CHAPTER 4 ADVANCED TECHNOLOGIES & THEIR APPLICATIONS

CHAPTER 4.11 ADVANCED TECHNOLGIES

1. PLASMA BASED TECHNOLOGIES AND APPLICATIONS

a) **Plasma Sterilization of Medical devices, components and baby utensils:** Healthcare-associated infections are a major problem in hospitals. Conventional sterilization techniques like autoclaves, hydroclaves and ethylene oxide (EtO) have certain drawbacks while sterilizing heat sensitive devices like catheters, endoscopes, etc. A recently completed collaborative project between IPR and B.V. PERD Centre, Ahmedabad on "Development of Prototype Plasma System for Effective and Uniform Sterilization of Medical Devices, Components and Baby Utensils", funded by the Gujarat Govt., clearly shows the killing of 4 different bacterial strains (Staphylococcus aureus, Escherichia coli, Pseudomonas aeruginosa, Salmonella abony) commonly prevalent in Healthcare-associated infections. The pulsed dc plasma of Ozone and Oxygen effectively kills bacterial species in 1 hour. Hospital components and baby spoons were also successfully sterilized.

Figure 1a: Plasma Sterilization System developed at IPR

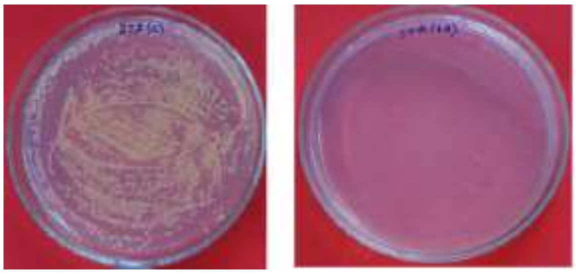

Figure 1b: Growth of *Staphylococcus aureus* (STA), in (a) Untreated (b) after plasma exposure

b) **Atmospheric plasma system for food grain processing:** Atmospheric pressure plasma technology (APP), involving the use of non-thermal plasmas, is an emerging technique for enhancing seed germination and better food preservation. Atmospheric pressure plasma generates reactive oxygen species and reactive nitrogen species which interact with seeds and etch the surface. Plasma treatment enhances soaking up of moisture, thus improving germination. Atmospheric pressure plasma treatment can also lead to inactivation of bacteria, bacterial spores, and fungi present on the surface of food grains. Such a plasma treatment system has been developed at IPR and commissioned at Anand Agricultural University for detailed study.

c) **Plasma system for In-line textile treatment:** Presently, in all textile industries, de-scouring (removal of wax from surface before printing) is performed using chemicals and water which can pollute the environment. An environment-friendly alternative, which does not use chemicals, is to use a uniform glow Dielectric Barrier Discharge (DBD) plasma. IPR has successfully developed such a system and tested it for 24x7 continuous operation in June 2018. The plasma is generated using air and no other gas is required. The DBD plasma was applied for treatment of various textile materials and significant functionality improvements have been found to occur within a few seconds of exposure. The system can accommodate a 2.5 m wide web and its guiding mechanism. This system, funded by DST, has been installed and commissioned at MANTRA, Surat.

Figure 2a: Plasma system for In-line textile treatment

Figure 2b: Uniform plasma discharge between the DBD rollers pairs

d) **Rotatable Magnetron:** A technically-challenging rotatable magnetron has been developed. It is the first of its kind in India for the sputter coating industry. As compared to the currently-used planar magnetron, where only 40-50% of the target material is utilized due to limited sputtering racetrack area, the rotatable magnetron permits utilization up to 80%. This is a major development for the coating industry using magnetron sputtering technology. The cost of this indigenously developed rotatable magnetron is ⅓ of an imported system.

