CHAPTER 2

EXPERIMENTAL TECHNIQUES

2.1 INTRODUCTION

Coumarin and xanthene dyes showed better solubility, compatibility with polymeric material methyl methacrylate (MMA). MMA showed higher optical homogeneity than silicate materials. MMA was chosen as a monomer for polymerisation. Coumarin and Xanthene dyes have good absorption at nitrogen laser emission wavelength, 2\textsuperscript{nd} and 3\textsuperscript{rd} harmonic Nd: YAG laser wavelength, hence these lasers are good pump sources for the dye doped polymers. This chapter describes the synthesis of dye doped polymer (DDP), design and construction of nitrogen laser, details of second harmonic and third harmonic Nd:YAG laser, details of spectrophotometer, spectofluorometer, details of experimental setup for gain studies of dyes in solid and liquid medium.

2.2 SYNTHESIS OF DYE DOPED POLYMER RODS

The dyes chosen for our studies were xanthene (Rh6G) and coumarin family dyes (coumarin 460, coumarin 490, coumarin 503, coumarin 521, coumarin 535, coumarin 540, LD 490) procured from exciton Co., U.S.A and were used as received. These dyes were of laser grade in purity (i.e. ultra pure). Thin layer chromatography (TLC) tests were carried out to confirm the absence of any impurities. The absorption and fluorescence spectra of standard
spectrographic solvents were recorded and compared with that published in literature as further checks for spectral purity. The chemical names and commercial names are given in Table 2.1.

Organic dyes showed better solubility, compatibility with the polymeric material methyl metacrylate (MMA). MMA was chosen as a monomer for synthesising dye doped polymer rods. It had better transparency at the pump wavelength. The monomer MMA was obtained from Fluka. In order to remove inhibitors in MMA, it was washed with aqueous NaOH solution and with distilled water until it became neutral. Then it was dried over anhydrous CaCl₂, and filtered by changing the pore size of the filters from 16 to 0.22μm, the filtrate was distilled under reduced pressure. Benzoyl peroxide was chosen as an initiator. Costela et al (1996) studied about red pigments formed during polymerisation with the increase of benzoyl peroxide. Hence, the concentration of benzoyl peroxide was chosen in such a way that it did not produce any red pigments during polymerisation. By trial and error method, we found 0.5 gm per 100 ml of the solution suitable for initiation. Adding an additive for modifying the polymers will enhance the solubility of the dye and increase the laser damage resistance. Gromov et al (1985), Dyanmeav et al (1992) found that EtOH as a modifying additive because it combines good solubility of xanthene dyes and enhancement of laser damage resistance. Hence, we have chosen EtOH as a modifying additive. Experimentally it was observed that MMA and EtOH mixed in the ratio 4:1 (v/v) gave a good laser damage resistance. MMA and EtOH were mixed in the ratio 4:1 (v/v) and dyes of different concentrations were prepared in this mixture. 0.5gm of benzoyl peroxide per 100 ml of the solution was used as an initiator for polymerisation. The solution was taken in polymerising tubes and kept in nitrogen atmosphere. Block radical polymerisation was carried out in thermostat controlled water bath (solid state water bath). The temperature of the water bath was maintained
<table>
<thead>
<tr>
<th>Dyes</th>
<th>Chemical Name</th>
<th>Commercial Name</th>
<th>Product of</th>
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<tbody>
<tr>
<td>C1</td>
<td>7-diethylamino-4-methyl coumarin</td>
<td>Coumarin1, Coumarin460</td>
<td>Exciton</td>
</tr>
<tr>
<td>C490</td>
<td>7-Amino-4-trifluoromethyl coumarin</td>
<td>Coumarin 490, Coumarin 151</td>
<td>Exciton</td>
</tr>
<tr>
<td>C503</td>
<td>7-ethylamino-6-methyl-4-trifluoro coumarin</td>
<td>Coumarin 503, Coumarin 307</td>
<td>Exciton</td>
</tr>
<tr>
<td>LD490</td>
<td>1,2,4,5-3H,6H,10H-tetrahydro benzopyrano[9,9a,1-gh]quinolizin 10 one</td>
<td>LD490, Coumarin 6H</td>
<td>Exciton</td>
</tr>
<tr>
<td>C521</td>
<td>9-cyano-1,2,3,4,5,10H tetra hydro 1-benzopyrano[9,9a,1-gh]quinolizin-10-one</td>
<td>Coumarin 521, Coumarin 334</td>
<td>Exciton</td>
</tr>
<tr>
<td>C535</td>
<td>3-(2-benzimidazolyl) - 7- diethyl amino coumarin</td>
<td>Coumarin 535, Coumarin 7</td>
<td>Exciton</td>
</tr>
<tr>
<td>C540</td>
<td>3-(2-Benzothiazolyl)-7-diethyl amino coumarin</td>
<td>Coumarin 540, Coumarin 6</td>
<td>Exciton</td>
</tr>
<tr>
<td>Rh6G</td>
<td>Benzoic acid,2-[6-(ethyl amino) -3-(ethylimino)-2,7-dimethyl-3H-xanthe-n-9-y]-ethyl ester, monohydrochloride</td>
<td>Rhodamine 590 chloride, Rhodamine 6G</td>
<td>Exciton</td>
</tr>
</tbody>
</table>
at 35°c for two days, 40°c for another two days, 50°c for seven days. The polymerised rods were taken by breaking the glass tubes. The rods were cut, and polished to the optical quality required, by polishing with polishing paper (rough polishing with polishing papers of grade-220, 320,400,600,800, fine polishing - 1/0,2/0,3/0,4/0), the final polishing was done using 0.3μm size alumina powder using rotatary wheel to obtain mirror polishing. 1% transmission at 532 nm and 25% at 562 nm through disk of 1 cm length has been recorded with spectrophotometer. No dispersion or distortion of He-Ne laser (632 nm) beam has been observed while passing through the sample. Rods of different lengths and diameters were fabricated. A small piece of rod was cut from the sample (1 mm thickness and 1 cm diameter) and polished. The absorption and emission spectra of this sample were recorded using spectrophotometer and spectrofluorometer as explained by Costela et al (1996).

