ACADEMY OF SCIENTIFIC AND INNOVATIVE RESEARCH

# SYLLABUS

# OF

# ADVANCED COURSES

# FOR

# PhD PROGRAM

*(A part of the August 2020 Revised Course Structure)*

Academy of Scientific and Innovative Research
CSIR-HRDC Campus, Sector-19, Ghaziabad, U P., India

Reommended at the 4th meeting of Board of Studies, AcSIR on Sep 7, 2020.
Approved at the 27th meeting of Senate, AcSIR on Sep 10, 2020

Revision of course curriculum from several perspectives (including updation to state of art knowledge & others) is a dynamic process restructuring for the contemporary needs and expectations w.r.t. courses of study for an academic program. This dynamic process is driven by growing needs and contemporary advancements in respective fields.

Academy of scientific & Innovative Research (AcSIR) aims to train and create quality human resource with positive attitude towards learning, leading to specialization in Ph.D. curricular education. An endeavour to revise the AcSIR Ph.D. study course syllabus has been done basically to provide opportunities to extend as well as deepen their knowledge, understanding, develop competencies & skills. It also emphasizes in the structure of teaching, learning and course duration so that it is optimum to earliest entry of students to their lab research phase of the program.

The academic programme in each of the five faculties in which AcSIR offers Ph.D. degrees is administered by a Board of Studies (BoS). The core courses have syllabi that are designed by the faculties in those areas, who have pursued research and taught these courses. Besides this, in order to get the most out of the expertise of the faculty members and their research experience in learning by students, some flexibility is given to the instructors in each course so that they can introduce a few special topics of their choice, making the course unique. Advanced courses are normally given by the faculty members in their own area of expertise. Each AcSIR Academic Centre has its area of specialization and expertise.

General Objectives of the course is that after successfully going through it, students will be able to understand the methods and techniques, developing knowledge and competencies, to be helpful in their research plans ahead in his/her selected field of research. Also, to support the students to understand the nature of problems faced during the Ph.D. period, develop suitable interdisciplinary scientific methods through some innovative remedies and learn to solve them.

Identical titles with identical contents listed across the faculty of Studies were pruned and only one is listed under the most relevant faculty with course serial no.

# Course Requirements

# For Completion of PhD Program

Minimum credits required to be successfully completed: 18 credits

Distribution of the 18 credits:

- Course 1: Total credits: 6 (consisting of two courses as under)
  - Research Methodology: 4 credits
  - Research Publication and Ethics: 2 credits
- Course 2: Total credits: 2 (consisting of one or two courses)
  - Inter-disciplinary/ Cross-disciplinary Course: 2 credits (either two courses of 1 credit each OR one course of 2 credits, to be opted from the list of offered courses)
- Course 3: Total credits: 6 (consisting of two or three courses)
  - Advanced Course: 6 credits (either two courses of 3 credit each OR three courses of 2 credits each, to be opted from the list of offered courses within Institute; restrictions of exclusion may apply when opted across Institutes)
- Course 4: Total credits: 4
  - Societal Program: Problem Understanding and Analysis: 4 credits (Group activity of upto five Team members from within Institute or across Institutes), no restriction of Faculty of Study, discipline of an AcSIR student.

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**How to read Course Codes:** Every Advanced Course in AcSIR has a unique course code. A code can be understood as under:

