RRCAT at a glance

राजा रामन्ना प्रगत प्रौद्योगिकी केन्द्र, इन्दौर

परमाणु ऊर्जा विभाग

भारत सरकार

Raja Ramanna Centre for Advanced Technology, Indore

Department of Atomic Energy

Government of India

Sukhniwas Lake at RRCAT

Convention Centre at RRCAT

Raja Ramanna Centre for Advanced Technology is a unit of Department of Atomic Energy, Government of India, engaged in R & D in front line research areas of Lasers, Particle Accelerators & related technologies.

The foundation stone of the centre was laid on February 19, 1984 by the then President of India, Gyani Zail Singh. Construction of laboratories and houses began in May 1984. In June 1986, the first batch of scientists from BARC, Mumbai, moved to RRCAT and scientific activities were started. Since then, the centre has rapidly grown into a premier institute for research and development in lasers, accelerators and their applications.

Illustrious scientists / technocrats have occupied the prestigious position of the Director of the Centre since its inception. The founding Director was Dr. D. D. Bhawalkar (Feb. 1987 - Oct. 2003), followed by Dr. V. C. Sahni (Nov. 2003 - July 2009), Dr. P. D. Gupta (Aug. 2009 - July 2016), Dr. P. K. Gupta (Aug. 2016), Dr. P. A. Naik (Sept. 2016 - March 2019), Shri S. C. Joshi (April 2019 - June 2019), Shri Debashis Das (July 2019 - May 2021). The current incumbent of this position is Dr. S.V. Nakhe (June 2021 onwards), a well known Laser specialist in the Country.

The RRCAT campus is a picturesque site on the outskirts of Indore city. The campus encompasses laboratories, staff housing colony and other basic amenities like school, sports facilities, shopping complex and gardens.

Research Activities

Laser

The Centre is involved in development of a variety of laser systems and their utilization for applications in industry, medicine and research. The laser systems developed include high power CO_2 lasers, flash lamp and diode laser pumped Nd lasers, semiconductor lasers, chemical lasers, excimer lasers and high energy/intensity pulsed lasers. Crystals of a variety of materials of interest to laser technology have been grown. The industrial applications being pursued include cutting, drilling, welding, surface modifications and rapid manufacturing. Various laser based instruments such as uranium analyzer, land leveler, compact N2 laser, photo-coagulator, fibre based temperature sensor, surgical CO_2 laser system have been developed. Home-made and commercial lasers are

being used for research in the areas of laser plasma interaction, laser-based charged particle acceleration, laser cooling and trapping of atoms, nonlinear optics, ultra-fast dynamics, material processing, laser fluorescence spectroscopy of tissues, effects of narrow bandwidth light on cells and animal models, imaging through turbid media, laser micromanipulation of microscopic objects etc.

Accelerator

The Centre has indigenously designed, developed, and commissioned two synchrotron radiation sources: Indus-1 and Indus-2, serving as a national facility. Indus-1 is a 450 MeV, 125 mA electron storage ring emitting radiation from mid-IR to soft x-ray with a critical wavelength of ~61 Å. Indus-2 is a 2.5 GeV, 200 mA electron storage ring designed for the production of x-rays. Synchrotron radiation emitted from its bending magnets has broad spectrum covering soft and hard x-ray regions with a critical wavelength of ~2 Å. With its circumference of 172.5 m, and beam energy of 2.5 GeV, Indus-2 is presently the largest and the highest energy particle accelerator in the country.

The Centre is pursuing several other key accelerator activities viz. development of a high energy proton accelerator for a spallation neutron source, electron accelerators for food irradiation and industrial applications, free electron lasers (FEL) in terahertz (THz) and infra-red (IR) spectral region, superconducting and magnetic materials required for accelerators, development of advanced technologies such as superconducting radio-frequency (SCRF) cavities and cryomodules, high power radio-frequency (RF) generators, cryogenics, magnets, ultrahigh vacuum, precision fabrication and control instrumentation to support the various R&D programmes.

RRCAT: Constituent Institute of the Homi Bhabha National Institute (HBNI), a Deemed to be University

RRCAT is also a Constituent Institute of the "Homi Bhabha National Institute" (HBNI), a Deemed to be University with NAAC “A+” grade. HBNI at RRCAT (HBNI-RRCAT) offers Ph.D. and M.Tech. programs in various specialized areas of Physical, Chemical, Life and Engineering Sciences. It is an academic framework integrating basic research with technology development, which is driven by an amalgam of established faculty members and experienced scientists fostering innovation and creativity. It offers a unique opportunity for holistic development adhering to highest ethical standards.

OncoDiagnoScope: A stand-alone, field-usable optical spectroscopy based point-of-care device for non-invasive screening of oral cavity cancer



Features:

- With the assistance of this device, it is possible to non-invasively examine, in real-time, the oral cavity of a patient for the presence of any pre-cancerous or cancerous lesion in less than 15 minutes as compared to several hours (~48 hrs) required by the conventional procedure of biopsy followed by histopathology.
- Two types of light (fluorescence and reflectance) returned from the oral tissue, following illumination by light from two LEDs, determines the tissue pathology with accuracy over 90%
- Equipped with touch-screen enabled GUI for hardware control, data documentation and analyses.
- Provides online probabilistic diagnosis of the interrogated tissue site based on an instant analysis of the acquired spectra through display of colored flashes.
- Generates a detailed diagnostic report of the patients investigated.
- Compact, portable and USB powered

Clinical Validation:

- Used at different hospitals including Tata Memorial Hospital, Mumbai and various cancer screening camps in Madhya Pradesh over ~5000 individuals
  - ➔ Accuracy of diagnosis > 90%

Benefits:

- The availability of this cost-effective, point-of-care diagnostic tool will facilitate screening/detection of oral cancer in population at large even at remote areas with limited resources.

Current Status:

- The technology has been transferred to the industry as well as the device is also fabricated by ECIL, Hyderabad through technology absorption. Units of the instrument are deployed for large-scale multi-centre clinical validation.

For more information:
✓ https://www.rrcat.gov.in

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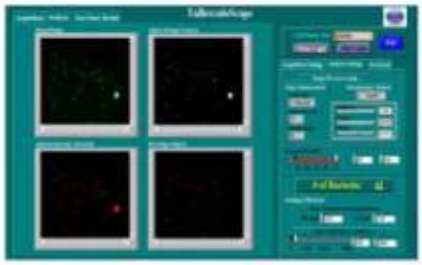
TuBerculoScope : A low cost fluorescence imaging device for sputum smear microscopy for diagnosis of Tuberculosis



Features:

- Performance comparable to the fluorescence microscope routinely used for TB diagnosis
  - ➔ Accurate diagnosis
- Significantly low cost (~ 20 times) as compared to the fluorescence microscope
  - ➔Will facilitate widespread use in hospitals /clinics with limited resources
- Compact, portable and USB powered
  - ➔Ease of use in remote areas
- Automated counting of number of bacteria in the field of view
  - ➔Rapid diagnosis facilitating immediate start of treatment

Clinical Validation:

- Validated by comparing the results of measurement with the clinical findings for ~1500 sputum smear slides. The slides included negative control samples as well as varying load of Mtb, graded as 1+, 2+ and 3+ depending upon the number of bacteria observed in each length of the smear.
  - ➔ Accuracy of diagnosis 100%

Benefits:

- The availability of this cost-effective, compact and portable diagnostic tool will facilitate rapid diagnosis of TB which otherwise is a time consuming procedure in the remote areas with limited resources.

Current Status:

- Technology has been transferred to Indian industrial unit. Units of the instrument are deployed for large-scale multi-centre data collection.

For more information:

✓ https://www.rrcat.gov.in

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'नीलभस्मी' : कोरोना वायरस सहित विभिन्न सूक्ष्म जीवों को निष्क्रिय करने के लिए परा-बैंगनी किरणों पर आधारित स्वच्छता उपकरण

'NeelBhasmi' : A UV based area sanitization device to inactivate various micro-organisms including corona viruses

Features:

- Equipped with eight UV-C lamps mounted on four arms having multiple degrees of freedom
- Easy to adjust arms for effective sanitization of areas having a combination of horizontal (table tops, floors), vertical (filing cabinets, doors) and inclined (ramps, staircases) surfaces.
- Remote on off control for the UVC lamps on each individual arm.
- Adjustable timer for setting the exposure time
- Motion sensor for safe operation.
- Ozone-free ambience while in operation.
- Mounted on a mobile trolley for easy movement across the room.
- Capable of sanitizing surfaces kept within one meter distance (from the lamps) in about 5 minutes and a room with a floor area of 10 square meter in about 45 minutes.

Evaluation:

The efficacy of Neelbhasmi for disinfection against SARS-CoV2 was evaluated at the BSL-3 Laboratory (VRDL) in ESIC Medical College, Hyderabad, an ICMR approved laboratory for COVID-19 test. It was found that UVC radiation from Neelbhasmi could inactivate SARS-CoV2 viruses from the surfaces of various materials as confirmed by the gold standard RT-PCR.

Benefits:

Neelbhasmi can be used to remotely disinfect the air as well as the surfaces of various objects inside a room at research centres, hospitals, offices, or any other places of work.

Current Status:

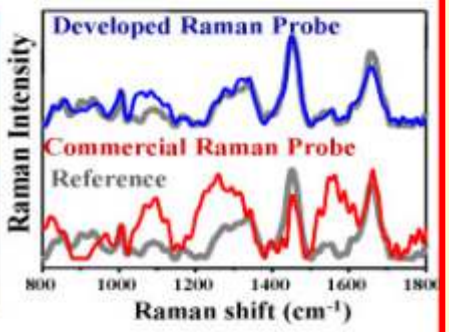
Technology has been transferred to Indian industrial units.

For more information:

✓ https://www.rrcat.gov.in

रमन जांच उपकरण: जैविक ऊतकों जैसे कम रमन सक्रिय सामग्री या पदार्थ से विरूपण मुक्त रमन स्पेक्ट्रा के यथास्थान मापन हेतु हस्त संचालित मॉड्यूल

Raman Probe : A hand-held module for in-situ measurement of artifact-free Raman spectra from low Raman active materials like biological tissues



Features:

- Yields artefact-free Raman spectra unlike the commercial probes which introduce spurious spectral features in the acquired signal that interfere with the 'Raman signatures' appearing in the fingerprint region (400 -1800 cm^{-1}) of the Raman spectra thereby limiting the utility of the 'Raman Spectroscopy' systems.
- Capable of collecting good quality in-situ Raman spectra within a few seconds of acquisition time from low Raman-active materials like biological tissues.

