August 19, 2009

Proposal for Setting up an

ION BEAM CENTRE for Science and Futuristic Technologies (IBC- SFT)

In

Indian Institute of Technology, Kanpur

I. Background and Motivation

On the basis of the fast and concurrent developments occurring in the fields of Nano Science and Technology (NS&T) and Ion Beam Technologies (IBT), it would be worth predicting that, in this decade the ion beam based technologies would bring about the same type of revolution in the field of NS&T that was brought by ion implantation process in the semiconductor device fabrication industry in mid 70s, which has resulted in miniaturization of devices that we see today. These predictions have a sound physical basis enshrined in the non-equilibrium nature of ion matter interaction and several controllable parameters, which can be used to tailor configurations and structures not achievable by the equilibrium processes on scales ranging from macro to nano level. The need of the hour is to develop the proper ion beam tools and facilities so that our country would also become one of the leaders in bringing about the revolution in the field of nano science and technology with direct benefit to Indian industries in this field.

In the recent past evolution of integrated science with quantum effects surfacing in device engineering, leading towards merger of photonics with electronics, nano-electro-mechanical systems (NEMS), quantum computers, etc. indicates emergence of new horizons. However it may be borne in mind that there are several key issues and bottlenecks which are to be resolved before these and other futuristic technologies can take off. For example, doping in nano-volume, making truly 3D objects such as nano-size springs or cantilevers, making a fine oblique cut of nano dimension in a mechanical device etc., are some of the basic things which need technological solutions and methodologies. Energetic ion beams have provided a unique solution in the fabrication of the said structures which are not possible to make by conventional methods. Therefore it is becoming apparent that the energetic ions in general and focused ion beams in particular will have a critical role to play to address the key issues in various disciplines (Annexure I and II). This fact needs to be recognized and reflected in our planning of research facilities and our human resource development strategies. This becomes all the way more important, since efforts to find technological solutions to the things mentioned above are going on all over the world and also in our country. In IIT Kanpur, in particular, we are in a comparable situation as far as the expertise in the field of ion beams and the present state of the art of the subject is concerned. Therefore, it is necessary to formulate an appropriate plan to achieve the objectives and deliverables and take leadership in this area of ion beam based technologies in the world scenario.

Ion beam Centre will provide appropriate ion beam facilities for front line research and development, develop appropriate ion beam technologies and tools, manufacture prototype devices and systems, help nationwide users with state of art ion beam tools for analysis, develop and open possibilities of research in emerging new areas requiring multidisciplinary efforts. It will evolve effective participation from other institutions and would invite entrepreneurs and relevant industries.

Recently several laboratories across the world have started centers based on ion beams and accelerators to tackle issues in science and technology. Most prominent among these are i) Surrey Ion Beam Centre, UK, ii) Institute of Ion Beam Physics and Materials Research, Dresden, Germany, iii) Center for ION Beam Applications (CIBA) , NUS Singapore , iv) Ion Beam Centre for Quantum Computer Technology under Australian Research Council, and v) CHARPAN Project (Charged Particle Nanotech) under the co-ordination of IMS Nanofabrication Vienna, Austria. The proposed centre at IITK will operate along similar lines. One of the advantages for the proposed centre at IITK is that, several researchers across the different science and engineering departments would like to explore and utilize the ion beam technology in their research program.

II. Mission

Establish a Centre with state of the art systems providing ion beams for multidisciplinary research in exciting new areas in basic and applied sciences as well as engineering disciplines, developing prototypes of micro and nano devices using ion beams, and delivering methodologies to answer key issues in manufacturing at micro and nano-scale using ion beam based approach.

III. Methodologies

- Form a core group of faculty members in the Institute who require ion beam facilities for their research & connected development efforts.

- Create an interactive environment for interdisciplinary research and focus on application oriented programmes involving energetic ions, to deliver viable technological solutions and methodologies in the manufacturing of modern and futuristic macro, micro and nano devices and components for variety of applications.

- Attract young new faculty to the Institute who would take up challenging new problems in basic and applied sciences, augment existing facilities and create novel types of ion beams for futuristic technologies.

- Establish links with other research groups in India for active collaborative efforts in focused areas.