Figure 3a:-Rotatable Magnetron Developed at IPR

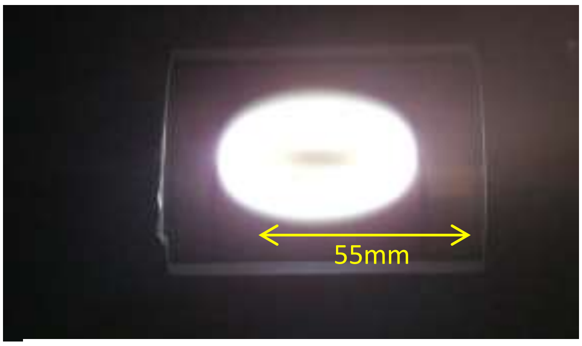

Figure 3b:-Image of rotatable magnetron while sputtering. Sputtering target (inside of rectangular boundary) is rotating while SS-shield (outside of rectangular boundary) is static.

e) **Denim fading using non-thermal air plasma jet:** A system has been developed which incorporates a computerized translation system to automatically make the design on denim using non-thermal air plasma jet as per the image selection.

Figure 4: Images of Denim Fading system

CHAPTER 5 BASIC RESEARCH

5.02 PHYSICS

a) **Laser driven nano-plasma: Does maximum laser absorption happen at resonance?** There is worldwide interest in laser-nanoplasma interactions at high intensities for developing compact multi-MeV ion accelerators. In laser-heated plasmas, maximum heating occurs when laser frequency matches the plasma frequency. However, recent Molecular Dynamics simulations at IPR have shown that in the presence of a nonlinear restoring force, maximum absorption occurs in an over-dense plasma regime where plasma frequency is marginally above (1-1.5 times) the laser frequency, this factor depending upon laser intensity. It is expected to have a large impact, not just for compact multi-MeV ion accelerators but also in the broader field of laser-heating of solid density plasmas.

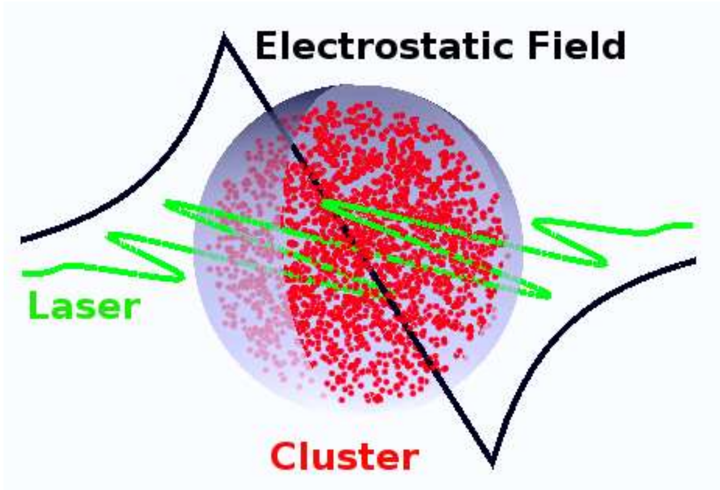

Figure 5: Laser impinging on a solid density spherical nano-plasma, e.g., argon cluster

b) **Atomistic simulations of turbulence in Yukawa liquids and its application to engines:** Fluid flow past an obstacle forms vortices in the downstream region - the higher the flow speed, the better is the turbulent mixing. This principle is used in internal combustion engines to improve mixing between fuel and air. Recent Molecular Dynamics simulations at IPR for highly charged fluid flow at ultra-low densities (Yukawa liquids) gave a surprising result that strong mixing can occur at extremely low speeds. This work is fundamental in nature and may also have applications in improving engines in automobiles as well as controlling impulse in plasma thrusters for space propulsion.