Validation:

- Validated by comparing the measured Raman spectra with those measured with a commercial Raman probe and also with a bench-top open-air Raman system.

Benefits:

- The developed Raman probe has high potential of wide-spread use for in-situ measurement of Raman spectra in the field of biomedical applications such as disease diagnosis based on analyses of tissue and body fluids, in situ monitoring of healing of wounds in patients etc. which have not been possible because of unavailability of a suitable Raman probe.

Current Status:

- Technology has been transferred to Indian industrial unit.

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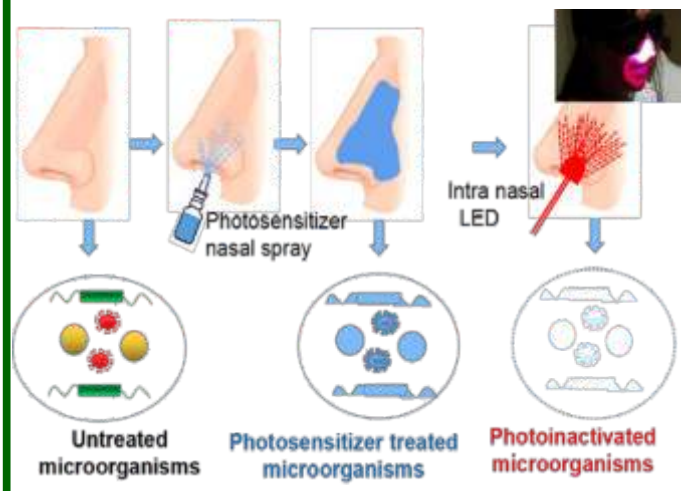
Nasolight™: A rapid and effective tool to kill nasal pathogens before they can cause severe infections

Components of the Kit



Schematic of intra nasal photodisinfection using Nasolight™

Features:

- Works on the principle of antimicrobial photodynamic therapy.
- Clinically proven effective for killing of superbugs, microorganisms causing COVID, influenzae, sinusitis, pneumonia, mucormycosis.
- Complete eradication (~ 8 log $_{10}$ / 99.999999 % survival loss) of bacteria, fungi in 3 min light exposure *in-vitro.*

Benefits:

- No side effects.
- Short treatment time.
- Usable in both clinical and home settings.

Current Status:

- Product is registered as OTC (over the counter) product with Tata 1 mg

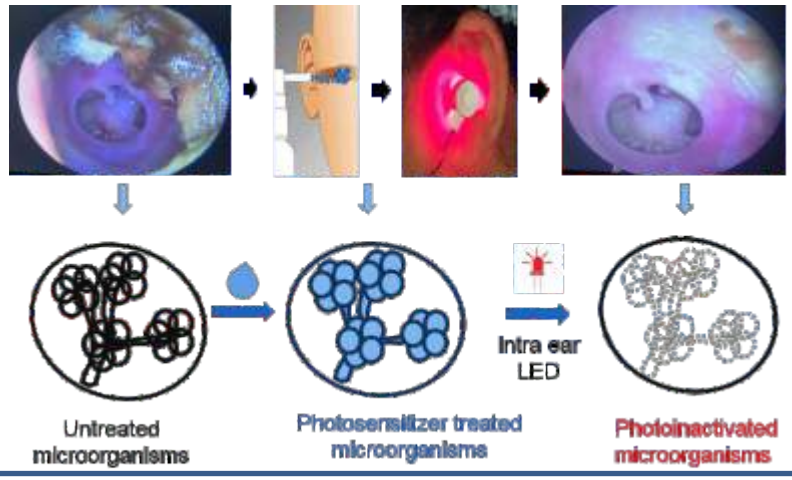
Uses:

- Treatment of Sinusitis, Chronic rhinosinusitis, COVID-19 etc.

For more information:

https://www.rrcat.gov.in

Earolight™: A rapid and effective tool for fast cure of external ear infections



Features:

- Works on the principle of antimicrobial photodynamic therapy.
- Rapid inactivation of microorganisms (fungi , bacteria) causing ear infections.

Benefits:

- Much faster effect compared to antifungal drugs, antibiotics
- No side effects
- Short treatment time
- Usable in both clinical and home settings

Validation and Current Status:

- Proven clinically effective for cure of external ear fungal infection; Otomycosis(50 subjects) within 3 days, compared to 10-12 days required for conventional treatments.

Uses:

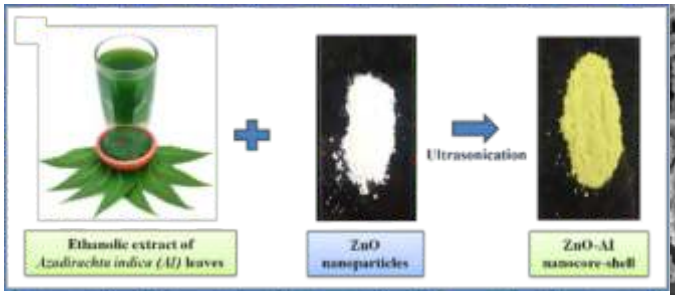
- Treatment of otomycosis and other external ear infections.

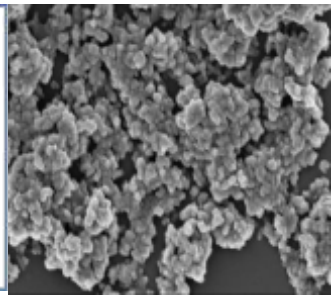
For more information:

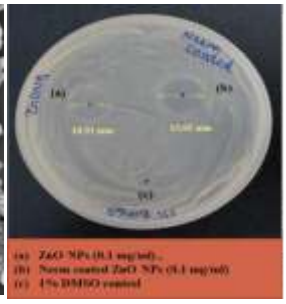
https://www.rrcat.gov.in

Materials for Bio-photonics applications

Azadirachta indica (AI) leaf extract coated ZnO-*AI* nanocore-shell particles for enhanced antibacterial activity against Methicillin-Resistant *Staphylococcus aureus* (MRSA)







An innovative approach to engineer antibacterial nanoparticles by leveraging the inherent antibacterial properties of Zinc Oxide nanoparticles (ZnO NPs) in combination with *Azadirachta indica (AI)* leaf extract, resulting in enhanced antibacterial efficacy. These findings suggest ZnO-*AI* nanocore-shell structures hold promise for the development of novel antibacterial creams and hydrogels for various biomedical applications.

Rare earth doped Y_2O_3 and LaF_3 nano particles are synthesized for different biological and photonics applications

One such application is UV-IR Beam visualizer

Technical Specifications
UV wavelength range: 275-350 nm
IR wavelength Range: 800-1600 nm
Emission : Green color (eye sensitive)
Sensitivity: 20mW/cm^2 (CW laser, 975 nm)
Damage Threshold: >35kW/ /cm^2 at 975 nm
Active Area= 10 mm diameter.

Applications:
Detection and visualization of UV and IR radiation from CW laser, pulsed laser and IR diodes.

These nano particles can be used in bioimaging, in-depth bioimaging using IR, activation of photosensitive drug using IR etc.

Patent: "A pass through type Infrared and Ultraviolet beam visualizer device based on rare earth doped transparent ceramics."
Patent No: 463706 Date of Grant: 30/10/2023

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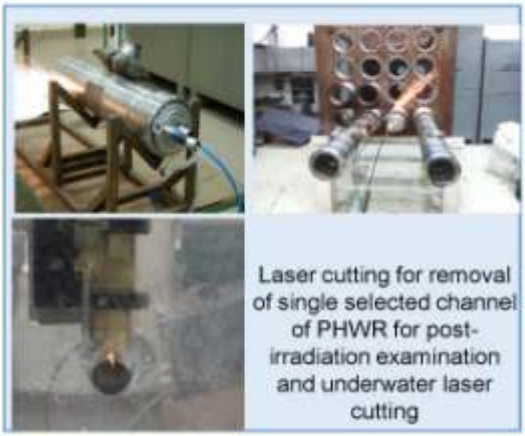
High Power Solid-state Lasers and their Applications in Nuclear Field

High power solid-state lasers with fiber optic beam delivery have potential applications in nuclear field for remote cutting and welding applications. RRCAT has developed high power long pulse Nd:YAG lasers of 250 W, 500 W, 1 kW and 1.5 kW average power with peak powers of 5 kW, 10 kW, 20 kW and 30 kW, respectively. Laser cutting and welding technology has the advantage of non-contact nature, remote operation, lower heat affected zone, distortion and shrinkage as compared to conventional technologies.

1 kW average power and 20 kW peak power Nd:YAG laser

Laser cutting of bellow lips during en-masse coolant channel replacement (EMCCR) campaign in PHWR



Laser cutting for removal of single selected channel of PHWR for post-irradiation examination and underwater laser cutting

Laser welding of heart pacemaker

Laser welding of PFBR fuel pins

Laser welding setup for hot cell at BRIT

I-125 brachytherapy capsule

Laser micro-welding of I-125 and Ir-192 brachytherapy capsules for cancer treatment

Highlights

- Remotely operable laser cutting technology has been developed & deployed successfully for various in-situ operations such as cutting of bellow lips during EMCCR, removal of single selected coolant channels of 220 MWe and 540 MWe PHWRs for post-irradiation examination (PIE), underwater laser cutting for retrieval of pressure tube (PT) stubs for PIE, cutting of steam generator tubes, etc. for refurbishing and maintenance of Indian nuclear power plants. Laser welding technology for PFBR fuel pins has also been successfully developed & deployed.
- These laser based technologies have enormously reduced radiation dose consumption, time and cost.
- For societal applications, laser micro-welding technology for I-125 and Ir-192 brachytherapy capsules for cancer treatment and heart pacemaker have been developed

For more information:

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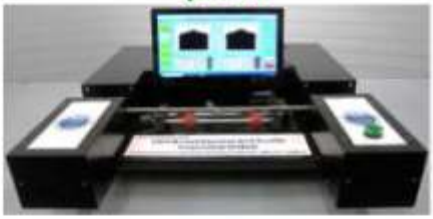
Machine Vision based Metrology and Inspection Systems

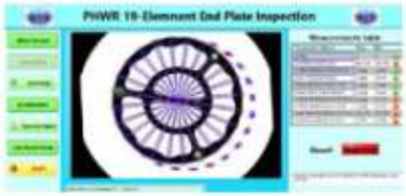
RRCAT is involved in design, development and fabrication of automated cost effective machine vision based visual inspection and metrology systems for nuclear fuel, fuel assembly components. These systems have been specially designed and developed as per the custom needs to maximize the inspection throughput and fulfil the accuracy and repeatability requirements of the user. These systems are provided with suitable component holder/jig, so that even an unskilled operator can utilize the system. The system software provides accept/reject decision for component along with complete report of all the measurements carried out. These system provides standard interfaces for integration with PLC/PC.