# AcSIR- 01- XX YY- 001

**Two numbers identify AcSIR centres code:**

| Code | Lab Name |
|---|---|
| 1 | CBRI, Roorkee |
| 2 | IGIB, New Delhi |
| 3 | CCMB, Hyderabad |
| 4 | CDRI, Lucknow |
| 5 | CECRI, Karaikudi |
| 6 | CEERI, Pilani |
| 8 | CFTRI, Mysuru |
| 9 | CGCRI, Kolkata |
| 10 | CIMAP, Lucknow |
| 11 | CLRI, Chennai |
| 12 | CMERI, Durgapur |
| 14 | CRRI, New Delhi |
| 15 | CSIO, Chandigarh |
| 16 | CSMCRI, Bhavnagar |
| 17 | IICB, Kolkata |
| 18 | IICT, Hyderabad |
| 19 | IIP, Dehradun |
| 20 | IMTECH, Chandigarh |
| 22 | IITR, Lucknow |
| 24 | NAL, Bengaluru |
| 25 | NBRI, Lucknow |
| 26 | NCL, Pune |
| 27 | NEERI, Nagpur |
| 28 | NGRI, Hyderabad |
| 29 | NIO, Goa |
| 30 | NISTADS, New Delhi |
| 31 | NML, Jamshedpur |
| 32 | NPL, New Delhi |
| 33 | IHBT, Palampur |
| 35 | AMPRI, Bhopal |
| 36 | IMMT, Bhubaneswar |
| 37 | IIIM, Jammu |
| 38 | NEIST, Jorhat |
| 39 | NIIST, Trivendrum |
| 41 | SERC, Chennai |
| 42 | NISCAIR, New Delhi |
| 43 | CIMFR, Dhanbad |
| 44 | URDIP, Pune |
| 45 | 4PI, Bengaluru |
| 61 | PHFI-IIPH-Delhi |
| 62 | PHFI-IIPH-Hyderabad |
| 63 | LVPEI, Hyderabad |
| 64 | BSIP, Lucknow |
| 65 | NIMR, New Delhi |
| 66 | IASST, Guwahati |

**These letters show the Faculty of Study i.e. XX can be:**

BS: for Biological Sciences

CS: for Chemical Sciences

PS: for Physical Sciences

ES: for Engineering Sciences

MIS: for Mathematical & Information Sciences

**Two letter shows course type i.e. YY can be:**

RM: for Research Methodology

RP: for Research Publication and Ethics

ID: for Inter-disciplinary/ cross-disciplinary Learning

AD: for Advanced

SP: for Societal Program

**A serial number for course to distinguish**

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# Advanced Courses and Syllabus

## Course contents

| | | | | |
|---|---|---|---|---|
| 33. | 38 | CSIR-NEIST | 40 | 574 |
| 34. | 39 | CSIR-NIIST | 11 | 617 |
| 35. | 41 | CSIR-SERC | 08 | 629 |
| 36. | 42 | CSIR-NISCAIR | 07 | 638 |
| 37. | 43 | CSIR-CIMFR | 18 | 646 |
| 38. | 44 | CSIR-URDIP | 09 | 666 |
| 39. | 45 | CSIR-4PI | 12 | 676 |
| 40. | 64 | DST-BSIP | 12 | 689 |
| 41. | 66 | DST-IASST | 31 | 702 |

| Faculty of Study | Course Code | Course Title |
|---|---|---|
| Chemical Sciences | AcSIR-32-CS-AD-001 | Advanced Polymer Science and Technology |
| Engineering Sciences | AcSIR-32-ES-AD-001 | Advanced Materials Characterization Techniques |
| Engineering Sciences | AcSIR-32-ES-AD-002 | Air Quality Measurement Science and Technology |
| Engineering Sciences | AcSIR-32-ES-AD-003 | Instrumentation for Calibration & Testing |
| Engineering Sciences | AcSIR-32-ES-AD-004 | Optimization Techniques and Finite Element Method in Engineering |
| Physical Sciences | AcSIR-32-PS-AD-001 | Engineering Materials |
| Physical Sciences | AcSIR-32-PS-AD-002 | Advanced Electronic Materials and Semiconductor Devices |
| Physical Sciences | AcSIR-32-PS-AD-003 | Thin Film Physics & Technology |
| Physical Sciences | AcSIR-32-PS-AD-004 | Nanostructured Materials |
| Physical Sciences | AcSIR-32-PS-AD-005 | Superconductivity and Magnetic Materials |

| AcSIR Academic Centre Code: 32 | |
|---|---|
| **CSIR-National Physical Laboratory** | **CSIR-NPL** |

| Course 3 : Advanced Course | Chemical Sciences | Total Credits 6 |
|---|---|---|

| Title: Advanced Polymer Science and Technology | Course Code | Credits |
|---|---|---|
| | AcSIR-32-CS-AD-001 | 3 |

