. Disease diagnostics from body fluids
4. Sensors for detection of heavy metals in water
5. Breathalyzer for non-invasive disease diagnostics
6. Development of environmentally stable and efficient organic solar cells
7. Self-assembled micron and nano-structures using solution processed materials
8. Development of a Compact Model for Organic Thin Film Transistor
9. Design and Fabrication of a Photodiode Sensor Array
10. Inorganic and Organic (IO) Hybrids for Flexible Memory and Smart Label Display Applications
11. Synthesis and Formulation of Conductive Metal ink for Printed Electronics

IIB: Academic collaboration with academic/research labs in India and abroad

1. Flexible solid state Li- ion battery
2. Printable functional materials and devices
3. Lab-on-chip configuration for diabetic management
4. Collaboration on Printed Solar Cells on Paper
5. Organic, Hybrid and Polymeric Functional Materials for Flexible Electronics

IIC: Component development by FlexE Team at the Centre

1. Passive components for flexible electronics
2. Conducting polymer based temperature sensor array
3. Development of mini-modules of organic solar cells on substrates of sizes 150x150 mm^2
4. Development of Thin Film Transistors for Diverse Range of Applications
5. White Organic Light-Emitting Diodes
6. Printed Organic Solar Cells on Paper

IID: Industrial partnership and prototype development

Minutes of the Workshop to Discuss and Finalize Concept Paper for Establishment of "Centre of Excellence for Large Area Flexible Electronics"

held in IIT Kanpur on March 15, 2013

Chairman: Prof. Vikram Kumar, IIT Delhi, former Director of SSPL (DRDO), New Delhi, and NPL (CSIR), New Delhi

1. Prof. Baquer Mazhari, IIT Kanpur, introduced the meeting Chair, Prof. Vikram Kumar and requested him to conduct the Workshop.

2. Prof. Vikram Kumar welcomed the participants and invited the Director, IIT Kanpur, Prof. Indranil Manna, to address the audience. The Director welcomed the participants and emphasized the importance of the meeting. He conveyed the positive feedback of Dr. R. Chidambaram, PSA to the Government of India, on this initiative, who had met with the team from IIT Kanpur the previous day, and also the need for identifying 1-2 areas to develop prototypes leading to field deployment.

3. The Chairman highlighted the need to fill the gap between research and delivery of market products and pointed out the lack of success in converting research ideas into products. Commenting that the country had missed the bus of miniaturization, he emphasized the importance of not repeating the same mistake in the case of large area electronics. He paraphrased the message from the PSA who advised that the application areas have to be chosen carefully with pertinence to the demands of the Indian market. He also advised that mission oriented agencies, such as ISRO, DRDO, DAE, could be consulted for possible applications.

4. The Secretary, DeitY, Shri J. Satyanarayana addressed the participants next. The Secretary, DeitY, complimented the team of IIT Kanpur for bringing academia and industry together for this workshop. He recognized the importance of this area and stressed on the efforts to exploit this opportunity. Further, he said this was the appropriate time to venture into new era of electronics with increasing domestic demands. The challenges lay in the translation from research to commercialization, non-conventional fabrication processes and new materials. The Govt. of India was aware of growing needs to intervene and support manufacturing in electronics sector. He briefed about the new ESDM policy. While mentioning about the various schemes of the government under the new electronics manufacturing policy to support to industry, he also emphasized the role of the support from the industry. He thanked IIT Kanpur and wished the workshop success.

5. Prof. Ananth Dodabalapur of Univ. of Texas at Austin, provided an overview of the published research in organic electronics and showed that the published research and citations from different countries were correlated with strong government funding. He then provided an overview of the several successful flexible electronics centres,

such as ACREO (Norkoping, Sweden), Holst Centre (Eindhoven, Netherlands), Flexible Display Center, (Arizona, USA) and NASCENT (Austin, USA). Further, he mentioned that a report prepared under his chairmanship for the US government recommended establishment of NSF-NNIN type networks and the establishment of a SEMATECH type platform. He then discussed why flexible electronics represented a great opportunity for India. He ended the presentation highlighting the importance of establishing such centres and emphasized the importance of Academia-Industry interactions.

6. Mr. Raghu Das, CEO, IDTechEx, UK, presented on the needs, opportunities and the market for printable electronics. He presented the leading market drivers for printable electronics and some success stories such as e-readers, OLED Displays etc. He said that there was no "one-stop-shop" yet and one such was needed. He then presented market potential for various flexible electronics products of interest to industry.

7. Prof. Deepak Gupta, IIT Kanpur, presented the concept note, highlighting its salient features and inviting suggestions for improvements, potential of participation and collaboration of academia and industry.

8. This was followed by a discussion on the concept note. The main points are summarized
   - There was a support for the concept note from participants from both the academia and the industry. There is a clear need for academia and industry to get together in the area of flexible electronics. As the area is in its incipient stages, there is a great opportunity ahead.
   - Several participants expressed a need to have greater interactions between various academic and research institutions. Also emphasized was the need to have other academic institutes as a part of the FlexE team, giving the team a pan-India character. It was clarified that this aspect was built-in in the concept note and that the IIT Kanpur team will ensure its implementation. Also, there was a suggestion to have the representatives from the academic partners stationed at the centre, depending upon the objective of the projects.
   - Involvement of the industry from the beginning is important and that R&D programme of the Centre is informed by needs of the industry. The products need to be futuristic and market intelligence could help identify them. The centre should focus on product development and production technologies (process, equipment). Sufficient expertise should be integrated in the team.
   - It was suggested that critical size of the FlexE Team should be no less than 30 technical persons.
   - Representation of the industry in the FlexE team in the development of different components is important.