Inspection system for weld quality of end profile



Element is rotated 180 degree
Resolution: 10 micron
Measures 9 parameters of end profile
Throughput: 200 Elements/ hour

Metrology system for end plate



Resolution : 20 microns
Measures 10 parameters
Throughput : 3 plates /minute

Depth, angle and width measurement of top plug slot

Photograph of Top plug slot

Depth resolution : 8 µm
Measures 3 parameters
Throughput : 2 plugs/min

Optical character recognition (OCR) for reading identification number of fuel bundle

Field of view: 100 mm diameter
Generates a QR code for identified number which is printed on a label tag.
Throughput : 1 bundle /minute

Advantages of machine vision based metrology and inspection systems

These systems provide accurate, non-contact, fast, 24x7 industrial grade inspection solutions. These systems are suitable for integration into existing production line, replacing the human based inspection which is highly subjective. Moreover, the machine vision based system provides high quality data for further analysis and quality control. The high measurement throughput enables 100% inspection of components leading to significant quality improvement of the final product. Commissioning of these state of the art systems at various DAE units helped in automation of inspection and quality assurance of components at lower cost with specific advantages of report generation, data analytics, etc. This not only helps in augmenting the fuel production throughput but also minimizes the radiation exposure.

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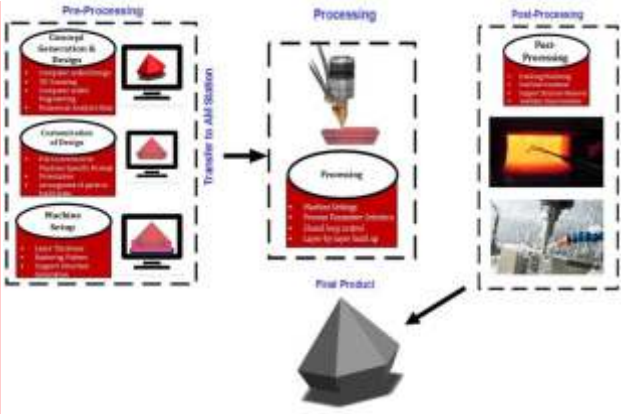
Laser Additive Manufacturing (LAM)

Laser Additive Manufacturing (LAM) is **a Laser 3D Printing** used for developing metallic components.

It is a step towards **Feature based design and Manufacturing**. It is attractive for **low volume manufacturing & mass customization** and paving the way to **4th Industrial revolution**.



Laser + AM = LAM

LAM Systems at RRCAT

Laser	2 kW Fiber laser
Workstation	5-axis
Working volume	400 x 400 x 300 mm³
Powder feed rate	2 – 20 g/min
No. of powder feeder	2
Purity in Glove box	< 20 ppm O_2 & < 30 ppm H_2O

Laser Directed Energy Deposition (LAM-DED) System

Build volume	300x 300 x 300 mm³
Beam manipulation	Galvanoscanner
Atmosphere	Controlled (O_2-10 ppm, moisture -10 ppm)
Build plate	Preheated (up to 350°C)
Laser	500 W Fiber

Laser Powder Bed Fusion (LAM-PBF) System

Engineering Applications

Components Developed using LAM-DED

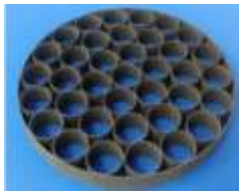
SiC clad layer on Zircaloy

Alternate layer of Cu/Ni

SS-Ti Transition joint

WC clad layer on SS 304

Components Developed using LAM-PBF



Spacer for fuel bundle

Fuel pin end plate

Conformal cooling channel

Gear With Honeycomb Structure

For more information:

https://www.rrcat.gov.in

Realization of Lab to Land of Laser Additive Manufacturing System

RRCAT has mastered the Art of Technology in development of Laser Directed Energy Deposition (LAM-DED) and Laser Powder Bed Fusion (LAM-PBF) Systems over last few years.

Recently (February, 2023), RRCAT has transferred the Technology of LAM-DED System (TVASHTR) to three Industries through AIC- Hub RRCAT, Indore for its commercial deployment.

Incubator for LAM-DED System

- Unnati 5D Manufacturing System Pvt. Ltd., Mumbai.
- VFuse Metal 4 Manufacturing Pvt. Ltd., Bhopal
- Lokesh Machines Limited, Hyderabad

One of the incubator Lokesh Machines Limited, Hyderabad together with AIC- Hub RRCAT, Indore launched the commercial version of TVASHTR at India's largest AMTech Expo for business networking platform for Additive Manufacturing Technology on 01-12-2023 at HITEX Exhibition Centre, Hyderabad.

RRCAT is Catalyzing the Ecosystem for Adaptation of Additive Manufacturing in the Country by transfer of Knowledge, Expertise, Technology, and Skills to Startups, MSME, and Corporates

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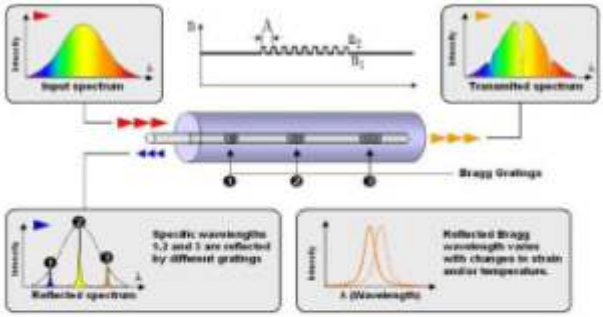
Fiber Bragg grating fabrication facility developed at RRCAT

A fiber Bragg grating (FBG) is a longitudinal periodic variation of the refractive index in the core of an optical fiber. This can be used as an inline optical filter to block certain wavelengths, or as a wavelength-specific reflector.

FBG Operating Principle



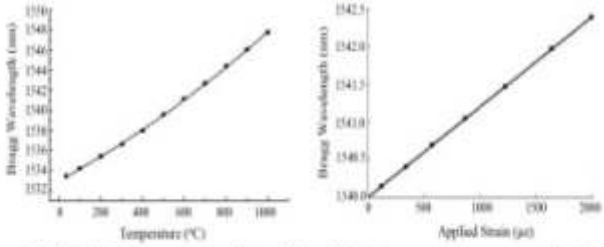
- The fiber Bragg grating (FBG) reflects the light as per the Bragg Condition

  Typically: λ_B= 1.5 μm, for Λ = 0.5μm

$$\lambda_B = 2\, n_{eff}\, \Lambda$$

- FBG fabrication time: 1 – 3 minute, Reflectivity ~ upto 99.9 %
- Fabrication facility of different types of FBGs : Type I, Type IIa, Tilted, Chirped and Regenerated FBGs

FBG Sensing Principle



Shift in Bragg wavelength with temperature and strain

- Bragg reflection wavelength changes with an external parameter (X)
- Here X can be temperature T, strain ε, pressure P, or surrounding refractive index, etc.
- α is the coefficient of the physical length change due to variation in parameter X

$$\frac{d\lambda_B}{dX} = 2\,\Lambda\frac{dn_{eff}}{dX} + 2n_{eff}\,\Lambda\,\alpha = \lambda_B\left(\frac{1}{n_{eff}}\frac{dn_{eff}}{dX} + \alpha\right)$$

- Temperature sensitivity ~13.6 pm/°C
- Strain Sensitivity ~ 1.1 pm/με

Applications:

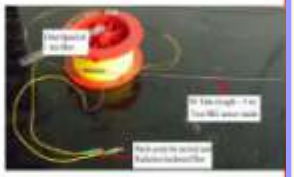
FBG Temperature monitoring system for vacuum chamber wall of dipole magnet (DP-12) of Indus-2

Temperature monitoring system of a gas discharge laser tube using FBG

Development of FBG based 'Wheel Impact Load Detection' system for Railway safety

FBG temperature monitoring system in radiation environment at Advanced Fuel Fabrication Facility, BARC, Tarapur

Temperature monitoring system using FBG for storage vault at Solid Storage & Surveillance Facility, BARC, Tarapur



Installation of RRCAT developed FBGs for train axle box temperature monitoring

For more information:

✓ https://www.rrcat.gov.in

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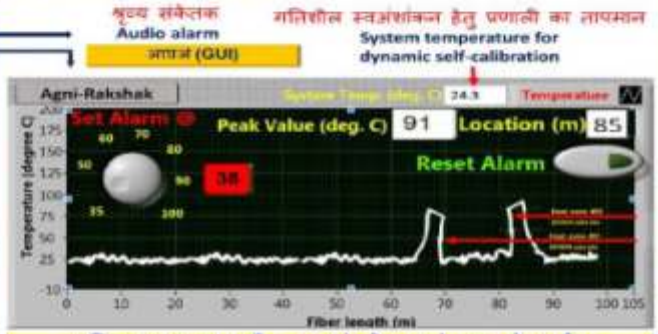
Raja Ramanna Centre for Advanced Technology, Indore

Agni-Rakshak: Raman optical fiber based fully distributed fire detection system

'Agni Rakshak' is a distributed fire detection system which provides the temperature profile of the sensing optical fiber connected to it. In other words, it is a distributed heat detection system that measures distributed temperature profile over long lengths. Here, the optical fiber itself acts as an array of several sensing elements. The system is very useful in detecting the onset of fire. It has the capability to provide the information about the location, width and temperature of the hot zone to which the sensing fiber is subjected. The system can generate the audio-visual alarm for various zones in the fiber if zone temperature crosses the set alarm temperature.