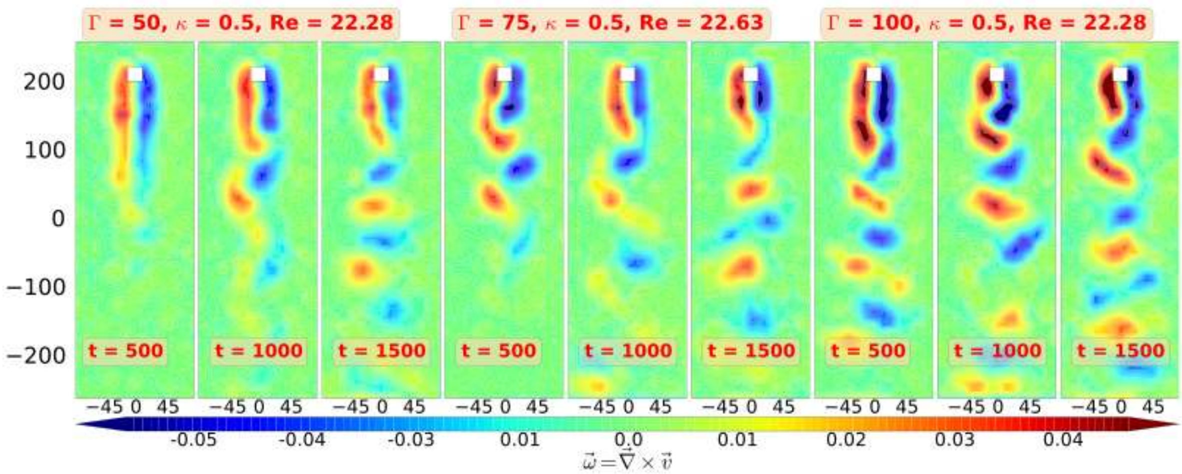

Figure 6 Atomistic simulations of turbulence in Yukawa liquids

c) **Development and Characterization of a Helicon Plasma Source:** The Helicon Plasma Source (HeliPS) designed and developed at CPP-IPR is a versatile helicon plasma device, which operates in a wide range of magnetic field configurations from 50 G to 500 G. This device is used for a broad range of research activities. The main objective for development of the HeliPS is to carry out studies on ion-ion plasmas in electronegative gases. In the near future, ion-ion plasmas will be formed in electronegative gases in the downstream of the plasma production region. Although the system is primarily designed to carry out ion-ion plasma experiments, the same system can also be used for experimental studies on some basic helicon plasma properties such as wave propagation, wave coupling, and plasma instability. At present, argon plasma is produced with a 13.56 MHz RF power supply. External circuit parameters, such as antenna current, plasma resistance (Rp), and internal parameters, such as electron density and temperature, are measured.

5.08 PLASMA FUSION & RELATED TECHNOLOGIES

a) **Aditya Tokamak Operation:** The discharge duration of confined plasma has been prolonged up to 330 ms (more than the design value of 250 ms) in ADITYA-U Tokamak for the first time. Using a novel gas-puffing technique, the peak plasma density has been raised to > 6 x 10^{19} m^{-3}, an all-time high for ADITYA-U tokamak, which led to a unique observation of rotation reversal of plasma, reported in very few tokamaks worldwide. The result signifies the achievement of maximum possible confinement time in this category of tokamaks known as *saturated Ohmic confinement*.

   (i) A plasma current of 175 kA has been achieved, higher than the value ever achieved in either Aditya or Aditya-U. This was done at a Toroidal field of 1.3 Tesla, 85% of the design value.
   (ii) For the first time, the horizontal plasma position in the ADITYA-U tokamak has been controlled in real time using a Fast Feedback Power Supply. The power supply, responding on fast timescales of ~1 millisecond, drives currents up to 1500 A in feedback coils newly installed in ADITYA-U. PID control has yielded good performance.
   (iii) In ECRH-assisted operation, successful start-up has been achieved at a loop voltage as low as 10 V, ~50% of the requirement without ECR.

b) **Steady-State Superconducting (SST-1) Tokamak Operation:** The Toroidal field coils, which had earlier been used to produce a maximum field of 1.5 Tesla (and 1.8 Tesla for short durations), have now produced 2.7 T at the plasma centre, corresponding to 90% of the design value. The toroidal magnetic field was raised in steps, and was kept above 2 T for more than 15 minutes. This is an important demonstration in terms of planned experiments in future campaigns, where long-pulse plasma operation above 2 T would be done with the assistance of Electron Cyclotron Resonance, Lower Hybrid and Ion Cyclotron Resonance systems. Helium Plasma experiments assisted by the ECR and LH have been performed. In addition, at the end of the experimental campaign, ICRH based wall conditioning experiments were successfully carried out at magnetic fields of 1.1T, 1.5T and 1.6T.