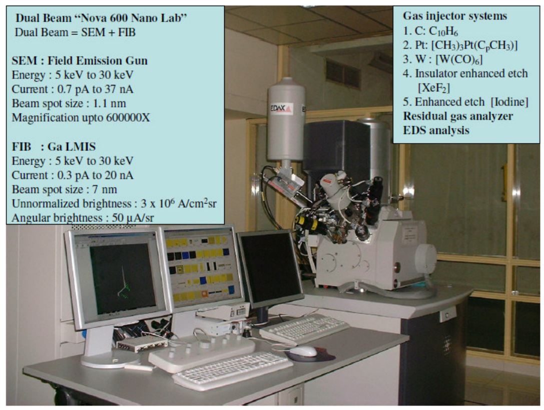
- Have synergy with National projects to develop required micro and nano-scale devices using ion beam technology for specialized applications.

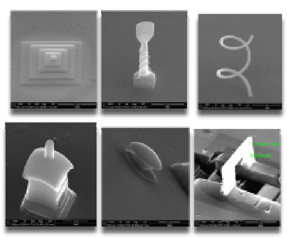
IV. Objectives and Deliverables:

- Enhance experimental knowledge of ion matter interaction for augmenting present technological applications.
- Develop new ion beam based technologies and applications.
- Fabrication of Prototypes of nano Sensors, photonic and electronic devices and MEMS and NEMS using focused keV and MeV ion beams.
- Fabrication of special sensors/components needed for space and energy research.
- Provide nano patterns for crucial scientific and technological studies to researchers in India.
- Extend state of the art ion beam analysis facilities to the researchers in India to enhance the understanding of the new materials and fabrication processes.
- Generate manpower who can handle modern and state of the art equipment and are trained to take up challenges to find technological solutions.
- Provide training to students and researchers in Universities/Institutes.

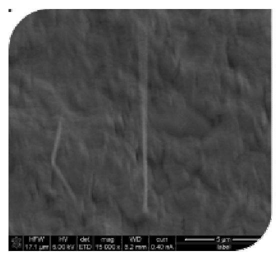
V. Present Status

A beginning was made by obtaining DST funding with partial support from IITK and commissioning a commercial Focused Ion Beam (FIB) facility which provides ~30 keV Ga ions focused to ~7 nm size. It is being used for multidisciplinary research by various departments (see under User Group below). The figure below is the facility installed at IITK along with some of the results obtained using the same.