राराप्रप्रौके में विकसित 'अग्नि-रक्षक' प्रणाली
'Agni-Rakshak' developed at RRCAT



'अग्नि-रक्षक' प्रणाली का आरेखीय प्रयोक्ता अंतरानीक
Graphical user interface (GUI) of 'Agni-Rakshak'

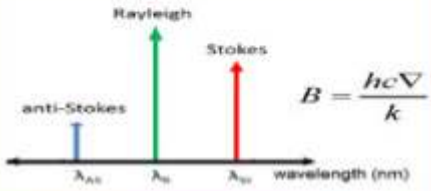
'Agni-Rakshak': Working principle

Raman scattering of light

- The form of scattering in which the frequency of incident light undergoes a definite change was observed and studied by Sir C. V. Raman in 1928 and is known as 'Raman effect.'
- Inelastic Raman scattering: Change in incident light takes place due to vibrational properties of a substance.
- Approximately only 1 in 10 million photons participates in Raman scattering.

How to measure temperature using Raman scattering of light?

$$R = \frac{I_{AS}}{I_{St}} = \left(\frac{\lambda_{St}}{\lambda_{AS}}\right)^4 \exp\left(-\frac{B}{T}\right)$$



$$B = \frac{hc\nabla}{k}$$

How to find location of hot zones using optical time domain reflectometry (OTDR)?

$$t = \frac{2z}{V_g}$$

V_g = Light velocity in fiber = (c/n)
z = Fiber length
t = Time of propagation

(d = c x t)

Specifications

1. Sensor: MM optical fiber (62.5/125 µm) in SS tube (1.8 mm dia.) 2. Sensor length: up to 500 m
3. Sampling length: 30 cm 4. Measurement time: 20 s 5. Indicators on fire: Audio-visual alarms
6. Zone wise alarm temperature on fire: User programmable

Applications

For more information: https://www.rrcat.gov.in

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Raja Ramanna Centre for Advanced Technology, Indore

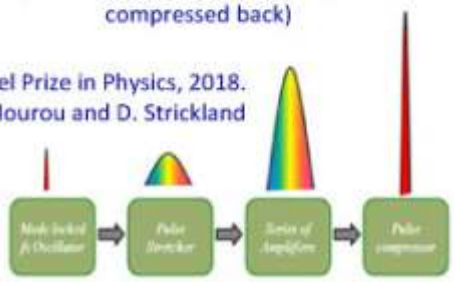
Laser Plasma Accelerator

RRCAT is engaged in R&D of laser and plasma based advanced accelerators and applications.
A promising technique for development of comparatively compact and low-cost particle accelerators.

- Availability of appropriate ultra-short (femtosecond) duration laser with high-power (several TW to several PW), developed using Chirped Pulse Amplification (CPA) technique, has led to research and development of laser driven plasma based particle (electron/proton/ion) acceleration.
- Being already in broken state and through generation of giant electron plasma wave by intense laser pulse, plasma could sustain huge electric field of ~10-100 GV/m (three orders of magnitude higher than RF field in a cavity).

CPA Scheme
(Short pulse is stretched in time, amplified, and compressed back)

Nobel Prize in Physics, 2018.
G. Mourou and D. Strickland

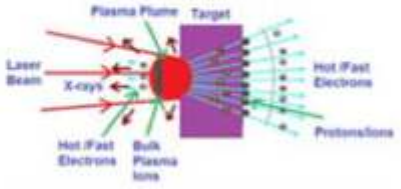


Laser Plasma Accelerator: Experimental Facilities and Methodology

Using commercial CPA based Ti:Sapphire laser systems (earlier with 10TW, 45fs; and recently with150TW, 25fs) extensive experimental investigations on particle (electron/proton/ion) acceleration has been performed. Laser is focused to tiny spots of 5-10 μm (intensity $>10^{19}$ W/cm^2) on solid or gas targets.

150TW, 25fs Commercial Ti:Sapphire Laser

Ultra-short, Ultra-intense Laser Plasma Interaction



Solid Metal Target: Sub-micron to few microns thick.
Various mechanisms of laser energy coupling to plasma electrons leads to generation of fast electrons (100s of keV to few tens of MeV), Ultra-short x-rays (Kα and hard-rays), proton / ion acceleration (few MeV to 100 MeV).
Gas Target (He, N_2 or mixed): Few mm to tens of cms length (gas-jets/gas-cells/capillary discharge plasma channel) Laser propagates long distance in gas plasma and generates wakefield (electric field due to charge separation) which along with laser field leads to acceleration of trapped plasma electrons to hundreds of MeV to several GeV energy.

High Impact Investigations Performed using 150 TW Laser

- High-energy electron acceleration in gas-jet target: >500 MeV electron beam in 4mm length plasma.
- Investigations on JxB mechanism of ultra-short laser absorption in plasma created on thin metal targets and generation of fast-electrons of several MeV energy.
- Investigations on short-duration Cu Kα (8keV) x-ray generation in solid target and its application for fast-electrons transport in thin metal targets.
- Proton acceleration from few MeV to 10MeV energy, and C^{4+} ion of energy upto ~ 14 MeV from rear surface of thin metal targets.
- Applications of particle beams:
  - Electron beam radiography of physical objects and plant leaves.
  - Production of ^{11}C radio-isotope using $^{11}B(p,n)^{11}C$ and $^{10}B(d,n)^{11}C$ reactions.
  - Investigation on proton-boron fusion reaction: $p + {}_5B^{11} \Rightarrow 3\alpha + 8.7$ MeV
- Betatron X-ray (1-30keV) generation in Laser Plasma Electron Acceleration in gas target and phase-contrast imaging application.

For more information ✓ https://www.rrcat.gov.in

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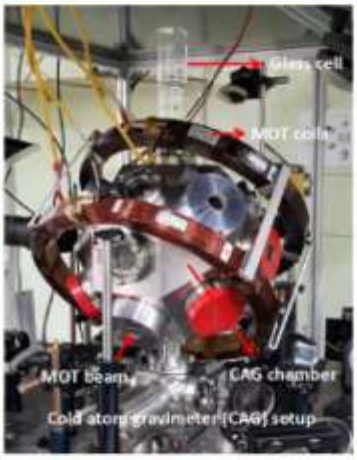
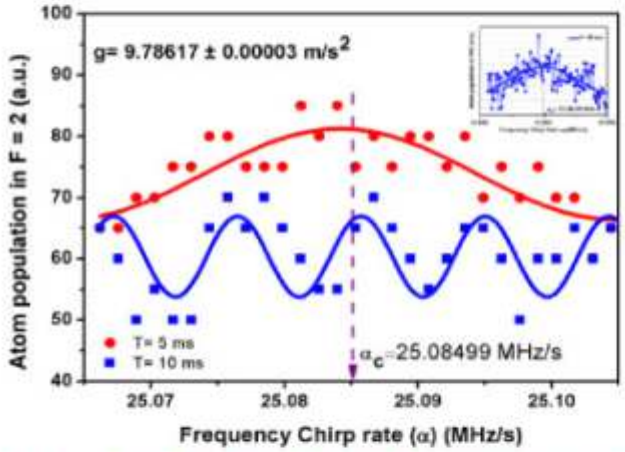
Raja Ramanna Centre for Advanced Technology, Indore

Cold atoms technologies pursued at RRCAT

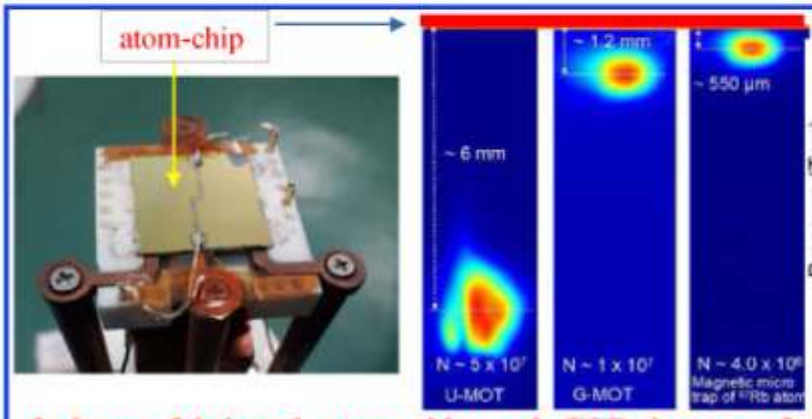
RRCAT is engaged in R&D work in the front-line of R&D activities in laser cooled atoms and their applications in different quantum sensing technologies. Presently work is in progress to develop cold atom based gravimeter, develop atom-chip and atom-chip based sensors. The work is also in progress in the basic research using cold atoms such as trapping atoms in RF dressed potentials and in optical dipole potentials.



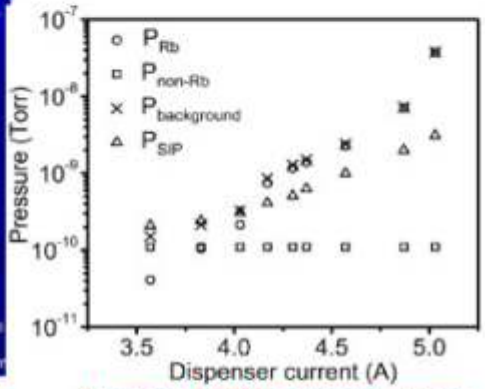
Cold atom gravimeter



Atom interferometry fringes for g measurement



In-house fabricated atom chip and CCD images of trapped cold atoms on chip



Sensing UHV pressure using atom-chip MOT

Highlights

- The cold atom based gravimeter for precision measurement of earth's gravitational acceleration (g) is under development. The initial results have shown the accuracy of g measurement as g = 9.78617±0.00003 m/s^2. Further improvement in g measurement is under progress.
- The accurate measurement of g has applications in exploration of minerals, monitoring seismic activities and space science and technology.
- Magnetic trapping of atoms on chip has been demonstrated, which is an state-of-art advancement in the trapping technology useful for miniaturization of atom trap based devices.
- Pressure sensing using the atom-chip MOT has been demonstrated.
- Research and development activities such as RF dressed potentials and optical dipole trapping extends further skills in trapping and manipulation of atoms for various quantum atom optic devices.