Introduction of conventional, specialty & engineering polymers, functional polymers, copolymers, polymer blends, micro- & nano-composites, conjugated & conducing, polymers, polyacetylene, polyaniline, polypyrrol, polythiophene derivatives & analogues, band structures, doping types, doping mechanisms, charger carriers, charge transport mechanism, conjugatedcopolymers, conjugated polymer blends: synthesis strategies, properties, processing techniques, specialized products, analytical and characterization tools, related metrology, environmental concerns, recyclability and practical applications, organic solar cells, organic light emitting diodes, transistors, display devices, solid state lighting, gas/chemical sensors, biosensors, actuators, healthcare & assistive, devices, electrochromic devices, memory devices, corrosion control, electromagnetic, interference shielding, electostatic charge, dissipation, air/water purification, supercapacitor, lithium ion battery,
theroelectrics etc., Polymer based certified, reference materials (CRMs) and Bhartiya Nirdeshak Dravva (BNDs)

| AcSIR Academic Centre Code: 32 | | |
|---|---|---|
| CSIR-National Physical Laboratory | | CSIR-NPL |
| Course 3 : Advanced Course | Engineering Sciences | Total Credits 6 |

| Title: Advanced Materials Characterization Techniques | Course Code | Credits |
|---|---|---|
| | AcSIR-32-ES-AD-001 | 3 |

Fundamentals of X-rays and X-ray crystallography, Instrumentation, Bragg's law, Data analysis by different software's, Determination of crystal structures-X-ray, Laue, Single crystal X-ray and powder X-ray methods, Applications & limitations, X-ray fluorescence spectrometry, Wavelength dispersive XRF, Instrumentation, Working procedure, Applications & limitations, Energy dispersive spectroscopy, X-ray photoelectron spectroscopy, Auger electron spectroscopy- Instrumentation, Working procedure, Applications & limitations.
Characterization of crystalline perfection of single crystals & epitaxial films - crystal defects and lattice mismatch, Theoretical aspects of X-ray diffraction, Reflection and scattering, High resolution X-ray diffraction for Bragg and Laue cases, Semi-kinematical theory for epitaxial layers for determination of thickness and composition, Xray reflectometry for determination of density, Thickness and interfacial roughness, Experimental aspects: Monochromators, Point and line focus configurations of X-ray beam, Parabolic graded multilayer mirror, Flow proportional and scintillation detectors, Solid-state pixel detector, High-resolution X-ray diffractometers high resolution X-ray diffraction curves, X-ray topography, X-ray reflectometry, Grazing incidence, X-ray diffractometry for in-plane diffraction, Reciprocal space mapping.
Thermo-gravimetric analysis (TGA), Measuring contact angle, Electron-sample interactions: Secondary electrons, Backscattered electrons, Lenses for electron beams, Lens defects and resolution, Structure of transmission electron microscopes, Mechanism of images formation and contrast, Structure of scanning electron microscopes (SEM, ESEM). Electron emissions sources, Vacuum conditions, Scanning electron microscopy, Conventional transmission electron microscopy, High resolution transmission electron microscopy, Selected area electron diffraction, Bright field and dark field imaging, Electron diffraction patterns, Correlation of image and diffraction pattern, Examples of indexing singlecrystals diffraction patterns, Sample preparation for SEM, TEM: Jet-polishing methods. Ion beam milling technique, Focus ion beam (FIB), Scanning transmission electron microscopy, Lattice scale imaging, Interpretation of high resolution images, Scanning tunneling microscopy, Atomic force microscopy, Helium ion microscope, Other advances techniques like, Holography, Lorentz microscopy.
Spectroscopy techniques: Fourier transform infrared spectroscopy, Raman spectroscopy, Secondary ion mass spectroscopy, Electron paramagnetic resonance spectroscopy, Photoluminescence, Defect structure analysis using microscopy and spectroscopy results, Particle size analyzer.



