L.4: Magneto-Photoluminescence: A tool for investigation of quantum structures

Optoelectronic devices based on semiconductor materials are developed at RRCAT by growing semiconductor heterojunction and quantum structures of excellent quality. The electrical to optical conversion efficiency and response of such devices, primarily depends on the crystalline and optical quality of the grown heterostructures. X-ray diffraction and transmission electron microscopy are old and efficient techniques to estimate the strain and lattice disorder in an epilayer and also in quantum structures using various mode of scanning. However, both the techniques do not predict directly the influence of ultralow disorder on the opto-electronic properties of the material. Generally, contact based transport of charge carrier, as in classical/quantum Hall effect experiments, are performed to realize the density of defects and their influence on the performance of optoelectronic devices. In contrast, contactless photoluminescence (PL) and surface photo-voltage (SPV) spectroscopy are more effective techniques for studying the optical quality and also the defects. Superiority of these contactless techniques lies in their simple and non-destructive nature. Localization of charge carrier and their dynamics can be understood from the conventional emission and absorption of photon based PL and SPV techniques. In order to acquaint quantitative information of exciton, such as effective mass, binding energy, Bohr radius, one can introduce magnetic field while performing PL measurements. It leads to additional confinement to charge carriers in quantum system. In order to obtain these details a contact less magneto-PL instrument is setup. In this setup sample is kept in a holder of variable temperature inserts (VTI) which is immersed inside a Dewar of the thermostat where the lowest temperature 1.4 K with mK accuracy can be achieved. High magnetic field up to 8T is achieved by helical shaped niobium-titanium superconducting magnet. Figure L.4.1(a) show the photograph of superconducting magnet. The laser light is passed through band pass filter to remove any unwanted fluorescence lines from the diode-pumped solid-state lasers, followed by neutral-density filters to control the laser excitation power. The laser excitation power is kept at minimum levels to reduce the intensity dependent effects, such as saturation of energy levels, linewidth broadening, temperature rise etc. The chopped laser light is focused into an optical fiber using gold coated GaAs mirror. The excitation laser beam is guided through an optical fiber having ~ 400 µm diameter with ~ 3 meter length. Samples kept at 1.4 K are excited by the laser light that is guided with the help of a fiber and the same fiber is used to collect the PL signal. The PL signal after suitable filters is dispersed by monochromator and detected by Si/Ge photodiode using lock-in amplifier technique. Figures L.4.1(b)&(c) show the optical and electrical data processing arrangement for magneto-PL experiment. In this experiment, the sample is mounted horizontally in the VTI assembly and field is applied along the growth direction, known as Faraday geometry, and excitonic properties are probed in the plane of the sample, shown in Fig. L.4.1(d). Under this condition the magnetic field driven confinement of charge carrier at high field produce discrete harmonic oscillator like Landau energy levels which blue shift with field. From the blue shift we have estimated the effective mass of charge carriers. In addition, the sample is also mounted vertically in the VTI and field is applied perpendicular to the growth direction, known as Voigt geometry and the extent of the wave function in growth direction is probed for studying the electronic coupling of stacked quantum structures.

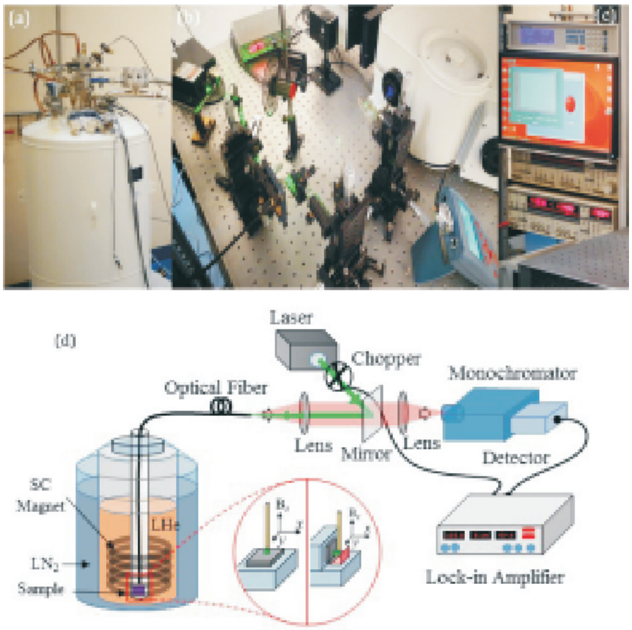

Fig. L.4.1: Magneto-PL setup at RRCAT (a) Superconducting magnet, (b) PL with fiber coupling, (c) Electronic controls, (d) Schematic of magneto-PL setup.

This setup is used to estimate several such parameters of AlGaAs/GaAs, GaAs/InGaAs, InP/InAsP and AlGaAs/GaAsP QWs and laser diode structures. Initial results reveal the necessary insight about the nature of confinement and the interaction between confined carriers which cannot be obtained from the complementary techniques. The new setup is a versatile and powerful for the investigation of microscopic properties of semiconductor quantum structures.

For more details, please refer to *G. Vashisht et al., J. Appl. Phys. 119, 095708 (2016); S. Haldar et al., Condensed Matter Physics under Extreme Conditions, CoMPEC-2016, BARC, Mumbai.*

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