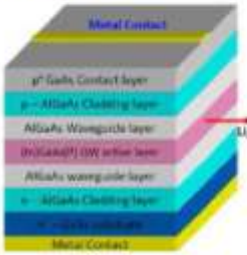
For more information:

✓ https://www.rrcat.gov.in

Bonding and packaging of laser diodes to develop 50 W CW solid state laser

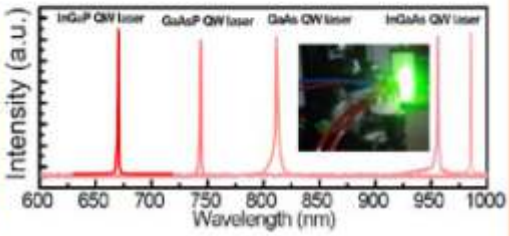
Laser diode arrays operating in the wavelength range of 650 to 1000 nm are developed by RRCAT. Efficient removal of heat from the laser diode (LD) arrays is critical for their operation at high power. Technology for the bonding and packaging of high power laser diode arrays on inhouse made mounts is developed and the operation of diode pumped solid state lasers is demonstrated.

MOVPE Facility



Laser diode

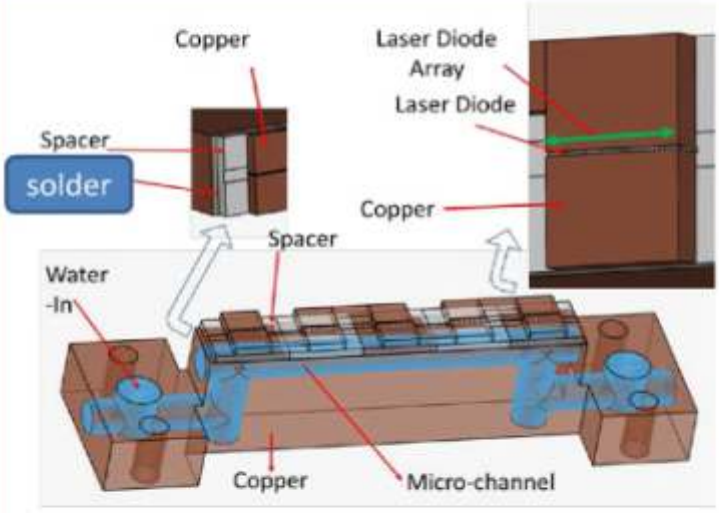
LD array



Laser diodes developed at RRCAT

Science & Technology Innovation / International impact

- The bonded and packaged laser diode arrays were used to pump a solid-state laser, where the peak output power of 25 kW with 80 ns of pulse duration at 10 kHz of repetition rate in Q-switched mode and 51.5 W CW power was successfully demonstrated.
- Such lasers find many applications in industry including diamond cutting and polishing.
- Scaling up of fabrication facilities can help to reduce the cost of indigenously made devices.
- Complete fabrication technology of laser diode arrays can be transferred to an Indian industry for commercial production leading to self reliance.



Schematic diagram of laser diode rods

Laser diode rod

Diode pumped solid state laser

❖ Technology for the bonding and packaging of laser diode arrays for the pumping of solid-state laser is ready for the transfer to industry. https://barc.gov.in/technologies/hplda/index.html

For more information:
✓ https://www.rrcat.gov.in

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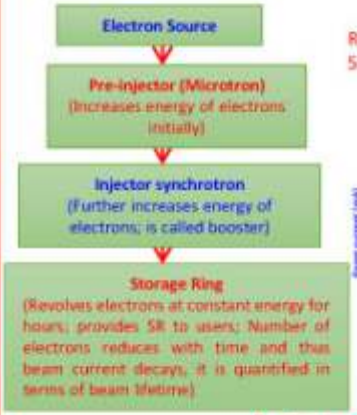
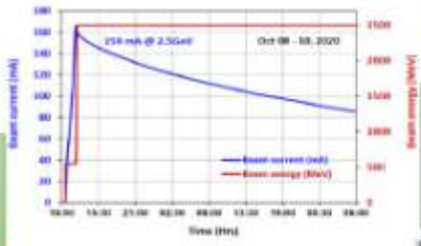
Raja Ramanna Centre for Advanced Technology, Indore

Synchrotron Radiation Sources, Indus-1 and Indus-2

When electrons at relativistic energies move in a curved path under the action of a magnetic field they emit electromagnetic radiation, known as 'Synchrotron Radiation' (SR). Raja Ramanna Centre for Advanced Technology (RRCAT), Indore, has set up country's two synchrotron radiation sources, Indus-1 (450 MeV) and Indus-2 (2.5 GeV) indigenously, right from the design, development, construction, installation, commissioning and operation. Indus-2 is the largest (172.5 m circumference) and highest energy accelerator built in India. Both these accelerators are operating in round the clock mode to provide SR for different applications.

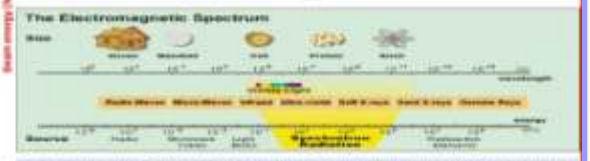


Regular Indus-2 operation, showing injection at 550 MeV, energy ramping to 2.5 GeV and stored electron beam in user mode



Features of Synchrotron Radiation

- High brightness
- Wide continuous spectrum
- Polarization
- Pulsed structure
- Clean source
- Well calculable properties



Synchrotron radiation is a tool of immense importance in scientific research.

Indus accelerator complex at RRCAT, Indore

Schematic view of Indus Accelerators

Indus-1 storage ring

Transport line-3

Indus-2 accelerator tunnel

Parameter	Indus-1	Indus-2
Circumference	19 m	172.5 m
Energy injection	450 MeV	550 MeV
Energy final	450 MeV	2.5 GeV
Beam current	125 mA	200 mA
No. of dipoles	4	16
No. of undulators	-	3
No. of quadrupoles	16	72
No. of RF stations	1	6
Critical wavelength	61Å	1.98 Å
Emittance	70 nm-rad	135 nm-rad
Brightness	3.2×10^{17}	1.02×10^{19}
Beam lines operational	7	18

Indigenous subsystems, designed and developed for Indus-2

Development, installation and operation of a synchrotron radiation facility requires state of the art sophisticated technologies like, Magnet Technology, RF and Microwave Technology, Instrumentation and Control engineering, Ultra High Vacuum systems, Precision Alignment, DC and Pulsed Power Supply technology, Temperature control systems etc. along with radiation monitoring and elaborate safety and protection systems. Presently RRCAT is the only centre in India where this SR facility is available.

Vacuum Technology: UHV dipole magnet chambers

Magnet technology (design, fabrication, testing of various types of magnets)

Various types of high stability power supplies

Beam instrumentation technologies

20 MeV electron injector & 5MW Microwave systems

Accelerating RF cavities with RF Feed

Indigenous RF cavity

Solid state RF amplifiers

60 kW 505.8 MHz Y junction circulators

Pinger Magnet with pulse power circuit

Remote Operation from Control room

For more information:

✓ https://www.rrcat.gov.in

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Beamlines at Indus 1 and Indus-2

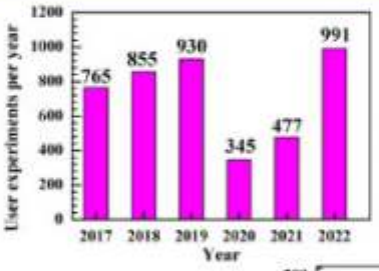
Indus–1 and Indus-2 synchrotron radiation sources are national facilities, which are in operation in round-the-clock mode, since Feb 2010. The accelerators and beamlines have been designed, developed and commissioned indigeneously.

Advantages of synchrotron radiation

- Far more intense (>10^6) than lab sources
- Tunable energy in the X-ray spectral region
- Naturally collimated with very short (ps) pulses

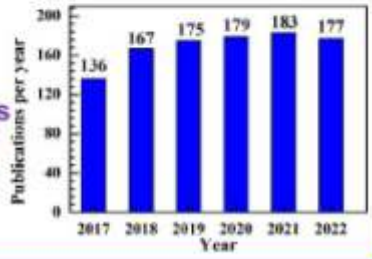
What is a beamline?

The X-ray optics and all other instrumentation used to monochromatize, collimate and/or focus the X-ray beam on a specific experimental station, is called a beamline.



Annual User experiments

Annual publications



Current status

There are 18 beamlines on Indus-2, and 7 on Indus-1
Researchers from about 150 different institutes, national labs universities have come for experiments.
Several industries also come regularly for experiments.

Operational beamlines on Indus-2

- BL-1 Soft X-ray Abs.
- BL-2 Engg. Appl.
- BL-3 Soft X-ray Refl.
- BL-4 X-ray Imaging
- BL-7 X-ray Lithography
- BL-8 Dispersive EXAFS
- BL-9 Scanning EXAFS
- BL-10 Angle Resolved Photoelectron Spec.
- BL-11 Extreme Conditions XRD
- BL-12 Angle Dispersive XRD
- BL-13 X-ray Scattering
- BL-14 X-ray Photo Electron Spec.
- BL-16 X-ray Fluor. Microprobe
- BL-18 Small Angle X-ray Scatt.
- BL-20 X-ray Mag. Circular Dichroism
- BL-21 Protein Crystallography
- BL-23 Visible Diag. Beamline
- BL-24 X-ray Diag. Beamline

Operational beamlines on Indus-1

- BL-1 High res. VUV Spec.
- BL-2 AIPES
- BL-3 ARPES
- BL-4 X-ray Refl.
- BL-5 Photophysics
- BL-6 IR Spec.
- BL-7 Photo abs. spec (PASS)

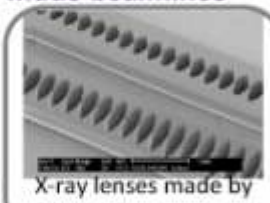
Applications of Synchrotron radiation:

- Crystal structure determination
- Structure of bio-molecules and proteins
- Electronic structure of materials
- Chemcial state of elements
- Trace element determination
- Sizes & shapes of nanoparticles/microparticles
- Magentic moment of individual elements
- *In-situ* /*in-operando* studies of reactions
- Lithography for MEMs & related development

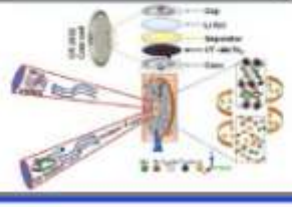
Hence important for numerous industries
eg. Pharma industry for drug design and development, energy sector, manufacturing sector, mining and metallurgy etc.