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| CSIR-National Physical Laboratory | CSIR-NPL |
|---|---|

| Course 3 : Advanced Course | Engineering Sciences | Total Credits 6 |
|---|---|---|

| Title: Air Quality Measurement Science and Technology | Course Code | Credits |
|---|---|---|
| | AcSIR-32-ES-AD-002 | 3 |

Aerosol and gas metrology, national ambient air quality standards (NAAQS), gas measurement techniques, certified reference material, gas mixtures preparation and validation technique, PM10 and PM2.5 measurement techniques and their calibration (gravimetric sampler BAM. TEOM), impactor and cyclone. WINS and VSCC. Andersen sampler, bioaerosol sampling and measurement, particle sizer - counter and calibration, particle size statistics, filter and mask testing, air purifier testing
and CADR, Reynolds number. Stokes's law. Stokes number, D50 cutoff size, isokinetic sampling and measurement of concentration, measurement of velocity, flow rate and pressure, stack sampling, analysis of particulate bound chemicals, AAS and ICP-OES instrumental techniques, VOC measurement techniques, measurementuncertainty in chemical analysis, MU budget estimations and data quality assurance, hands-on training on the parameters of NAAQS.



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| AcSIR Academic Centre Code: 32 | | | |
|---|---|---|---|
| CSIR-National Physical Laboratory | | | CSIR-NPL |
| Course 3 : Advanced Course | Engineering Sciences | | Total Credits 6 |
| Title: Instrumentation for Calibration & Testing | | Course Code | Credits |
| | | AcSIR-32-ES-AD-003 | 3 |

Measurement and Instrumentation, Fundamental of measurement systems, Instrument Types and Performance Characteristics, Measurement Uncertainty.
Calibration/Verification of measuring instruments: what need for users; Calibration principles: Calibration system
procedure, Calibration and Testing standards for instruments and transducers; Best practices for handling the measurement instruments. OPAMP
characteristics & circuits, Sensor & transducer characteristics, Instrumentation and Telemetry, quantum instrumentation & metrology. Instrumentation: Industry 4.0
perspective; Instrumentation Design: Need Analysis, product specifications, solution search strengths & weaknesses of instruments.
Performance characteristics & criteria fortransducers selection. Performance test (electrical, impedance, noise, resolution, threshold and environmental test etc).
Need of signal conditioning. Interface to the end i.e. display and storage devices. Computer based instrumentation. Virtual Instrumentation.



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|---|---|---|
| CSIR-National Physical Laboratory | | CSIR-NPL |
| Course 3 : Advanced Course | Engineering Sciences | Total Credits 6 |

| Title: Optimization Techniques and Finite Element Method in Engineering | Course Code | Credits |
|---|---|---|
| | AcSIR-32-ES-AD-004 | 3 |

Introduction: Introduction to Optimization, Adequate and Optimum Design, Principles of Optimization, Statement of an Optimization Problem, Classification, Formulation of Objective Function, Design Constraints; Classical Optimization Techniques and Multi Variable Unconstrained and Constrained Optimization; Traditional Optimization Techniques: Genetic Algorithms, Simulated Annealing, Geometric Programming; Finite Element Method: Basics and Applications in Engineering systems, Case study of applications in design of force sensor, vibration analysis of machines. Optimum Design of Machine Elements: Functional Requirement, Material and Geometrical Parameters, Loading parameters, design morphology, case study; single degree and two degree of freedom systems, vibration isolation, active and passive vibration absorbers, Acousticc induced vibration: measurement and control.