(i) PF3 coil power-supply up-gradation: Series connection of two half-wave three-phase rectifiers has been successfully demonstrated (uniform voltage sharing) on a 3A load and also at no-load full firing. This will allow higher PF coil voltages to drive time-varying currents in the PF3 coils, which is necessary for producing a shaped plasma

c) **Development of Ka-Band Reflectometer System for measuring Radial Electron Density Profile:** A Ka-Band Frequency Modulated Continuous Wave (FMCW) Reflectometer has been designed and developed to measure the electron density profile. The super heterodyne detection scheme in conjunction with quadrature down conversion is used for unambiguous phase determination. To overcome the deleterious effects of plasma density fluctuations, the implemented Reflectometry system is capable of ultra-fast sweep over the entire Ka-Band in 5μs and has high data acquisition rates of 200MSps.

d) **A Study on Neutron Emission from a Cylindrical Inertial Electrostatic Confinement Device:** CPP-IPR has successfully demonstrated some essential parameters required for the emission of 2.45 MeV DD fusion neutrons from a steady state portable linear neutron source based on inertial electrostatic confinement scheme. The parameters that control the production of neutrons are the working pressure of the fuel gas, applied voltage, measured current and cathode geometries. The neutrons emitted from the source are confirmed using neutron monitor, bubble dosimeters, nuclear track detectors, and He-3 proportional counter. Presently, the device produces neutrons $\sim 10^6$ n/sec at discharge voltages ranging from -60 kV to -80 kV, and discharge current of 20 mA to 30 mA.

e) **Solid-state RF generator coupled to ROBIN negative-ion source:** An indigenously developed (40 kW, 1 MHz) solid state RF generator has been integrated with an RF based negative ion source (“ROBIN”). Such a coupled system has been set up only for the second time in the world. The aim was to establish generator performance with respect to power coupling and plasma production in the source. Power ranging from 23-40 kW was successfully coupled to produce the desired plasma at pressures between 0.9 and 0.5 Pa.

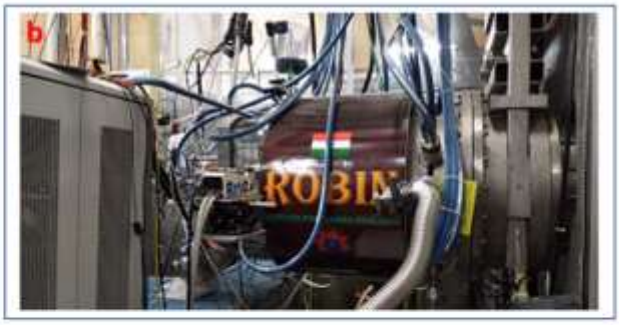

Figure 7: (a) 40 kW solid state RF generator (b) coupled to the negative ion RF ion source test bed (ROBIN)

f) **High Temperature Technologies**: Seven-layered W/Cu functionally graded material (FGM) (100 W, 80W-20Cu, 60W-40Cu, 50W-50Cu, 40W-60Cu, 20W-80Cu, 100Cu, by wt %) were fabricated by a spark plasma sintering process (SPS). The influences of sintering temperature on microstructure, physical and mechanical properties of the sintered bulk FGM were investigated. Results indicate that the graded structure of the composite densification after the SPS process and interfaces of the layers also are clearly visible. All of the layers have a very high relative density, thereby indicating their densification and excellent sintering behavior. SEM and EDX study of the bulk sample cross-section reveal that the graded structure can be retained up to sintering temperature of 1050 °C. In addition, fine microstructure within each layer with good interface bonding was also observed. Sample sintered at 1050 °C exhibited excellent mechanical and physical properties (hardness 239 ± 5 Hv and relative density of 90.5%). The result demonstrates that SPS is a promising and perhaps a more suitable process for fabrication of W-Cu functionally graded materials.

g) **Magnet Technology development**: Work is being continued in technological developments related with Nb3Sn and high temperature superconductors (HTS). A laboratory scale Nb3Sn solenoid coil which can produce magnetic field of ~1 T has been wound and heat treatment of the same is in progress. The high voltage compatible electrical insulation system has been developed and Paschen test has been carried out at low temperature. The laboratory scale high temperature superconductor (HTS) based D-shaped magnet fabricated and tested for its cooling characteristics up to 77 K, current charging and magnetic field measurement. The low resistance joints of ~5 nΩ have been developed and tested at 77 K for HTS magnet applications.

h) **Remote Handling and Robotics Technologies:** The major activities include a high vacuum and high temperature compatible inspection arm with supporting advanced technologies like haptic force feedback, dexterous hyper redundant end-effector and a fully immersive virtual reality facility.

