Chapter 2
Experimental Scheme

Abstract

This chapter deals with different experimental techniques used for the present study. Experimental system has been designed and developed to perform diagnostics of plasma formed from lithium solid as well as multicomponent thin film (LiF-C) targets under various experimental conditions. The experimental procedure for optimizing the setup, such as the production of pulsed field and its synchronization with pulsed plasma and diagnostics systems are also discussed.
2.1. Introduction

Diagnostics of edge plasma parameters in Tokamak using lithium neutral beams are important as they play key role to determine the global plasma confinement {1-6}. The principle of measurement using laser blow off (LBO) technique and the reason for the selection of lithium fluoride-carbon (LiF-C) thin film target has already been discussed in chapter 1. In the previous chapter, we have also discussed quite a few methods to measure plasma parameters. In order to get more insight into these topics, it is necessary to characterize the lithium plasma formed by LBO scheme under various experimental conditions.

Present chapter focuses more into the details of the experimental scheme used for the characterization of LBO plume. Main diagnostic techniques used in plasma characterization are the gated time-resolved imaging using intensified CCD (ICCD), emission spectroscopy and ion probe. Among these, more focus has been given to imaging characterisation using ICCD. Fast imaging using ICCD is one of the commonly used diagnostic techniques and it provides the two dimensional snapshot of the three-dimensional plume {7-9}. Analyses of the recorded images give exact information of the modifications induced in the plume geometry and various other alterations, as a function of time, under different experimental conditions {10-13}. In most of the cases multiple diagnostics are performed simultaneously and this practice offer better understanding of the propagation dynamics {11, 12}.

During the study, we have investigated the influence of various ambient gases, different laser intensity profile and magnetic field over the plasma plume propagation {10, 13}. A comparative study has also been performed on the plasma generated from lithium solid as well as thin film of LiF-C. In the case of LBO, plasma plume (Li) consists of mainly neutral and singly ionized atoms and hence recombination processes could lead to the enhancement of neutral emission lines {14}. This study is important from the point of view of plasma diagnostics in
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Tokamak, as the magnitude of magnetic field depends on the location of LBO system with respect to Tokamak. For the study of the effect of variable transverse magnetic field on LBO plume, a system have been developed where, pulsed magnetic field was generated using Helmholtz coil arrangement {15}. Mapping of the field was performed in order to ensure the uniformity over the plume area. As there were many elements involved in each study, it was essential to synchronize all these components. Time synchronization of the various subsystems has been achieved with a synchronization circuit.

2.2. Layout of the experimental setup

This section discusses the different elements involved in the creation of plasma from thin film/solid target. The generated plasma is then diagnosed using fast imaging, emission spectroscopy and probes. Creation of pulsed magnetic field is another important part of the study in this thesis. In order to perform the experiment, it is necessary to synchronize the whole setup and this aspect is discussed in section 2.5

2.2.1. Laser systems

All the experiments in the coming chapters were conducted using the electro-optically Q-switched Nd:YAG laser and utilized its fundamental wavelength 1064 nm. There were two lasers (laser I, laser II), mainly classified based on their laser output intensity profile. Laser I (QUANTEL, Brio) produces output pulses with Gaussian intensity profile while Laser II (CONTINUUM) produces pulses having top hat intensity profile.

In the fundamental mode of the Q-Switched Brio laser (laser I), it is possible to obtain a maximum energy of approximately 130 mJ at a pulse width of 6 ns {16}. The average power of the laser depends on the energy per pulse and the repetition rate. This laser can produce an average power of 2.6 W at a frequency of 20 Hz. The beam divergence for laser I is less than 5 mrad. Connector terminals attached to
the laser allows synchronization to the laser flash lamp (and the laser Q-switch, through a positive TTL trigger signal (5 V, 20 mA max, 50 μs duration). All operating parameters and settings for the laser can be controlled through a remote box, which is connected to the laser power supply.

Pulses from the laser II (CONTINUUM), which operates at a frequency of 30 Hz gives a maximum energy of 1.6 J \{17\}. This has a pulse width of 8 ns and the beam divergence is less than 6 mrad. Like laser-I, this laser also provides the trigger input-output terminals for the flash lamp and Q-switch. These pulses are utilized to synchronize other subsystems which include beam shutter, PMT, ICCD, magnetic field etc.

### 2.2.2. Multipurpose chamber and pumping system

The experimental study for laser plasma from solid/thin film target was conducted in a multipurpose chamber made of non-magnetic stainless steel cylinder of 160 cm length and 21 cm inner diameter. This chamber with 28 view ports, each fitted with CF 100 coupling, in an equal-spaced cross geometry. These couplers can be replaced with quartz windows to view the plasma. Chamber was evacuated down to 2x10^{-5} mbar using two rotary pumps and an oil diffusion pump (500 liters/second). Gases can be introduced into the chamber at desired pressures through a fine controlled needle valve. Some of the view ports also have the provision for keeping probes without disturbing the vacuum.