2.3 THE NITROGEN LASER

2.3.1 Energy Levels of the Nitrogen Molecules and Lasing Processes

Figure 2.1 shows the energy level diagram of the nitrogen molecule. The nitrogen molecule in level 1 (X\(^1\Sigma^+_g\)) is excited to level 3 (C\(^3\Pi_u\)) by electron collision and this level 3 has a lifetime of about 40 ns at low pressures.

The molecule in level 3 decays radiatively to level 2 (B\(^3\Pi_g\)) that has a lifetime of 5 to 8 μsec (Geller et al 1968). Levels 3 and 2 are the upper and the lower laser levels. Since level 3 has a short lifetime, the excitation process should be rapid in order to establish a population inversion between level 3 and level 2. Due to collisional deactivation of nitrogen, the C\(^3\Pi_u\) level of nitrogen has lifetimes much less than 40 ns even at pressures of a few torr. Hence at high pressures the excitation process should be accomplished in a time interval
Figure 2.1 Energy level diagram of nitrogen laser
much less than 40 ns. The inversion duration and hence the pulse duration is also of the order of few nanoseconds at the most.

For a selective excitation of level 3 by electron collision, an electric field of 120 V cm\(^{-1}\) torr\(^{-1}\) is optimal (Fitzsimmons et al 1976). This corresponds to electron energy of 7 eV. Hence, to create population inversion and laser action in the nitrogen medium, it has to be excited with an intense pulse of electrons of kinetic energy of about 7 eV and with duration much less than 40ns. From the second positive system of nitrogen molecule, the laser output occurs at 337.1 nm. Under intense excitation and with long enough excited gas columns, the nitrogen laser works in the Amplified Spontaneous Emission (ASE) mode without the help of a resonator cavity.

2.3.2 Working Principle of a Transverse Discharge Nitrogen Laser

Transverse electric discharge excitation is the most commonly used excitation technique in nitrogen laser. A schematic diagram of the transverse discharge nitrogen laser (single plate type) and its equivalent circuit are given in Figures 2.2 and 2.3. The top plates of the parallel plate capacitor strip lines \(S_1\) and \(S_2\) are connected to two electrodes about 1 metre long in the laser cavity LC. The capacitors \(S_1\) and \(S_2\) are made up of dielectric materials like mylar or polyester or high dielectric constant and high dielectric strength coated with copper on both sides. The laser cavity has provisions for nitrogen gas flow and has quartz window ports at either end to allow the nitrogen laser radiation to emerge. There is a spark gap SG on the \(S_2\) side and \(S_1\) and \(S_2\) are connected through a high inductive resistance \(R\) of about 300 kilo ohms. The bottom plates are earthed and \(S_1\) is connected to a high voltage source through \(R_C\). When the capacitors \(S_1\) and \(S_2\) are being charged they attain the same voltage \(V\).
Figure 2.2 Schematic diagram of a nitrogen laser