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| AcSIR Academic Centre Code: 32 | |
|---|---|
| CSIR-National Physical Laboratory | CSIR-NPL |

| Course 3 : Advanced Course | Physical Sciences | Total Credits 6 |
|---|---|---|

| Title: Advanced Electronic Materials and Semiconductor Devices | Course Code | Credits |
|---|---|---|
| | AcSIR-32-PS-AD-002 | 3 |

Energy band diagrams, Theory of semiconductor transport, Quantum hall effect, Colloidal nanoparticles and quantum dots for optoelectronic applications, Mechanical, optical & electrical properties, Nucleation & growth mechanism, Sizefocusing & Ostwald ripening, Hybrid nanocomposite solar cells: Charge & energy transfer (FRET), Excitons, Plasmons-polaritons-polarons: Raman & Rayleigh scattering, Surface-enhanced Raman scattering (SERS), Phase change materials, Ferroelectrics and dielectrics, Semiconductor crystals, Photonic devices and their applications: (i) Photovoltaic devices (i.e., solar cells), (ii) Lightemitting diodes (LEDs) and laser diodes, (iii) Photodetectors, Basic device physics (p-n junction diode, semiconductor contacts, Schottky barriers/diodes), Structures, characteristics and operational principles (based on elemental and compound semiconductors), Latest developments and advanced applications, organic electronics (like solar cells, light emitting diodes, transistors etc).

Practicals: Particle size and size distribution measurement of semiconductor nanoparticles by dynamic light scattering (DLS), Dark and illuminated I-V characteristics of p-n junction diode/solar cell and evaluation of solar cell efficiency, Spectral response and quantum efficiency measurements of solar cells and performance comparison,

Fabrication and testing of organic devices.



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|---|---|---|---|
| CSIR-National Physical Laboratory | | | CSIR-NPL |
| Course 3 : Advanced Course | Physical Sciences | | Total Credits 6 |
| Title: Thin Film Physics & Technology | | Course Code | Credits |
| | | AcSIR-32-PS-AD-003 | 3 |

Vacuum science & technology for thin film processing, Vacuum systems for thin film growth & characterization, Gas transport and pumping, Thin films growth mechanisms, Kinetic models of nucleation, Thermodynamics aspects of nucleation, Island and coalescence growth, Factors influencing thin film growth, Role of surface energy in thin film growth, Steps in thin film formation, Thin film deposition techniques: Physical vapor deposition (PVD), Evaporation (resistive heating, flash, electron beam, ion beam and pulsed laser), Physics and chemistry of evaporation, Sputtering (mechanisms and yield, dc and rf sputtering, Bias sputtering, Magnetron sputtering, Unbalanced magnetron sputtering), Physics of sputtering and reactions in plasma, Hybrid and modified PVD, Ion plating, Ion beam assisted deposition and processing of thin films, Cathodic vacuum arc deposition, Quasi-continuous theory of arc plasma, Magnetic filtered arc and industrial systems & processes. Chemical vapor deposition (CVD): Reaction chemistry and thermodynamics of CVD, Thermal CVD, MOCVD, Hot wire CVD, Ultrahigh vacuum techniques and processes, Contamination and cleaning, Molecular beam epitaxy: Principal & operation, Knudsen cell, kinetics & thermodynamics, Growth of epitaxial films & nanostructures, Adsorption at surfaces, Atomistic processes in the early stages of thin-film growth, Adatom diffusion on terraces & nucleation of islands, Diffusion & fractal island growth, Surface reconstruction, Adsorbate-induced reconstructions. Reflection high energy electron diffraction: in-situ two & three dimensional growth characterization, Surface crystallography and diffraction, Surface symmetry, Description of overlayer structures, Reciprocal net & electron diffraction, Qualitative consideration, Domains, Steps and defects, Low energy electron diffraction (LEED): Principles, Instrumentation, Qualitative information, LEED Pattern, Spot profile analysis, Quantitative structural information.

X-Ray photoelectron spectroscopy: Principles, Instrumentation, X-Ray sources, Synchrotron radiation, Electron energy analyzers, Spatial resolution, Spectral information and chemical shifts quantification, Depth profiling & imaging, Auger parameter, Applications in catalysis, Polymers, Corrosion and passivation, Adhesion, Superconductors, Semiconductors, Ultraviolet Photoelectron spectroscopy: Concept, Instrumentation and Spectral analysis, Auger electron spectroscopy (AES): Principles, Instrumentation, Electron sources, Electron-energy analyzers, Spectral information, Quantification and depth profiling, Applications in thin films and interfaces, Surface segregation, scanning auger microscopy.