(i) ***Development of Indigenous haptic force feedback arms for Tele-operation***: For the flexibility to execute dynamic tasks safely, the RH manipulators are typically controlled using a 'man in the loop' architecture. Haptic systems with real-time force feedback integrated to full 3D virtual reality environment can enable the RH operators to have the sense of virtual presence. A 6 axis master arm has been developed and successfully tested for position control.

i) **Fusion Blanket Technologies:** This caters to the indigenous development of blanket technologies required for a future fusion reactor as well as to the development of Test Blanket Module to be tested in the ITER project.

(i) ***Numerical and Experimental MHD Studies of Lead-Lithium Liquid Metal Flows in Multichannel Test-Section at High Magnetic Fields:*** Numerical simulation and experiments have been performed at high magnetic fields (1–3T) to study the MHD assisted molten Lead-Lithium (PbLi) flow in a model test-section which has typical features of multiple parallel channel flows as foreseen in various blanket module of ITER.

(ii) ***Corrosion Behavior of IN-RAFM Steel with Stagnant Lead-Lithium at 550°C up to 9000 h:*** Corrosion study of IN-RAFM (India specific reduced activation ferritic martensitic) steel with static lead-lithium, Pb-16Li has been carried out at 550 °C for different time durations, 2500, 5000 and 9000 h. Flat and tensile INRAFM samples were exposed to liquid metal. Exposed samples were analyzed for micro structural observation and chemical composition by scanning electron microscope equipped with EDX (energy dispersive X-ray spectrometer). Hardness reduction was observed up to a depth of ~15 μm after exposure to liquid metal. There was no significant reduction in the tensile strength. Dimpled ductile fracture was observed after exposure to liquid metal up to 9000 h.

(iii) ***Neutronic Design Optimization of ITER TBM Port#2 Bio-Shield Plug:*** In order to serve the requirement of TBM system, a Bio-Shield Plug (BSP) is placed at biological shielding location of the equatorial port. The neutronic design of BSP is important because it serves the purpose of biological shield boundary of ITER port. The neutronic analyses have been performed using the MCNP radiation transport code and FENDL-2.1 nuclear cross section data library. The Activation code FISPACT2007 has been employed to estimate the contact dose rates. The outcome suggests that B4C and Ferro-boron would be better candidate materials for the bio-shield plug of TBM port.

CHAPTER 5.11 INTERNATIONAL RESEARCH COLLABORATION

A) ITER PROJECT

Developments at International Level: Construction and commissioning activities are moving fast at ITER site. Several contractors are working at present for the completion of civil works, piping network and plant-systems. Live webcam is relaying updated information continuously. Tokamak complex has reached up to its ‘movable roof’ level and installation of piping and HVAC inside will start soon. The ITER Council met in Nov’18 to review the progress of the project, which reported 58% physical progress by the end of October 2018. Following CCS approval, a discussion was taken up by India’s IC members with DG, ITER on how to reduce Cash contribution by making additional in-kind contributions. This seems possible as per the provisions of the ITER Agreement.

Progress in Procurement Arrangements (PA): From the beginning of the project in 2007, a total of 14 Procurement Arrangements (PA) have been signed. Eleven major contracts for the manufacturing of ITER components have been signed till date. Significant progress has been made by ITER-India for delivery of Cryostat, cooling Water System Components & Cryogenic Distribution Lines to the ITER Project at Cadarache, France. Site acceptance test of one 100 kV High Voltage Power Supply, made in India by M/s ECIL, has been completed at Padova, Italy. Other systems are reporting good progress in works.