Figure 2.3 Equivalent circuit for the nitrogen laser
and there is no net voltage across the electrodes in the LC. When $S_2$ gets charged to a high enough potential the spark gap $SG$ can electrically break down. When the spark gap brakes down, an oscillating voltage wave is setup in $S_2$ whose frequency is equal to the resonant frequency of the part of the LC circuit pertaining to $S_2$. Since the time constant of this LC circuit of $S_2$ is very small, the reflection of the voltage wave from $+V$ to $-V$ is sharp occurring in a time of the order of 10ns. Since the resistance $R$ and inductance $L$ are of very high value, within this 10ns there is no transfer of charge from $S_1$ to $S_2$, and hence the voltage of $S_1$ is essentially clamped at $+V$. Thus there exists a transient potential difference of about 2V appearing between the two electrodes in the LC. If the separation of the electrodes and the pressure of the gas inside the LC are such that the gas brakes down electrically then a high current step function discharge of many kilo amperes takes place as shown in Figure 2.4. This technique of generating high current pulses is called the Blumlein voltage pulse generation method.

2.3.3 Design and Constructional Details of a Double Parallel Plate Nitrogen Laser.

A double parallel plate transmission line (DPTL) type of nitrogen laser has many advantages. The outer electrodes of DPTL are earthed and electromagnetic interference due to the discharge is substantially reduced. Also, for the same dimensions of the laser, DPTL gives half the characteristic impedance of the single plate transmission line, thus enabling a more optimal match of cavity and line impedance's. Woodward et al (1973) has shown that the laser output power grows linearly with decreasing line inductance, other parameters remaining the same. Keeping this in mind, we choose to build a double parallel plate transmission line (DPTL) type of nitrogen laser. The
Figure 2.4  (a), (b) and (c) Time variation of voltage  (d) Time variation of current and (e) Time variation of power
design and constructional details of a high power, DPTL nitrogen lasers are given below.

Since in this laser, the stored electrical energy is converted into optical energy, the energy stored in the capacitor should be made as large as possible for laser outputs. For this one must choose a dielectric constant and high dielectric strength and of small thickness and large surface area.

The two pairs of stripline capacitors $S_1$ and $S_2$ used for construction of the nitrogen laser were made from HYLAM phenolic resin laminate with double side copper cladding. Copper from either side of the laminate was removed by etching a 5 cm strip right round the edge to avoid any flashover while operating at high voltage. The calculated capacitance of the plates $S_1$ and $S_2$ are 46 nf each and at 10 kV the stored energy in the capacitors is 2.3 J. A high resistance $R$ (47 KΩ) and an inductance $L$ of 20 turns of insulated copper wire was used to connect the inner two high voltage plates $S_1$ and $S_2$ together. High voltage was applied to the plates through a resistance $R_c$ (1 MΩ).

The inner electrodes of $S_1$ and $S_2$ are soldered to cylindrical copper electrodes $E_1$ and $E_2$ using copper foils. $E_1$ and $E_2$ were 110 cm long and had 8mm separation. A Perspex tube of length 125 cm was used to house the electrodes $E_1$ and $E_2$. The two halves of the Perspex tube were stuck together using araldite. Detachable fused quartz windows were provided at either ends of the tube as output ports for the laser. The laser discharge tube also has an inlet and outlet for the flow of nitrogen gas. This complete assembly constitutes the plasma tube of the nitrogen laser. The rotary pump is connected to one end of the tube to produce low pressure inside the discharge channel.
Flow of nitrogen gas through the other end flushes out the ions and impurities that may be produced during the discharge.

The spark gap is placed as shown in Figure 2.3 towards the edge of S$_2$ and on the middle line of S$_2$. It is pressurised using nitrogen gas. The gap and the nitrogen pressure could be adjusted to provide the desired breakdown voltage. The spark gap must have the minimum possible inductance so as to produce a faster voltage reversal of S$_2$. This in turn produces a more rapid voltage pulse across the discharge and thus better population inversion. A coaxial type spark gap appears best suited for this purpose.