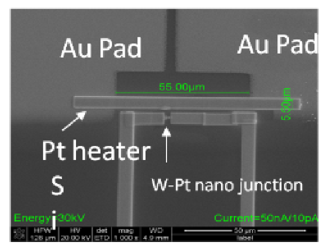




Variety of 3-D nano-structures fabricated by FIB

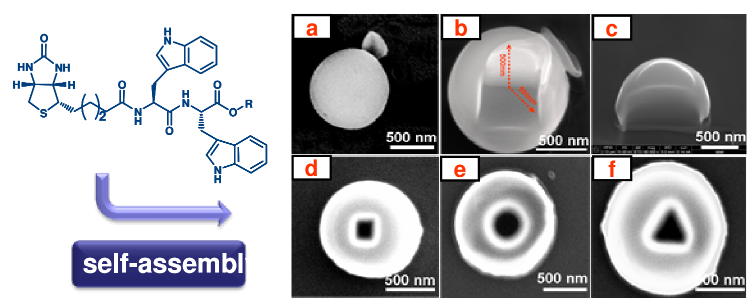


Vibrating nano pillar



FIB Fabricated nano-thermocouple

FIB Probing of Self-Assembled Structures



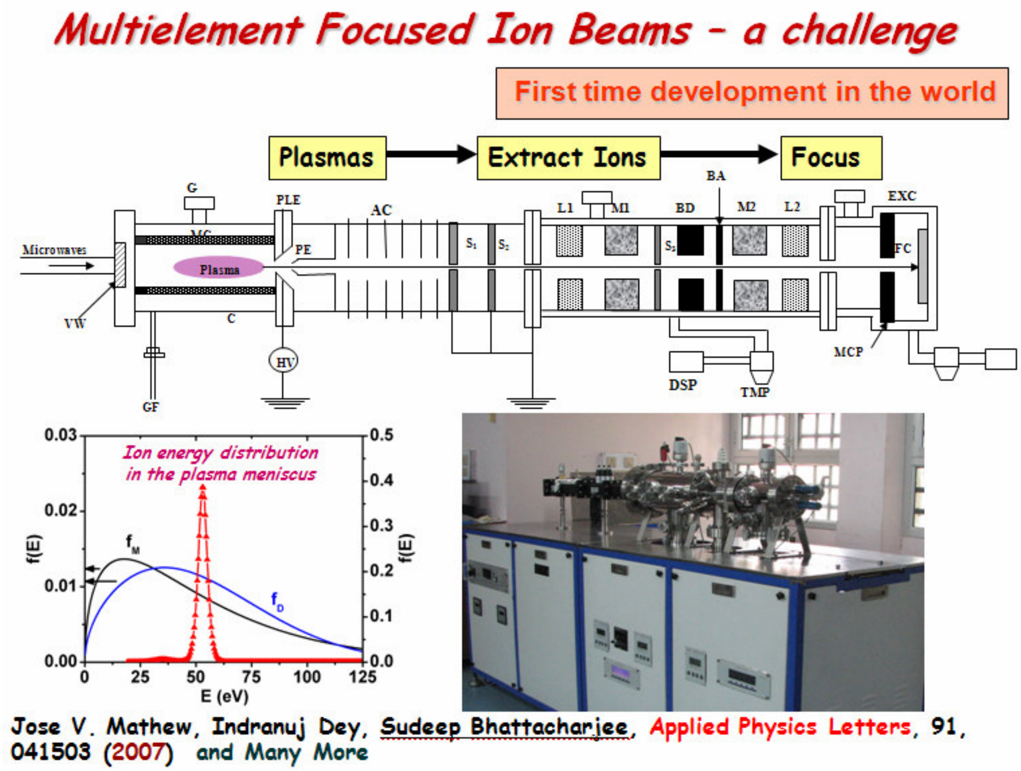
FIB milling of a vitamin-peptide conjugate:

- Scooping solid core of spherical structure
- Creating shapes on the soft structure

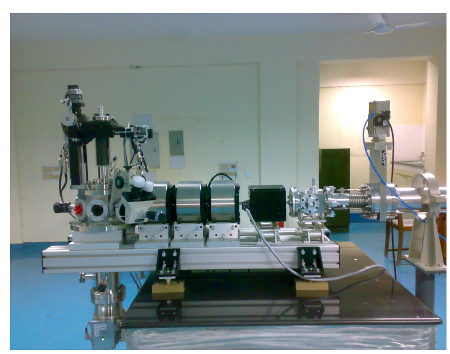
Joshi and Verma. *Angew. Chem. Int. Ed.* **2008**, 47, 2860-2863

A project funded by the Nano Science & Nanotechnology Initiative (NSTI) has been initiated to develop Multi-Element Focused Ion Beams (ME-FIB) by Dr. Sudeep Bhattacharjee, which will be a unique facility in the world. Also Dr. Sudeep Bhattacharjee has a project on the development of a

"Microwave Plasma based Negative Ion Source" and study of plasma dynamics through a transverse magnetic filter in the negative ion source funded under the National Fusion Programme.



A major project under IRPHA scheme of DST on "Ion Beam Facility for Micro and Nanoscale Science & Engineering" has been started in March 2006. A 1.7 Million Volt Tandem accelerator capable of producing variety of ions from H to Pb has been procured and installed under this project in September 2008. A nuclear microprobe for proton beam writing has also been installed in June 2009. The following figures show the installed facilities



1.7 Million Volt Tandem Accelerator with beam lines for ion beam analysis and microfabrication

VI. Plans

The Institute has two major ongoing initiatives as "Centre of Nanoscience" and a "Centre of Nanotechnology" and is nucleating a programme on "Futuristic Manufacturing". Thus the proposed "Ion Beam Centre" is going to provide excellent possibilities for cross-disciplinary work with novel output in emerging technologies where ion beams will play critical role. This statement is based on the fact that

Ion beams are the tools which provide ultimate control in terms of material removal and addition, doping, patterning, single ion implantation, spatial resolution and several such parameters which no other technique can provide till date.