Some examples from Indus beamlines

Structure of DNA ligase from Mycobacterium tuberculosis



X-ray lenses made by X-ray lithography



Schematic setup of *in-operando* studies of battery

For more information:
✓ https://www.rrcat.gov.in

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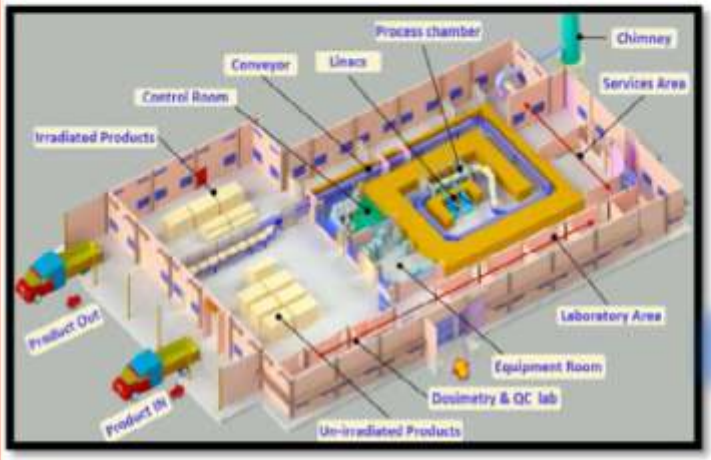
Raja Ramanna Centre for Advanced Technology, Indore

Electron beam Facility for Sterilization of Medical Devices at RRCAT, Indore



- DAE, RRCAT has set up a radiation processing facility (ARPF) based on 10 MeV, 6 kW electron accelerator at Indore.
- The first e-beam facility in the country providing sterilization services for medical devices.

Features

- Indigenously developed accelerator technology
- Licensed by AERB
- Comply the requirement of MDR-2017
- FDA Licensed (Risk Class-A devices)
- ISO 9001:2015 certified
- ISO 13485:2016 certified
- Calibrated dosimetry laboratory
- Dosimetry & parametric based product release system

Processing Capacity

Processing capacity	6 kGy.tons/hour
Typical box size (L x W x H)	60 x 45 x 35 cm^3
Typical weight of box	12-13 kg.
Throughput for 25 kGy dose	15-18 boxes/hr

Product Performance Qualifications Carried out at ARPF

COVID-19 VTM sample Tubes

Petri dishes

Latex Surgical Gloves

One Truck load bulk processed

Cotton Gauze pieces

Blood Vacutainers

Collagen Sheets
(for burn healing)

- One truck load of VTM tubes & petri-dishes sterilization in a batch.
- Sterility test performed at NABL certified lab.
- Sterility established successfully

For more information:

✓ https://www.rrcat.gov.in

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Raja Ramanna Centre for Advanced Technology, Indore

India's first Infra Red Free Electron Laser (IR-FEL) facility

RRCAT is engaged in R&D work in front-line areas of accelerator science, technology, and applications. As a part of this R&D, the Raja Ramanna Centre for Advanced Technology has indigenously designed, developed, and commissioned an Infra-Red Free Electron Laser (IR-FEL), which has achieved saturation with a CW average power ~ 20 mW at 23 μm wavelength.

Advantages of FELs

Wide tunability: Wavelength can be tuned by varying either the electron beam energy or undulator gap. $\lambda_L = \lambda_u(1 + K^2) / 2\gamma^2$, where λ_L is radiation wavelength, λ_u is undulator period and γ is the relativistic γ factor for the electron beam.

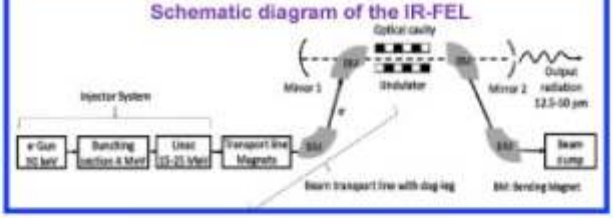
Short Pulses: FELs can produce ultra-short pulses at all wavelengths.

High Brightness : FELs deliver high average brightness ~ 10^{23} - 10^{26} .

High Power: No fundamental limit on the operating power because the lasing medium is an electron beam.

IR-FEL Design Parameter	Value
Wavelength λ_L	12.5 – 50 μm
Electron beam energy	15 – 25 MeV
Peak electron beam current	> 30 A
Planar, pure permanent magnet (NdFeB) undulator	
Undulator parameter ***K*** (RMS)	0.5 – 1.26

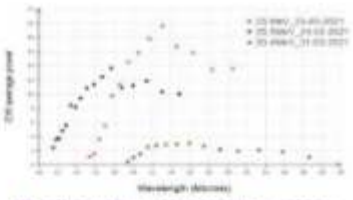
Schematic diagram of the IR-FEL



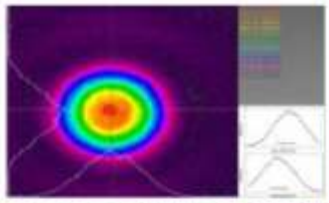
IR-FEL operation parameters	
Electron beam energy tuning range	18 – 25 MeV
Energy spread	≤ 1 % RMS
Macro-pulse width	6.4 μs
Charge per micro-pulse	~ 0.64 nC
CW average power at 2 Hz	20 mW
Estimated peak power in 10 ps	> 5 MW
Wavelength tunability achieved	12.5 – 40 μm
K parameter tuning range(RMS)	0.5 – 1.26

Full system view of IR-FEL setup inside its radiation shielded area

Measured IR power stability from the FEL



Typical IR wavelength tuning



Transverse optical mode profile

Highlights of the IR-FEL

- First signature of lasing (~ 10^5 times growth in power) observed at a wavelength of 34 μm in November 2016 using ~ 26 A peak beam current at 18.4 MeV beam energy.
- Saturation of lasing with 7 mW CW power output at 28 μm achieved in March 2020 using ~ 50A beam current at ~ 24 MeV electron beam energy.
- CW average optical power from the IR-FEL increased up to 20 mW at 21.6 μm with 6 W electron beam power, with output power stability within ± 5%.
- Out put wavelength from the FEL tuned from 12.5 to 40 μm by varying electron beam energy from 19 to 25 MeV and the RMS undulator parameter from 0.5 – 1.26.
- Transverse optical profile of the IR-FEL radiation measured to be close to Gaussian.

For more information:
✓ https://www.rrcat.gov.in

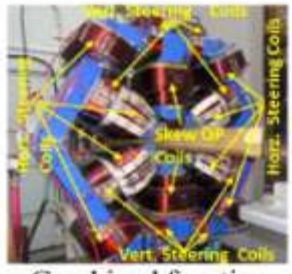
Accelerator Magnet Technology

RRCAT is involved in design, development, characterization and deployment of magnets (DC, ramped, pulsed) for Indus Accelerators, IRFEL and ARPF. Accelerator magnets are required to produce very high quality magnetic fields. So far, more than 400 magnets have been developed indigenously. Also, fast current transformers and microwave circulators have been developed.


1.5 T Dipole


Quadrupole


Sextupole



Combined function


Kicker

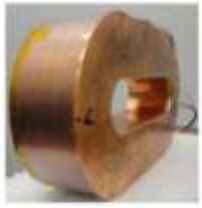

505.8 MHz, 60 kW circulator


ARPF solenoids


500 mm long pre-prototype undulator, period length 56 mm


Planar PM undulator

Under Development




Various components of SC Wavelength Shifter

International impact

- RRCAT has designed, developed and supplied various types of magnets for CERN and other accelerator establishments. These include 80 corrector magnets for LEP, 5 dipole magnets for CLIC and 3100 superconducting magnets (sextupole, octupole and decapole) for LHC.
- This activity has resulted in capacity building in Indian industry enabling them to develop magnets complying to precision geometric tolerances, thus making us Atmanirbhar in the area of precision magnets and circulators.

For more information: https://www.rrcat.gov.in

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Accelerator Power Supply Technology

RRCAT is involved in research and development of precision power supplies required primarily for various accelerators. Large number of power supplies based on various power converter topologies have been designed, developed and successfully deployed. Accelerator power supplies are known for stringent specifications in terms of (i) high stability (ii) repeatable performance (iii) precision timing (iv) high reliability etc. Application requirements of the power converters are diversified: power rating ranges from few 10s of watts to few 100s of kWs; output is ac, dc and pulsed. Emphasis is on the development and application of state-of-the-art technologies.

High-stability, switch-mode power converters for Indus and IRFEL

Ultra stable power converters for FAIR, Germany

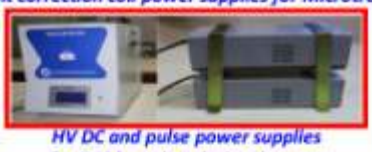
Bipolar Power Converters: Technology Transferred to Industry

Power supply for Indus-2 dipole magnets

Active shunt power supplies

Booster QP Magnet Adjustment Coil Power Supplies

Orbit correction coil power supplies for Microtron



HV DC and pulse power supplies for IMS based explosive detector

8.5kA,100us septum power supply

11 kA,3us kicker Power supply

5.5kA,1us Pinger power supply

1.5kA,200ns fast rise current pulse supply

Magnet power supplies for 10 MeV Vertical Linac

-30 kV, 10ppm power supply with integrated filament power supply for SEM, BARC

International impact

- Precision and specialized power supplies is a very important technology with concerted design and development efforts, self-reliance in this technology area has been achieved. The capability to design, develop, test, qualify and operate the precision power converters has been demonstrated in various accelerators. These power converter technology will play a crucial role in upcoming mega science projects.
- This activity has resulted in capacity building in Indian industry enabling them to develop precision power supplies of international standard, thus making us Atma Nirbhar in this advanced technology area.