Thin film characterization: Defect analysis, Surface profiler (contact & non-contact mode), Spectroscopic ellipsometer: Concept, thickness and optical parameter (n, k, a) evaluation. Applications of thin films in optical coatings & solar cells.



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| CSIR-National Physical Laboratory | | CSIR-NPL |
| Course 3 : Advanced Course | Physical Sciences | Total Credits 6 |

| Title: Nanostructured Materials | Course Code | Credits |
|---|---|---|
| | AcSIR-32-PS-AD-004 | 3 |

Physical scaling laws applied to understanding the properties of materials at the nanometre scale. Self-assembly, surfaces and interfaces in nanotechnology.
Nanostructuring techniques: Nanopolishing, Etching of nanostructures, Lithography procedures: Optical lithography, Electron beam lithography, Ion beam lithography, X-ray, Synchrotron lithography, Focused ion beams, Nanoimprinting. Nanolayers by physical vapor deposition methods, PLD, Sputtering, e-beam evaporation, MBE, Chemical vapor deposition (CVD); Characterization of nanomaterials: Structure, Composition, Defects, Interfaces, Grain boundaries. Characterization of nanostructures by scanning probe microscopy, Near-field optics, Electron microscopy etc. Physics at low dimensions, Heterostructures, Band engineering, Quantum wires, Quantum dots, Effective mass approximation, Quantum wells in heterostructures, Square well of finite and infinite width, Triangular and parabolic quantum wells, Tunneling transport, Potential step, T-matrices, Current and conductance, Resonant tunneling, Tunneling in heterostructures, Effects of electric and magnetic fields, Density of states, Conductivity and resistivity tensors, Quantum correction to conductivity, SD effect, Quantum hall effect, Aharanov-Bohm effect, Nanomagnetism, Surface/interface magnetism, Anophotonics. Electronic devices based on nanostructures, High electron mobility transistors, Resonant tunneling diode, Quantum cascade laser, Single electron transistor, Carbon nanotube and grapheme devices and spintronic devices, Phase transition in nanostructures systems.



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|---|---|---|
| CSIR-National Physical Laboratory | | CSIR-NPL |
| Course 3 : Advanced Course | Physical Sciences | Total Credits 6 |

| Title: Superconductivity and Magnetic Materials | Course Code | Credits |
|---|---|---|
| | AcSIR-32-PS-AD-005 | 3 |

Introduction to superconductivity, Thermodynamics of superconducting transition, Two-fluid model London theory Pippard's non localization, Fluxquantization, Superconducting tunneling phenomena and energy gap, Introduction to microscopic theory (Bardeen-CooperSchrieffer) of superconductivity. Type II superconductivity, Mixed state and Ginzburg-Landau theory, Critical currents, Flux-pinning and flux-flow. Applications of superconductivity, Materials requirement for superconducting devices, Superconducting thin films, SQUIDs and Josephson junction based devices, Detectors and bolometers. High current applications, Synthesis methods for wires and tapeconductors, Superconducting magnets, Energy storage. High temperature superconductors: Introduction & their unusual fundamental properties, Electronic and power applications of hightemperature superconductors. Physical properties of materials at low temperatures (specific heat, thermal conductivity, thermal expansion, electrical conductivity, magnetic and mechanical properties). Production of low temperatures, Cryogenic fluids their properties and storage, Transfer devices, Temperature control & measurement, Production of very low temperatures, Vacuum systems as applied to cryogenics. Magnetism: Magnetic moments of a body, Alignment of atomic magnetic moments in a solid, Ferromagnetism, Curie point and exchange integral, Magnetisation and magnetic domains, Temperature dependence of magnetization, Coercive force and hysteresis, Coercivity in fine particles. Ferrimagnetism and antiferromagnetic order, Neutron magnetic scattering magnetism of transition metals, Rare-earths and special oxides (spinels, garnets and perovskites). Magnetoresistance, Tunnel magnetoresistance, Spintronics.