A simple voltage doubler power supply giving 0 – 25 kV is constructed using locally available materials. The circuit diagram is given in Figure 2.5. The diodes D$_1$ and D$_2$ (SRX100) are rated to withstand peak inverse voltages of 100 kV. C1, C2 and C3 are oil filled paper capacitors, which were used in series – parallel combinations to have the required voltage ratings and capacitance for smoothing the rectifier output. The transformer had a secondary rating of 0-15 kV, 500 mA and the primary voltage was controlled by using an autotransformer. R$_1$, R$_2$ and R$_3$ are bleeder resistors.

2.3.4 Output Characteristics of the Nitrogen Laser

The nitrogen beam that comes out from the quartz window is of rectangular cross section with dimensions of about 10 mm breadth (x) and 6 mm height (y) at the exit window. The divergence of the beam was found to be about 7.5 mrad along x direction and 5 mrad along y direction at a distance of 50 cm from the exit window. The pulse width was nearly 12 ns. A vacuum photodiode (PD50) and a Tektronik 485 oscilloscope with a combined rise time
Power output (kW) 41

\[ C_1 = C_2 = 0.25 \text{ uF} \]
\[ C_s = 0.05 \text{ uF} \]
\[ R_1 = R_2 = 10 \text{ M}\Omega \]

Figure 2.5  Power supply for nitrogen laser

Figure 2.6  Variation of nitrogen laser power output with pressure inside the plasma tube
of less than 1.5 ns was used to measure the peak output power of the nitrogen laser. The sparkgap pressure was kept at 1.5 atmosphere. For two breakdown voltages of 8 kV and 10 kV respectively. The laser pressure in the laser channel was varied and the output power was measured. The output power has a peak value around 40 to 50 torr as may be seen from Figure 2.6. For higher pressure the discharge may become filamentary and arching become predominant. For applied voltage of 8 kV for a pressure of 40 torr the peak power of nitrogen laser output beam was 8 kW. For higher voltages of about 15 kV and a gas pressure of about 60 torr the maximum output power that could be obtained was 100 kW. The E/P value used here was about 210 volt torr$^{-1}$ cm$^{-1}$ at the optimum output power. With a 100% reflecting rear mirror the output energy was found to increase by about a factor of 5. It was found that for an optimum distance of 25 cm from the rear window, the output was maximum and the beam quality was improved and the divergence decreased (Masilamani et al 1985).

2.4 Nd:YAG LASER

The neodymium ion is a particularly useful example of an optically pumped rare-earth laser system. The trivalent neodymium ion Nd$^{3+}$ has now been incorporated into great many lattices. The more widely used system is one in which Nd$^{3+}$ ion is incorporated in the Y$_3$ Al$_5$ O$_{12}$ lattice. This crystal is represented by a symbol YAG – acronym for Yttrium Aluminium Garnet. A simplified energy level scheme for Nd:YAG, is presented in Figure 2.7. The energy levels of this ion in almost any crystalline lattice are essentially the same.
Figure 2.7  Energy level diagram of Nd: YAG
The levels shown in figure are all associated with the inner 4f shell, which is screened from external fields by the 5d and 6s outer shells, as a result of which the lower levels are narrow. The Nd\textsuperscript{3+} ion surrounds itself with several oxygen atoms that largely shielded from its surroundings. Some of the upper levels, however, are broadened due to the interaction with 5d configuration. Fluorescence occurs from \( ^4\!F_{3/2} \) level to the four multiplets (not shown in Figure) of the ground state. It should be noted that the F\( \rightarrow \) I transitions are forbidden in the dipole approximation, since the orbital quantum numbers change by three. Hence, F levels are metastable levels. The probability of transition to level \( ^4\!I_{11/2} \), however, is an order of magnitude higher than that of the other members of the multiplet. This level is about 2000 cm\(^{-1}\) (\( \nu = 6 \times 10^{13} \) Hz) above the ground state and, hence at room temperature \( h\nu >> kT \). The \( ^4\!I_{11/2} \) level, therefore is virtually empty in thermal equilibrium. Any population in this level \( ^4\!F_{3/2} \) gives rise to an inversion. Transition from the level \( ^4\!I_{11/2} \) to the lowest level takes place by non-radiative processes and is quite fast. The laser transition \( ^4\!F_{3/2} \rightarrow ^4\!I_{11/2} \), corresponding to \( \lambda \rightarrow 1.06\mu \), observed as a Lorentzian line shape of width \( \Delta \nu = 6.5 \text{ cm}^{-1} \) (195 GHz) at room temperature. The lifetime of upper level is \( \tau = 0.23 \times 10^{-3} \text{ sec} \). The Nd\textsuperscript{3+} concentration, normally, corresponds to the ground state population \( N_g = 6 \times 10^{19} \text{ ions/cm}^3 \).