Controllable parameters:

Energy	: eV to GeV (eV to 5 MeV generally used)
Ions	: all elements
Charge states	: 1+ to 92+, singly charged Negative Ions
Current Density	: few $\mu A/cm^2$ to few Amp/cm^2
Pulsing	: Continuous or Pulsed (50 Pico-sec.)
Size	: ~5 nm at low energy (keV), 100 nm in MeV range
Ambient	: UltraHigh Vacuum to Atmospheric Pressure (As per the need of experiments ranging from device fabrication to biological samples)

Considering the emerging scenario/possibilities in near future it has become essential that this research area must be explored from all possible angles and long range plans must be made to ensure that the various types of ion beam facilities are gradually developed and existing ones are efficiently and effectively used and constantly augmented. The continuous augmentation would ensure that all the state of the art ion beam facilities are available in the Institute for front ranking research & development in this area which will provide solutions to the key issues in modern and futuristic manufacturing, device technology, sensor technology, MEMS and NEMS. Further, the emerging basic science challenges in nanoscience associated surprises and their impact on technologies can also be explored.

Presently, efforts are being made to exploit the focused ion beams for the exciting research and development of unique nanostructures not possible to make without the use of focused ions. New possibilities are emerging with special beams such as Neutralized Ion Beams, Cluster Beams, and Ultra Low Energy Ion Beams etc.

Efforts are being made to attract young faculty to join and take up challenges to set up such state of the art facilities by obtaining project funding.

VII. Organizational Structure

Administrative: The Center will have a core faculty group and a team of research engineers and scientists. The core group will be directly involved in the development of various ion beam facilities along with other ancillary equipment and will be outreaching to the faculty/ researchers in the institute and outside for collaborative projects in addition to their own research using ion beams. In addition, there will be technical staff and supporting staff assisting the core group. All such staff of Center will be appointed as per the rules of the Institute/Dean R&D. The Center will have a Coordinator chosen from the core faculty members.The centre will administratively function under the Centre Co-ordinator, nominated by the Director.

Core group: 1. Dr. Vishwas N. Kulkarni, 2. Dr. Harish C Verma, 3. Dr. S. Bhattacharjee, 4. Dr. S Dhamodaran, 5. Dr. J. Ramkumar and 6. Dr. S. A. Ramakrishna.

Mentor: Prof. G K Mehta, Distinguished Visiting Honorary Professor, IITK.

User Group: The user group will consist of Faculty, Researchers, Post Doctoral fellows and Doctoral students who utilize the facility. The user group will meet once in a month to discuss the work done and will consider possibilities of evolving collaborative activity. A Convener, elected by the group, will be responsible to arrange the meetings, preparing the minutes and will act as a bridge between the core group members and the users.

Following is the list of the faculty members/researchers who are currently using the FIB system and/or have plans to use the Tandetron accelerator:

1.	Dr. Vishwas N. Kulkarni (Phy)	: Ion–Matter interaction, FIB Basic effects, Nano and Micro structure Fabrication, sensors, electrical and mechanical properties. Ion beam analysis.
2.	Dr. H.C. Verma (Phy)	: nano magnetic materials
3.	Dr. S. Bhattacharjee (Phy)	: Discharge phenomena at nano dimension, ME-FIB
4.	Dr. S. Dhamodaran (Phy)	: Opto-electronic materials and ion beam engineering
5.	Dr. Y.N. Mohapatra (Phy. & MSP)	: Organic molecules/films
6.	Dr. Ramesh Budhani (Phy)	: Oxide materials, superconductivity, magnetism
7.	Dr. A. Ramakrishna (Phy)	: Plasmonic structures
8.	Dr. Anjan K. Gupta (Phy)	: Micro SQUID, nano Pattern Generation
9.	Dr. Asima Pradhan (Phy & CELT)	: Biomaterials
10.	Dr. Satyajit Banerjee (Phy)	: Patterning of Superconducting structures
11.	Dr. V.K. Jain (ME)	: Micromachining and Fabrication
12.	Dr. J. Ram kumar (ME)	: Mechanical Devices and Sensors
13.	Dr. S. Bhattacharya (ME)	: Micro and Nano fluidics
14.	Mrs. Anjali Kulkarni (ME)	: Hybrid micro and nano systems, Automation
15.	Dr. Ashutosh Sharma (CHE)	: CNT growth
16.	Dr. K.K. Kar (ME and MSP)	: Nano structures for imaging
17.	Dr. Sandeep Verma (CHM)	: Soft peptide structures
18.	Dr. Jitendra Kumar (MSP)	: nano electrical components
19.	Dr. Ashish Garg (MME)	: Patterning
20.	Dr. Bikramjit Basu (MME)	: Deformation substructures