For more information:

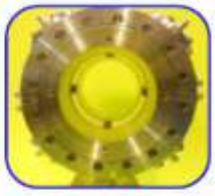
✓ https://www.rrcat.gov.in

Beam Diagnostics Technology for Accelerators

Beam diagnostics plays a crucial role in commissioning and operation of any particle accelerator. Beam diagnostic systems and devices provide information about the beam parameters required for optimization of beam and smooth operation of the particle accelerator. Various beam parameters that need to be monitored are beam position, beam profile, beam current, betatron and synchrotron tunes, bunch length, coupled bunch modes, beam instabilities etc.

In Indus accelerators, a number of ultra high vacuum compatible beam diagnostic devices have been installed which are used during regular machine operation, machine experiments and studies.


Beam Position Monitor for Indus-1


Beam Position Monitor for Booster


Low Aperture Beam Position Monitor

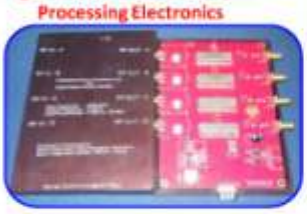

Digital Beam Position Monitor Processing Electronics


Vertical Scrapper for Indus-2


Beam Position Monitor for Indus-2


Beam Profile Monitor for Indus-2


Stripline Assembly for Indus-2


RF front End Electronics for Beam Position Monitor

Application of Various Beam Diagnostic Devices

Beam Position Monitor: It is used to measure the position of the charge centroid of the particle beam.

Stripline: It is used to measure the betatron tune and beam instabilities. It is also used in multi-bunch feedback system to control beam instabilities.

Beam Profile Monitor: It is used for visual observation of the beam shape and position.

Beam Scraper: It is used to locate the center of beam in beam duct and to infer about the transverse limit of the beam.

DC Current Transformer (DCCT): DCCT is used for measuring stored beam current (average) circulating in the storage ring. The beam lifetime is found out by plotting the decay of stored current with respect to time.

Wall Current Monitor (WCM): WCM is used for observing the bunch signal. Operator gets the information about the number and amplitude of bunches passing through it.

Fast Current Transformer (FCT): FCT is used for on-line observation of the beam current waveform.

Beam Slit Monitor: It is used as a slit with adjustable aperture to define the beam. It is also used to determine the horizontal and vertical beam profile.

For more information:
✓ https://www.rrcat.gov.in

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RF Technology Development

- In Particle Accelerators RF System provides energy (in terms of gap voltage) for acceleration of charge particles, beam power and also compensates for the losses like Synchrotron Radiation in Synchrotron Sources like Indus-1 and Indus-2. RRCAT has successfully executed design, development and applications of important indigenous advanced technology components/systems like RF Cavity, Circulator, wide band solid state amplifiers, very high power solid state (SSPA)and vacuum tube based RF Amplifier, solid state pulse modulator and Digital Low Level RF control system for various CW and pulsed RF systems of particle accelerators in India and abroad.
- Low and high energy charged particle accelerators are finding applications in scientific, industrial, societal, space and defence areas.

505.8 MHz RF Cavity of Indus-2 SRS

24 MW microwave system for IR-FEL

505.8 MHz RF Circulator for Indus-2

325 MHz, 150 kW pulsed SSPA

RF technologies like electron Gun, Multi way coaxial RF Combiner/Splitter, HV Pulse Transformer,LLRF boards,3 way RF Power Combiner, Directional Coupler

International impact

- RF Technology development is very important for achieving self reliance in the challenging field of high energy particle accelerators. This state-of-the-art technology development involves design, development, characterization, high power testing and commissioning of various RF sub systems in particle accelerators.
- This technology development will play a crucial role in future mega science projects. Also these RF technology innovations has resulted in infrastructure development of Indian industries enabling to develop RF systems of international standard.

For more information:

✓ https://www.rrcat.gov.in

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Superconducting Radio Frequency (SCRF) Cavities: Design, Fabrication and Testing

DAE's future accelerator projects will need large number of superconducting RF cavities. RRCAT is contributing to PIP-II project at Fermilab, USA (under IIFC collaboration) for superconducting cavity development.

Advantages of superconducting RF cavity

- Negligible surface resistance → Power consumption is much less than the normal conducting RF cavity.
- Nearly all RF power goes to the beam.
- CW operation at higher gradient possible
- Need fewer cavities for CW operation → Less beam disruption
- This is in contrast to normal-conducting cavities where the wall power loss can easily equal or exceed the beam power consumption.

SCRF cavity development progress at RRCAT

- Infrastructure has been developed for SCRF cavity forming, machining, electron beam welding (EBW), surface processing and vertical & horizontal testing at 2K.
- Initially few 1.3 GHz single-cell, 1.3 GHz multi-cells and 650 MHz (β=0.9) single cell SCRF cavities have been fabricated, processed and tested .
- Recently, seven 650 MHz (β=0.92) five-cell SCRF cavities have been fabricated, processed, tested & three have been supplied to Fermilab under IIFC. These cavities have been successfully qualified as per norms and are part of PIP-II prototype Cryo-Module.

1300 MHz 9 cell cavity

Multi-cell SCRF cavity development status

- Fabrication of six five-cell 650 MHz (Beta=0.92) & few 1300 MHz multi-cell SCRF cavities have been completed using the in-house infrastructure.
- Machining of components was carried out at Indian Industries which were developed previously to make them ready for future large scale requirements.
- Presently, these cavities are in various stages of processing and testing. Three of these cavities were sent to Fermilab, where these cavities are tested, qualified and dressed for PIP-II Cryomodule.
- RRCAT successfully dressed one SCRF cavity in indigenously build Glove Box.

650 MHz 5 cell cavities

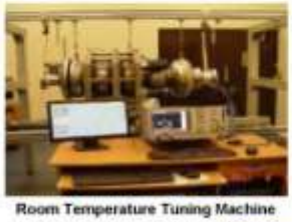
Dressed 5 cell cavity in glovebox

Electron Beam Welding Machine

Electropolishing Setup

ISO-4 Clean room for high pressure rinsing

High Vacuum Annealing Furnace



Room Temperature Tuning Machine

Vertical Test Stand (VTS)

Horizontal Test Stand (HTS)

650 MHz five-cell SCRF cavity in VTS and HTS

For more information:
https://www.rrcat.gov.in

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Ultra High Vacuum Technologies

RRCAT is involved in research and development of ultra high vacuum (UHV) systems required primarily for various accelerators. UHV systems of accelerators at RRCAT have been designed, developed and successfully deployed. UHV systems of Indus synchrotrons are highly specialized type of vacuum systems that is designed to create and maintain an extremely low-pressure environment, typically at or below 10^{-9} mbar stably for long beam life time as required for beamline users. Continuous efforts are being made for the development and application of state-of-the-art technologies, including metallic/non-evaporable getters (NEG) coatings, hybrid sputter ion pump, NEG pumps, & UHV gauge controllers.


Dipole UHV Chamber


Quadrupole / Sextupole UHV Chamber


Septum Chamber


Ti coated Ceramic Chamber for Pinger Magnet


Diamond Profile Al Sealed UHV Flange Joint


Water Cooled SR Heat Absorber


RF-Shielded SS Bellow


NEG Coated Undulator Chamber


Sputter Ion Pumps (SIPs)


SIP P/S


TSP P/S


BAG Controller


Hybrid (SIP+NEG) UHV Pump


NEG Coating Deposition Setup


TCU & Valve controller


UHV qualification of Prototype Undulator Vacuum Chamber

International impact

- UHV systems for modern storage rings consist of a variety of advanced technologies and techniques (advanced materials, manufacturing methods, metallic/NEG film deposition, UHV pumping & measurement, controlled bake-out system, compatible control & interlock systems and residual gas analysis). With intensive design and development efforts, self-reliance in this technological domain has been achieved. The capability to design, develop, install and operate the large UHV systems has been demonstrated in various accelerators.
- Development of state of art NEG and hybrid UHV pumping technologies will play a crucial role in upcoming mega science projects, thus making us Atma Nirbhar in this advanced technological domain.

For more information:

✓ https://www.rrcat.gov.in

Liquid Nitrogen Based Transportable Refrigerated System SHIVAY (Sheetal Vahak Yantra)

A new technology has been developed for transportation of cold cargo which uses liquid nitrogen(LN_2) for refrigeration instead of conventional diesel powered CFC based system. This will be useful for transport of fruits and vegetables produced by farmers. It is a more economical method as compared to conventional system of reefers. The farmers will be benefited significantly. This will also be useful for pharmaceuticals and vaccines. System has been designed keeping Indian conditions in mind.

20 Feet Full Truck Sized Container During Road Trial

The advantages over conventional system are:

- The cost of liquid nitrogen consumed is significantly lower than cost of diesel consumed under same conditions.
- This standalone system needs no input from vehicle or driver. Multi modal features are significant as it can be used on truck, train both.
- Prototypes have been road tested for ~3000km cumulatively. Only two moving parts are used so minimum maintenance is expected.
- LN_2 is 100% eco friendly. It is a by-product of oxygen plants, with no appreciable demand and huge excess capacity exists in India.

Technology has been transferred to M/s Tata Motors Ltd. through Incubation centre, RRCAT

For more information:
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भारत का पहला स्वदेशी हीलियम द्रवीकरण यंत्र

India's First Indigenous Helium Liquefier

Description of R&D Efforts

- An indigenous Helium liquefier based on reciprocating type expansion engines was developed to support our various developmental programs.
- Its liquefaction capacity is gradually increased from 8 litres/hour to the present 45 litres/hour.
- To handle the high heat of compression for helium gas, suitable modifications were incorporated to provide additional cooling. Compressor oil removal system was designed and fabricated by local fabricators. The main process compressor, which maintains and supplies pure oil free high pressure helium is also procured from an Indian manufacturer. Gradually, improvements were carried out to increase the liquefaction rate of this liquefier by adding larger size cryogenic expanders, liquid nitrogen pre-cooler stage, plate fin heat exchangers and an additional compressor.
- State of the art brazed aluminium plate fin heat exchangers having very high efficiency and compactness with few mbar of pressure drop were developed with an Indian vendor.

Indigenously designed and developed Helium liquefier with important sub-components

Science & Technology Innovation/International impact

- Development of Swadeshi helium cryogenic technological know-how is very crucial for achieving self-reliance in the strategic area of high power future accelerator systems. Only few countries in the world have technological prowess to build helium liquefier.
- Maximum liquefaction achieved with present the system is 45 litres/hour.