The Nd:YAG laser is most often used in a quasi-continuous (cw) fashion that is repeatedly pulsed at higher rate.

### 2.4.1 Details of Nd:YAG Laser Used

The Nd:YAG laser supplied by Continuum, USA was used for our studies. Continuum’s suralite laser and the laser bench is shown in Figure 2.8.
Figure 2.8  Schematic diagram of Nd: YAG laser
The laser bench is a modular design incorporating a rod, a flash lamp and a coupling medium. It has a linear flashlamp, which is in a close coupled configuration surrounded by a high brilliance magnesium oxide diffuser. This results in a high pumping efficiency that minimises thermal loading and reduces power consumption. These features combine to create the excellent pumping homogeneity required for producing high gain, superior quality beams. The load is design to pump Nd$^{3+}$ doped YAG. The doping levels vary from 0.9 to 1.4%. The rod ends have hard dielectric anti-reflective coatings (AR). The rod length is 115 mm measured along the optical axis. The diameter of the rod is 6mm. The head is pumped by a linear flash lamp uses a negative, critically damped pulse (-18 MV max.) with a duration of 200 microseconds full width half maxima (FWHM). The gas in the flash lamp and the laser rod is cooled by distilled, deionized water.

A Q-switch prevents lasing in the resonator until the laser gain reaches its peak and then opens the cavity to allow oscillation. This then produces ultra-fast, high peak power laser pulses. The Q-switch consists of optical elements- (a) Pockels cell, (b) Plate polarising element (c) Quarter-wave plate and electrical elements- (a) Timed pulse generated by the PCU UNIT (b) Marx bank (750 V) (c) 750 Volt power board. The pockels cell has a longitudinal field KDP crystal with a 15 mm clear aperture mounted at 43 mm beam height. A voltage of approximately 3600 V results in a quarter wave rotation for photons at 1064 nm passing in either direction. A voltage of 0 volts results in no rotation.

The thin film multilayer dielectric polarizer is highly transparent (>95%) to horizontally polarised light. The contrast/extension ratio is 500:1. The plate used introduces quarter wave rotations to photons at 1064nm as they pass
in either direction through the plate. The plate has a clear aperture of 15 mm and is mounted at a beam height of 43 mm. THE control unit tracks the firings of the flashlamps in the laser head and then at a preselected delay of approximately 200 µs triggers the marxbank with a +15V. The marx bank (750V) charges 7 capacitors in parallel and then discharges them through fast switching transistors in series, so as to generate approximately 4 kV with a rise time of 20 ns. This board is in a metal box next to pockels cell. The 750 V power board located above the oscillator cavity in a small box with the marx bank, generates the dc voltage necessary to power the marx board. The beam propagating within the oscillator cavity makes a double pass through the pockels cell and quarter wave plate. At 0 volts on the Pockels cell (PC) no rotation is added while the quarter wave plate adds 45° with each pass, giving a total rotation of 90°. Thus the beam that is transmitted through the plate polarises and no oscillation occurs. The beam propagating within the oscillator cavity makes a double pass through the pockels cell and quarter wave plate. At 3600V on the pockels cell a 45° rotation is added and the quarter wave plate adds 45° with each pass, giving a total rotation of 180°. Thus the horizontal beam that is transmitted by the polarizer allowing oscillations to occur. The Nd:YAG laser generates laser light at the fundamental wavelength of 1064nm. The second harmonic emission is at 532 nm is achieved by passing the fundamental beam through a second harmonic generator positioned at the end of the laser bench. The second harmonic of Nd:YAG at a wavelength of 532nm is circular in cross section. The maximum energy per pulse is about 200 mJ. The divergence of the beam is about 0.6 mrad. The duration of each pulse is 5-7 ns and the pulse repetition rate is 1-10 Hz. The maximum peak power output that can be obtained is 40 MW. Wavelength 532 nm output energy 200 mJ at 10 Hz and 160 mJ at 20 Hz. Stability of the laser is about ± 3.5%. Pulse width of the second harmonic Nd: YAG laser is 1 ns less than the input
pulse. The polarisation is >95% vertical, line width ~1.5 times the line width of the 1.06\,\mu m. Wavelength 355\,nm, output energy is around 60 to 80\,mJ at 10\,Hz and 55 to 65\,mJ at 20\,Hz. Stability of the laser is ± 4% pulse width 1\,ns less than the input 1.06\,\mu m, polarisation >95% horizontal and line width 1.5 times the line width of the 1.06\,\mu m.