Institute Management Committee : A Committee, comprising of the Centre-Coordinator, Dean R&D, Two HODs of the of the departments whose faculty is in the core group, Convener of the User group, two faculty members nominated by the Director will be formed under the chairmanship of Director. This committee will monitor the progress and will address and advise over the issues related to the functioning of the Centre and its technical and financial problems or any other difficulties. The committee will meet once in three months to discuss the matters.

National Advisory Committee: A Committee, under the Chairmanship of Director, IIT Kanpur, with at least three external experts and two members from the User's Group will meet once in a year to review the activities and advise future possibilities.

VIII. Staff

On the basis of the experience of the people involved with the centre, the need of staff for maintenance and operation of the sophisticated facilities like FIB and Tandetron are must. It is proposed to have the following staff structure,

Scientific Officer/Research Engineer : 2
Technical Staff for support : 5 (Present strength 3, one person retiring in Feb 2010)
Operation and Maintenance Engineer : 1

Total Staff needed : 8

The centre will also require several post-doc fellows (with attractive fellowship/pay). I. Input through SURGE program for undergraduate research will also be targeted.

IX. Space

The facilities under the proposed center are hosted in the Central Nuclear Laboratory (Northern Laboratories) under the physics Department. The present building was planned for a small accelerator which is now decommissioned and a new accelerator (1.7 MV Tandetron), which is bigger in size is installed. Additional small annexure has been made for the Micro-Beam Facility. FIB facility has been commissioned in the old Data Acquisition Room. For the conduct of already running projects, such as development of Multi–Element FIB , some space in a corner has been made available. It is estimated that additional space of 5000 Sq.ft of area is required to run install and run the facilities effectively. A rough break up is- 2500 sq ft for ME-FIB and negative ion projects, 1000 each for nanophotonics and micromachining and about 500 sq ft for housing common equipment for sample preparation etc. The centre will urgently require a time bound plan for providing space for these and other activities which are growing at a fast pace.

We suggest having a modular laboratory structure adjacent to the Northern Laboratories which will connect to the present laboratory for hosting the different facilities mentioned. . This is shown in Annexure III.

X. Finances

In the year 2005 the Institute gave seed money to make it possible to install the first Focused Ion Beam facility of the Country in our campus. The facility was procured with this seed money and the money given by DST for the nanoscience project. Subsequently, Nano Science & Technology Initiative [NSTI] of DST sanctioned ~ 3 crores for the project for the development of a Multi Beam FIB. Such a facility at present does not exist any where in the world. A major project of establishing heavy ion accelerator with a provision to create Proton Micro-Beam has been funded under the DST scheme of "Intensification of Research in High Priority Areas [IRHPA] to the tune of ~ 15 Crores. So the total funding of about 23 Crores has been obtained by way of sponsored projects.

It is expected that the faculty will continue to get the project funding required, for augmenting the existing facilities and the new faculty inducted will get the funds required to establish new facilities. Considering the world wide attention towards ion beam based solutions in manufacturing of futuristic devices and components it is expected that the faculty associated with the center will garner significant funding by way of sponsored projects in the next 3-5 years.

Institutional support is needed to augment the infrastructure and auxiliary facilities needed to support the major research programs established. A yearly budget allocation from the institute under non-plan heads is needed. The amount should be sufficient to maintain and run the facilities installed and should have a provision for travel within the country. A budget will be required for a limited number of fellowships to the M.Tech/PhD students conducting their major part of thesis research in the centre.

The centre is expected to obtain a special grant under a possible MoU between IITK and DST with some unique feature which can help to make impact by finding technological solutions to the important issues in futuristic manufacturing.