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**AcSIR Academic Centre Code: 32**

**CSIR-National Physical Laboratory** **CSIR-NPL**

| **Course 3 : Advanced Course** | **Physical Sciences** | **Total Credits 6** |
|---|---|---|

| Title: | Course Code | Credits |
|---|---|---|
| **Quantum Optics & Advanced Solid State Optical Devices** | **AcSIR-32-PS-AD-006** | **3** |

Quantum mechanics, quantum optics and Devices: Quantum theory and wave nature of matter, wave function and its interpretation, wave equations and solutions, Egen value and eigen functions, motion of wave packets, double oscillator; different types of potentials - normalization of free particle wave function, coherence theory - classical coherence, quantum coherence; semiconductor photon sources and detectors - light emitting diodes, laser amplifiers and injection lasers, photodetectors, photoconductors, photodiodes and avalanche photodiodes, single photon detectors; theory of photoelectric detection of light - differential photodetection probability, joint probability of multiple photodetection, integral detection porbabilities, photoelectric detection in a fluctuating field - photoelectric bunching, photoelectric counting statistics of a fluctuating field, photoelectric current fluctuations, Hanburry Brown - Twiss effect - photon antibunching. Quantum Metrology of Time and Frequency. Frequncy standards, macroscopic frequency sources. laser frequency standards. Characterization of noise processes - amplitude and phase noise. Statistical characterization of the noise processes. Measurement techniques of phase and frequency noise. Atomic frequency standards, primary and secondary frequency standards. Microwave atomic frequency standards as H-maser, Rb cell standards, cesium beam standards. Sources of frequency biases and their evaluation. Physics of cold atoms - laser cooling and trapping. Optical Molasses and magneto optic traps. Polarization gradient cooling. Bose Einstein condensation. Atomic Fountain frequency standards based on cold atoms. Cesium fountain frequency standard. Evaluation of sources of frequency biases. Ion trap frequency standards. Realization of different types of traps. Microwave and optical frequency standards based on trapped ions. Synthesis and translation of optical frequencies including femto-second comb, applications of precision frequency standards.

Experiment:
1. Doppler free absorption spectroscopy of atomic vapor for frequency stabilization
2. Absolute measurement of frequency, time interval and phase differences

**AcSIR Academic Centre Code: 32**

| **CSIR-National Physical Laboratory** | **CSIR-NPL** |
|---|---|

| **Course 3 : Advanced Course** | **Physical Sciences** | **Total Credits 6** |
|---|---|---|

| **Title:** | **Advanced Measurement Techniques & Metrology** | **Course Code** | **Credits** |
|---|---|---|---|
| | | **AcSIR-32-PS-AD-007** | **3** |

Overview of measurement science, physico-mechanical and electrical metrology, International System of Units (SI), brief about evolution of metrology and SI, recent advancements in SI units. Evolution of SI base and related derived units, current status, realization through primary and secondary standards, advanced measurement techniques, metrological traceability, dissemination, beneficiary industries and sectors; (i) Length and dimension (frequency comb, frequency stabilized lasers, interferometers, other optical methods); (ii) Mass (Watt balance, X-ray-crystal-density method, robotic comparators, vacuum comparators) and related quantities such as force, pressure, vacuum, fluid flow; (iii) Electrical quantities such AC-DC Voltage (Quantum voltage standard), Resistance (Quantum Hall standard), current (Single electron tunneling, Quantum phase slip) and AC-DC power; (iv) Thermometry (triple point of water, International Temperature Scale ITS-90, fixed points, realization of Boltzmann constant, radiation pyrometry); (v) Radiometry and Photometry (cryogenic radiometry, spectroradiometry, goniophotometry, sphere-photometry, quantum radiometry). International and national metrological infrastructure.