- It was suggested that the centre should also associate various Indian associations of electronics industry with it.
- The plan for the centre should have a long term vision beyond the current phase being immediately planned for.
- A more concrete and detailed proposal will be drawn after consultations with several industrial as well as academic partners within the next couple of months.
- All industry participants enthusiastically supported the idea of establishing such a centre in flexible electronics.

9. Recommendations from The Workshop

The initiative taken by IIT Kanpur and the concept note on the large area flexible electronics centre presented at this workshop was noted to be timely and the recommendations from the workshop are:

1. The core team should prepare a detailed proposal for establishing a centre, taking into account the needs of the industry and the views expressed in the workshop.
2. The process of preparing detailed proposal should include consultations with potential industrial partners and mission oriented government agencies.
3. Efforts should be made for wider participation of various academic and research institutions in and outside the country.
4. The centre could focus on one or two application sectors keeping in view the needs of the country.
5. The centre should have a long term vision and its scale should be appropriate to have impact on manufacturing in this emerging area.

10. The meeting ended with a vote of thanks to the Chair and all participants.

Prepared by:

B Mazhari

Prof. Baquer Mazhari, Dated: 1 · 4 · 2013
IIT Kanpur

Approved by:

Vikram Kumar

Prof. Vikram Kumar, 17/4/2013 Dated:
Workshop Chairman

WORKSHOP TO DISCUSS AND FINALIZE CONCEPT PAPER FOR ESTABLISHMENT OF "CENTER OF EXCELLENCE FOR LARGE AREA FLEXIBLE ELECTRONICS"

15 March 2013

Venue: IME Room 104, Time: 2:30 PM
Indian Institute of Technology, Kanpur

List of Participants

1. Prof. Vikram Kumar (Chairman), IIT Delhi, Ex. Director SSPL (DRDO) and NPL (CSIR), New Delhi
2. Prof. J. Vasi, IIT Bombay, Member SAC-PM
3. Prof. Ananth Dodabalapur, University of Texas, Austin (USA)
4. Dr. V. K. Aatre, IISc Bangalore & Ex. Scientific Advisor to Raksha Mantri
5. Prof. D. Chakravorty, IACS, Kolkata
6. Prof. Rajat Moona, DG, C-DAC, Pune
7. Dr. Shivananda Wagle, Sr. Manager R&D, Manipal Technologies Ltd., Mangalore
8. Mr. Sudheesh Rao, VP and R&D Head, Manipal Technologies Ltd., Mangalore
9. Dr. Rajeev Jindal, Head R&D-Lighting Business, Moser Baer India Ltd., Greater Noida
10. Dr. P. Ganesan, Tata Steels Europe, Netherlands
11. Dr. S. P. Singh, BHEL, Noida
12. Mr. Yogesh Adalatwale, ELCINA, New Delhi
13. Mr. Vikrant Chaudhari, SunEdison Energy, Bengaluru
14. Dr. Rajesh Manapat, Head R&D Operations India, SunEdison Energy, Begaluru
15. Mr. Rajiv Jain, Associate Director, Indian Semiconductor Association, New Delhi
16. Mr. A. Manwani, Chairman and MD, Sahasra Electronics Ltd., Noida
17. Dr. Abhey Kumar, GM R&D, Sahasra Electronics Ltd., Noida
18. Mr. Mohan Kakarla, Bilcare Research, Pune
19. Mr. Selva Kumar, Hind Hi-Vac, Bengaluru
20. Mr. P. Narendra Babu, GM, Hind Hi-Vac, Bengaluru
21. Mr. Prasanth, MD, Hind Hi-Vac, Bengaluru
22. Mr. K. G. Suresh, Sharp Software Development India, Bengaluru
23. Mr. Sudhakar Jayanty, Sharp Software Development India, Bengaluru
24. Mr. Shrikant Varku, Achira Labs, Bengaluru

25. Mr. SrinivasanKandaswamy, Achira Labs, Bengaluru
26. Dr. Ramnuj Narayan, Indian Institute of Chemical Technologies (IICT), Hyderabad
27. Prof. Viresh Dutta, IIT Delhi
28. Prof. Deepti Gupta, IIT Bombay
29. Prof. Navakanta Bhat, IISc, Bangalore
30. Mrs. Bindu Salim, PSG Institute of Advanced Studies, Coimbatore
31. Dr. P. Nath, Department of Physics, Tezpur University
32. Dr. Inamur Laskar, BITS, Pilani
33. Dr. Ketaki Bapat, Office of PSA, Govt. of India, New Delhi
34. Dr. Arun Agarwal, Terminal Ballistics Research Laboratory (DRDO), Chandigarh
35. Dr. B. Singh, CSIRO, Australia
36. Prof. Baquer Mazhari, SCDT, IIT Kanpur
37. Prof. S. S. K. Iyer, SCDT, IIT Kanpur
38. Prof. Deepak Gupta, SCDT, IIT Kanpur
39. Prof. Monica Katiyar, SCDT, IIT Kanpur
40. Prof. Y. N. Mohapatra, SCDT, IIT Kanpur
41. Prof. Ashish Garg, SCDT, IIT Kanpur
42. Prof. Siddhartha Panda, SCDT, IIT Kanpur
43. Prof. Ashish Gupta, SCDT, IIT Kanpur
44. Prof. Anshu Gaur, SCDT, IIT Kanpur
45. Dr. Narayanan Unni, SCDT, IIT Kanpur
46. Dr. J. Narain, SCDT, IIT Kanpur
47. Dr. Vandana Singh, SCDT, IIT Kanpur

Via Video Conferencing

1. Mr. J. Satyanarayana, Secretary DeitY
2. Mr. Mr. Raghu Das, CEO, IDTechEx, UK
3. Mr. M.Sesha Giri Rao, Addl. Director, DeitY