XI. Outcome:

In addition to the research publications and PhD thesis the outcome will be in terms of development of ion beam technology and applications leading to patents, fabrication of unique micro- &

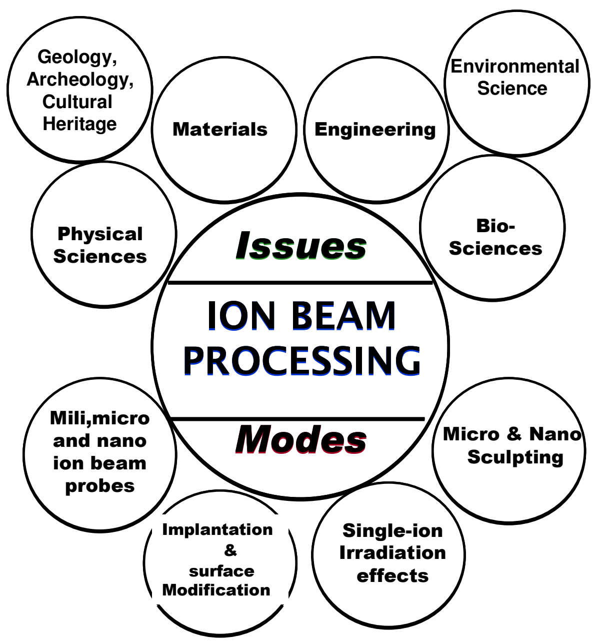
nano-scale components, sensors & devices for futuristic applications. Critical strengthening of interdisciplinary research & generation of high quality scientific manpower equipped with skills to tackle technological challenges.

Annexure I

Ion Beams for Multidisciplinary Research and Development

Control Parameters:

1. Ions : from A=1 to A=92)
2. Energy : eV to GeV (**Range normally used few keV-5 MeV**)
3. Current density: micro Amp/cm^2 to Amp/cm^2
4. Beam size : **few nm** to 20 mm dia



An overview showing disciplines where ion beams are used to study the science, engineering and technology issues and the modes of carrying out these studies.

ANNEXURE -II

Emerging Scenario in various areas with Ion Beams

1. Atomic and Ionic Collisions: Slow, highly charged ions have exotic properties. They are normally observed only in the outer atmospheres of stars, in interplanetary space or in energetic plasma fusion devices .They can now be studied in the laboratory.

2. Archaeological & Environmental Science: External Proton Micro beam provide excellent facility for Trace elemental finger printing of remains, artifacts and art materials .Ion Beam Analysis (IBA) techniques provide unique ways for monitoring environment.

3. Bioscience & Radiobiological Research: Elemental analysis of individual whole cultured cells using Particle Induced X-ray Emission (PIXE), and Rutherford Backscattering Spectrometry (RBS) yields quantitative results at ppm level. Sub-cellular structures can be analyzed with microbeams. Presently there are only two microbeam laboratories operational for radiobiological research; Gray Cancer Institute, North London and Columbia University, New York.

4. Engineering, Technology & Industry: In sixties ion accelerators were considered as the facilities for fundamental research in nuclear physics. In early seventies they became indispensable for electronics industry. Miniaturization drive is now coming to a position which will require focused ion beams for Nanoelectronics, Microelectromechanical systems (MEMS) in submicron scale encountering Casimir force are leading to challenges in design of mechanical parts. Ion beams are essential for studying the dynamical behavior and fabrication of systems.

Ion beams are now indispensable for prototyping all futuristic micro & nanoscale products.

5. Materials Science: Ion beam techniques provide unique capability for us to obtain atomic information related to surface/interface structures and nanomaterials, as well as to achieve novel functionality in materials through ion beam induced structural modifications.

Uniqueness of the role of ion beams in materials science emanates from the nonequiblrium nature of the ion matter interaction which can be used to tailor configurations and structures not achievable by the equilibrium processes.

6. Nuclear Physics: Fundamental nuclear physics studies have been gradually moving towards higher energies. Some recent measurements on low energy fusion reactions are leading to exciting challenges and interesting application oriented projects.

Annexure III

Location of Present Facilities showing additional construction needed to start with.