2.5 SPECTROPHOTOMETER

The basic block diagram of the spectrophotometer is shown in Figure 2.9. This consists of a halogen lamp, prism, photomultiplier tube, and amplifier and digital readout. The light from the halogen lamp is passed through the prism to get the required wavelength. This is allowed to pass through the sample, which is kept in a quartz cuvette. The amount of light that is transmitted depends on the absorption of the solution. The transmitted light is allowed to fall on a phototube, which is a measure of the transmittance, and from this value the instrument directly gives the value of absorption. The absorption spectra of dye solution were obtained using the Hitachi model U2000 spectrophotometer.

2.6 SPECTROFLUOROMETER

This is a vital instrument to obtain the fluorescence and excitation spectrum of the liquid sample. This instrument is interfaced with a computer, so that a small program can be written and the required excitation wavelength, emission scan range, scan speed etc, can be fed to the instrument through the computer and we can get the fluorescence spectrum / excitation spectrum either on the CRT or on a dot matrix printer.
Figure 2.9  Block diagram of spectrophotometer

Figure 2.10  Block diagram of spectrofluorometer
The basic block diagram of the spectrofluorometer is shown in Figure 2.10. The spectrofluorometer basically consists of a Xenon lamp, which excites the sample, and the fluorescence is collected at right angles to the direction of excitation. The xenon lamp emits light in the entire spectrum including UV, VIS and IR. Therefore we have to select a particular wavelength out of this band to excite the sample. Using monochromator, which is controlled by stepper motor, does this. Similarly the fluorescence of the sample is also broad band and this is also passed through a monochromator to get a single spectrum. The output fluorescence is detected by a photodetector and this signal is amplified by an amplifier. (Variable gain amplifier) so that the output relative intensity can be calibrated to a fixed value. Hitachi F2000 spectrofluorometer was used to record the fluorescence spectra of the dye solutions. Fluorescence spectra of the solid samples were obtained from thin strips cut from the samples used in the lasing experiments. Fluorescence spectra were recorded as explained by Costela et al (1996).

2.7 THE AMPLIFIED SPONTANEOUS EMISSION METHOD FOR DETERMINING THE GAIN OF THE OPTICALLY PUMPED DYE DOPED POLYMER

Various experimental methods have been reported to determine the gain of the dye laser medium (Ganical et al 1975). A single pass gain measurement using the ASE method proposed by Shank et al (1970) can be applied transversely pumped dye doped polymer laser, when the gain is uniform along the pumped region. This method is adopted in this thesis for studying the gain of the coumarin dye doped polymer laser pumped by nitrogen laser.
The schematic diagram of the experimental setup is shown in Figure 2.11. The dye laser is placed in a slightly tilted rigid platform to avoid optical feedback and is transversely pumped by the 337.1 nm light from a pulsed nitrogen laser. This rectangular laser beam is focused by a cylindrical quartz lens of focal length 5 cm. This produces a line shaped image of uniform intensity along this line of length l and width 2r (Where 2r << l). A beam block is used to change the length of the pumped region of the dye doped polymer. The spontaneously emitted photons from the excited dye doped polymer are amplified by the gain region and then pass through a distance p (p >> l) before being apertured by a pinhole whose diameter is less than the diameter of the gain region. The ASE photons are then sampled by a monochromator – photomultiplier combination, which measures the intensity at the desired wavelength.