Benefit to Nation

- Development of helium liquefier opens new vistas for understanding complex technologies such as helium cryogenics.
- This resulted in development of new subsystems which are building blocks for any cryogenic system such as reciprocating cryogenic expanders, plate fin heat exchangers, transfer lines for cryogen transfer and sensor calibration near to absolute zero temperature.
- These technological developments are in particular valuable for the development of high intensity proton Linac for national large scale projects like Spallation Neutron Source (SNS) and Accelerator Driven Systems (ADS).

अधिक जानकारी के लिए For more information:

✓ https://www.rrcat.gov.in

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अत्याधुनिक त्वरकों के निर्माण में भारतीय योगदान : अंतर्राष्ट्रीय सहयोग

Indian Contributions to Large Hadron Collider (LHC) at CERN

- The Large Hadron Collider (LHC), constructed through a world wide collaboration, accelerates and collides high energy protons/hadrons for fundamental high energy physics studies.
- India has supplied a significant number of components and equipment for the construction of LHC under co-operation agreement & related protocols. Based on its contributions India is accorded Associate member status of CERN Council on January 16, 2016.
- RRCAT, Indore has been the Nodal Institute for the DAE-CERN Collaboration.
- India participated in construction of Linac 4 for LHC upgrade and Compact Linear Collider Test Facility.

LHC, Biggest Accelerator in the world installed in 27 km circular tunnel, 100m below ground.

LHC machine resting on PMPS jacks supplied by RRCAT Indore

High Technology components supplied from India to LHC

SC corrector Magnets

Quench Heater Protection System

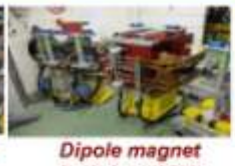
Circuit Breaker Electronics

Local Protection units

Contributions for Novel Advanced Accelerators at CERN

100 kV Solid state modulator

Power couplers for Linac 4 accelerator



Dipole magnet in TL2 of CTF3

Racetrack and Round profile Vacuum Chambers for CTF3

20kW SSPA for CLIC

Contributions under Novel Accelerator Technology Protocol

- A 110 kV state of the art solid state bouncer modulator developed by RRCAT, for LINAC 4 at CERN.
- WR 2300 Cu coated SS high power couplers for Linac 4 accelerator for LHC luminosity upgrade
- Optics design, Dipole magnets, Vacuum chambers and expert support for Compact Linear Collider Test Facility -3
- State of the art 20 kW wide band Solid state RF power amplifier for sub harmonic buncher for CLIC injector.

Subsequent to India becoming Associate Member of CERN, Indian industries are able to participate in CERN procurement/tendering and are manufacturing and supplying items to CERN.

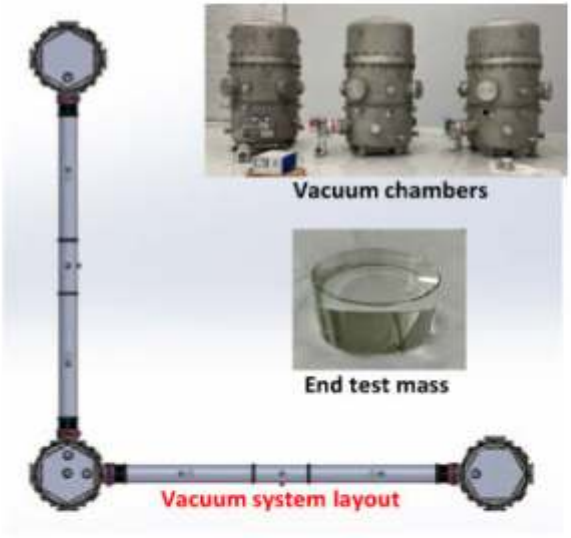
अधिक जानकारी के लिए For more information:

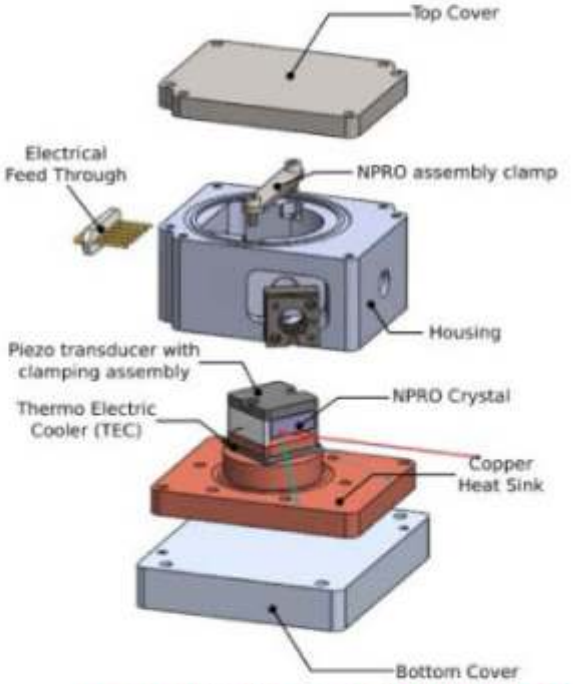
✓ https://www.rrcat.gov.in

LIGO-India Project

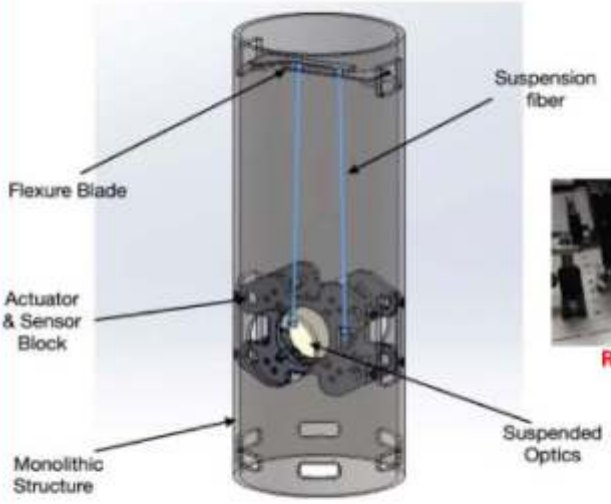
(DAE - DST Mega Science Project in collaboration with LIGO-USA)

The LIGO-India Project proposal is for the construction of an advanced interferometric gravitational wave detector in India, called LIGO-India, under an international collaboration with Laser Interferometer Gravitational–wave Observatory (LIGO) Laboratory, USA. The four lead institutes (IUCAA, DCSEM, IPR & RRCAT) and the LIGO Laboratory, USA will work together in realizing the Indian node (LIGO-India) of the international gravitational wave detector network in India.



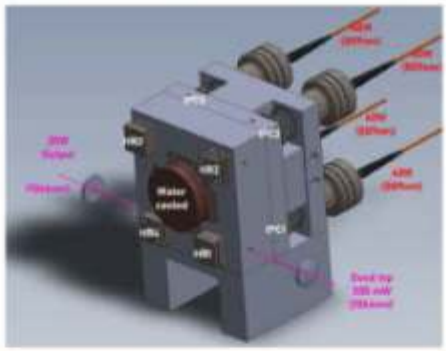


Laser system (Oscillator four-pass amplifier)



Optics suspension scheme

Reference cavity



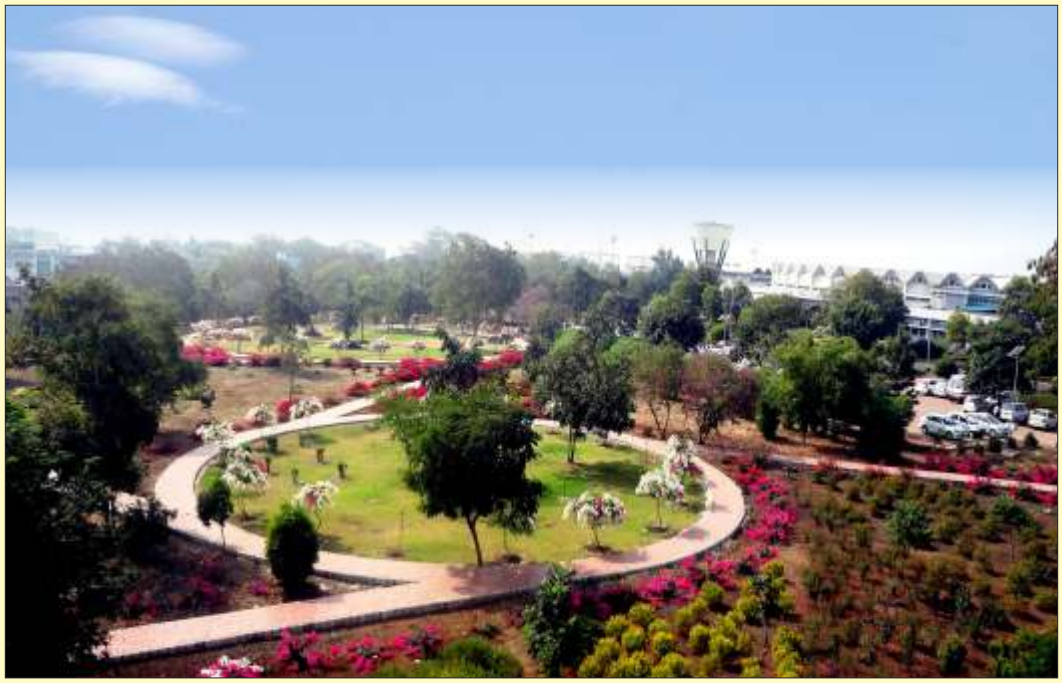
Different sub-systems of 10 m arm length prototype interferometer being setup at RRCAT

As a lead institute for LIGO-India Project, RRCAT is responsible for setting up the 4 km arm length interferometer, overall coordination for the project and R&D towards the next generation of Gravitational Wave Detectors. As part of the project RRCAT is setting up a 10 m arm length Interferometer for training and testing of techniques and components for the next generation detectors. All the key components for the 10 m Interferometer have been designed and developed in-house.

For more information:
https://www.rrcat.gov.in

Flora and Fauna in RRCAT

Diamond Jubilee Park at RRCAT



Garden in front of Indus Complex