Figure 8 a

Largest capacity chillers ever made in India for ITER

Figure 8 b

Figure 8 c

CHAPTER 7 TECHNOLOGY TRANSFER

A) TECHNOLOGY TRANSFER AND MOU SIGNED

IPR has transferred innovative technologies to various private entrepreneurs and to some government organizations as well. The details are given below.

i) A technology knowhow and license agreement was signed between IPR & RUBAMIN Ltd., Vadodara on 5th March 2019 at IPR. The agreement covered the license of patented knowhow on ‘Metal oxide nano powder production technology’ on non-exclusive basis to M/s Rubamin Ltd. Zinc oxide nano powders have immense applications in the field of pharmaceuticals, paints & chemicals, fertilizer & agri-nutrients, animal health, etc. Since this technology will foster production of zinc oxide nano powders in India, this agreement contributes directly to the ‘Make-in-India’ programme of Government of India.

Figure 9: Technology knowhow and license Agreement signed by IPR & RUBAMIN Ltd. Signatories exchanging the agreements with each other in presence of Director – IPR and Chairman – RUBAMIN LTD. and other team members from both the organizations.

ii) MoU between IPR & Saurashtra University for development and supply of experimental plasma systems for academic purpose, signed in July 2018. The agreement deals with the development of an experimental plasma systems for academic use.

iii) MoU between IPR & VSSC for development of electro magnet module for structural analysis software package was signed in July 2018.

CHAPTER 10 OTHER ACTIVITIES

A) OUTREACH PROGRAMME

(i) **27th IAEA Fusion Energy Conference (FEC-2018), 22-27 October 2018**: IPR hosted the 27th IAEA Fusion Energy Conference (FEC-2018) at Gandhinagar during 22-27 October 2018. A total of 718 participants from 39 member countries of IAEA and 4 international organizations participated in this conference, which had both oral (131) and poster (641) presentations. There were 225 Indian participants. There was an exhibition area for vendors and institutes to showcase their wares and achievements. There were stalls in the exhibition from IPR, FCIPT, CPP-IPR as well as BARC, along with exhibits from private agencies. The conference was inaugurated by Dr. R. Chidambaram, ex-PSA and ex-Chairman, AEC and Secretary, DAE.

(ii) **106th Indian Science Congress:** The 106th Indian Science Congress was organized at the Lovely professional university, Phagwara, Punjab during 3-7 January, 2019. IPR participated in the “Pride of India” exhibition along with other DAE units. The exhibition was inaugurated by Dr. Harsha Vardhan, Honorable Minster of Science & Technology, Government of India. IPR stall was part of the DAE Pavilion which also had exhibits from other units of DAE. Over 6,000 visitors visited the exhibition during the Science Congress. The DAE pavilion won the “Most Informative Pavilion” award of the exhibition.

Figure 10

(iii) **<u>Pravasi Bharti Divas Exhibition, Varanasi:</u>** The 15th Pravasi Bhartiya Divas was organized at Varanasi during 21-23 January, 2019. IPR participated in the exhibition organized during this event along with other DAE units. Visitors included NRIs and other participants. The exhibition was visited by Hon. Prime Minister as well as the Minister of State for External Affairs, the Chief Minister of Uttar Pradesh as well as several high-ranking officers of the state and central government. Over 1,000 visitors visited the exhibition during the event.

(iv) **Parmanu Tech, New Delhi:** The Conference and exhibition was held at the Pravasi Bharatiya Kendra, Chanakyapuri, New Delhi. IPR participated in the exhibition along with other DAE units. The Conference was presided over by Dr. Jitendra Singh. Hon. Minister of State for PMO, who is also in-charge of DAE. The visitors included Indian diplomats and other senior officers from MEA and diplomats of foreign missions in India. Over 80 participants of the event visited IPR stalls and had discussions with the IPR team. IPR displayed exhibits of societal applications of plasma including Plasma pyrolysis, Plasma nitriding, Hyper-redundant robotic arm, AI based software for x-ray and sputum analysis, Plasma treatment for textiles, Plasma torch for medical applications at the event.