For an excitation wavelength $\lambda$, of the dye doped polymer the time averaged intensity measured at wavelength $\lambda$ can be written as

$$I(\lambda) = C \int_0^1 \frac{\exp[G(\lambda)x]}{(p+x)^2} \, dx \quad (2.1)$$

where, $p >> l$. $C$ is a constant for a given pumping intensity, $G(\lambda)$ is the intensity coefficient at wavelength $\lambda$. From the intensities $I_1(\lambda)$ and $I_2(\lambda)$ of the medium, for two active lengths $l_1$ and $l_2$ of the medium one can determine the gain per unit length $G(\lambda)$ from the expression

$$\frac{I_1(\lambda)}{I_2(\lambda)} = \frac{\exp(G(\lambda)l_1) - 1}{\exp(G(\lambda)l_2) - 1} \quad (2.2)$$

The gain $G(\lambda)$ was determined from equation – using Newton-Raphson numerical method.
Figure 2.11 Schematic diagram of the experimental arrangement for measuring dye doped polymer laser gain
2.7.1 Experimental Arrangement

Figure 2.12. gives the experimental setup for the measurement of gain by ASE method. The nitrogen laser beam is allowed to pass through a beam splitter (uncoated quartz plate) and is focussed by a quartz cylindrical lens of 5 cm focal length, on a dye doped polymer placed in a platform. The reflected beam from a beam splitter is made to fall on a photocell PC. The output from a photocell is fed to channel 1 of the CRO (model OS768A) to monitor the pump power. Under conditions of nonsaturation the output of PC is proportional to the peak power of the nitrogen laser pulse and the detector is thus calibrated. A 2 mm thick aluminium sheet, mount on a micrometer arrangement served as a beam block. It enabled one to expose different lengths of the solution for excitation. The dye doped polymer rod is kept tilted to avoid optical feedback due to reflections from the ends of the cell walls. The ASE output traverse a distance of 100 cm before being apertured by a pinhole, p on the input side of the monochromator M (CEL model 3134) and detected with a photomultiplier tube (RCA 931A). The time integrated signal from the photomultiplier is fed to the other channel of the CRO.

To measure the gain per unit pump power dye doped polymer laser, the calibrated channel 1 of CRO is used to read the pump power, The amplitude of dye doped polymer laser pulse (ASE intensity) displayed in channel 2 is noted when channel 1 indicates the required pump power. The nitrogen laser power fluctuation from shot to shot is minimum for a nitrogen gas pressure of about 50 - 60torr. At this optimum pressure, the variation of the nitrogen laser output is less then 5%. The nitrogen laser intensities and the dye doped polymer laser intensities were simultaneously monitored on a dual beam CRO.
Figure 2.12  Experimental set-up for the measurement of Dye doped polymer gain
Figure 2.13  Dye doped polymer laser intensity Vs nitrogen laser power
Figure 2.14 Variation of dye doped polymer laser gain with nitrogen laser power.
For each power settings of the nitrogen laser the dye doped polymer laser intensity was monitored and measured on channel 2 only when the nitrogen laser pulses had the exact preselected power as verified on the oscilloscope channel 1. This effectively eliminated dye laser pulse fluctuations. The dye laser intensities $I_1$ and $I_2$ were measured for two lengths of the active medium $l_1$ cm and $l_2$ cm respectively at given wavelength and for a fixed nitrogen laser power. For different nitrogen laser excitation powers the intensities $I_1$ and $I_2$ of the dye doped polymer laser ASE were measured and a graph is drawn between the logarithm of intensity and nitrogen laser pump power as shown in Figure 2.13. From these straight-line graphs, the gain of the various pump powers is calculated and another graph is plotted between gain and pump power as shown in Figure 2.14 and gain slope is determined from this graph. Care is taken to see the gain thus determined is the small signal gain, by monitoring and verifying that the logarithm of the dye doped polymer laser intensity varies linearly with the nitrogen laser pump power (Figure 2.13). Since the medium is homogeneous and the excitation is spatially uniform, every molecule in the active region can be considered as contributing equally to the gain. Therefore the gain is presented as gain per molecule per kW pump power. By expressing $p(t)$ in terms of photons/sec and by dividing by $p(t)$ and by absorption cross section of the dye at 337.1 nm we can obtain the gain of the molecule per absorbed photon.