### 2.2.3. Target and its handling system

The thin film target was composed of uniform layers of 0.5 μm thick carbon and 0.05 μm of LiF (Lithium Fluoride-Carbon) film on a 1.2 mm thick quartz plate. In the case of laser blow off (LBO), power density of the laser was adjusted to ablate the entire material from the thin film target on each laser hit. Excess laser power will cause etching of the substrate material.
Figure 2.1 Photograph of the target plate fixed on a holder. Each circular spot represents the ablated areas.

For performing LBO plasma studies, it was necessary to change the target position after each laser hit to provide fresh surface for ablation. The targets were placed inside the chamber, on a stainless steel axle with 6 mm diameter through a vacuum compatible Wilson-seal feed through fixed to a motorized X-Y translator system to provide a fresh surface for ablation. The stepper motor driver of the translator and hardware were interfaced to a computer system. By using the software interface of the translator system, position of the target can be adjusted (both X and Y directions) at regular intervals specified by the user. Photograph of the target plate on a target holder is shown in Fig.2.1. To avoid back-reflection into the laser system, the incident laser beam was focused on the target at an angle of 6 degrees.

In the case of LPP studies, multiple laser hit at the same portion of the target may result in the pitting on the surface and thereby change the spot size. In order to eliminate this problem, the target was attached to a motor which rotate continuously and this avoids laser hit in the same target area.
2.3. Diagnostic techniques

This thesis mainly comprises the experimental study of laser blow off (LBO) plasma from thin film targets, using diagnostic techniques such as emission spectroscopy, fast imaging using ICCD and probe diagnostics.

![Schematic diagram of the details of experimental setup.](image)

**Figure 2.2 Schematic diagram of the details of experimental setup.**

In subsequent sections of this chapter, we discuss these techniques in detail. The block diagram of experimental scheme used for the study is shown in Fig. 2.2.

2.3.1. Optical emission spectroscopy

Optical emission spectroscopy (OES) is one of the most commonly used non-invasive techniques to investigate dynamics of atoms, ions and molecules within plasma \{18-21\}. This non-perturbing diagnostic method can provide information about properties, such as excited species densities, electron-atom, atom-
atom and ion-atom collisional effects, energy distribution of species, charge transfer between plasma constituents and electric and magnetic fields etc. Its use as a diagnostic tool for emitting media has led to a greater understanding of very complex phenomena such as the evolution of stellar atmospheres and the study of fusion plasmas. Since the interpretation of OES observations is dependent on the source of emission and the understanding of the physical processes occurring within the source, this technique finds application in plasmas that are suitable for the processing of materials.

It is important to define the quantities involved in the use of OES as a diagnostic tool. A portion of this volume emission is focused onto the slit of a spectrometer via a lens or mirror optical system. The calibration of the detected signals are normally done by substituting a surface emitting continuum source of known spectral radiance, like a calibrated tungsten strip lamp in place of the volume emitting source. This calibrated lamp is positioned at the focus of the emission optical system and the amount of its radiation per unit time per unit solid angle per unit wavelength-band per unit area element is precisely known. Thus, the signal from the spectrometer and detection system is calibrated. The spectral radiance of any emitter, \( L_1 \), is given in units of radiant energy per unit time per unit area per unit solid angle per unit wavelength-band.

Plasma is created inside the vacuum chamber by irradiating the target (thin film/solid) with the Q-switched nanosecond laser pulse. As we are concentrating on the plasma edge density parameters in this study, lithium emission lines are monitored. For space and time resolved spectroscopy, the expanded plasma is viewed through a quartz window normal to its direction of expansion with appropriate optics. The light emission from the plume is imaged onto the entrance slit of a 0.35 m Jobin-Yvon monochromator (\( \Delta \lambda = 12.5 \, \text{Å} \)) by means of two lens system with unity magnification. For spatially resolved study, monochromator along with the focusing system is mounted on the X-Y translator system, which
facilitate controlled scan of the plume along its expansion axis with spatial resolution ~ 250 μm. The characteristic line selected by the monochromator is detected by a photomultiplier tube (BURLE C31034) having 2 ns rise time. For recording the temporal profiles, output of PMT is directly fed to a 1 GHz digital oscilloscope (Tektronix, TDS 540) through a 50 Ω termination. The time resolution in the present experiment is about 200 ns. A photodiode is placed just behind the focusing lens of the incident light. A small fraction of scattered light from the lens is detected by the photodiode and this signal is used to trigger the oscilloscope. So we have taken the photodiode signal as a time reference in the present experiment. Data management, analysis and plotting are made possible by directly interfacing the oscilloscope with computer through wave-star software. Interpretation of the spectral data obtained reveals various atomic processes involved during and after the laser irradiation.

2.3.2. Fast imaging using ICCD

Recent developments in imaging technologies provide an effective way to record and analyze ultra fast events. The picosecond gating capability of Intensified CCD (ICCD) cameras are essential for high speed imaging applications in the area of ultrafast phenomena. Fast imaging diagnostics is the main technique employed for most of the investigations in this thesis. We have ICCD used extensively for studies of the LBO plume under various experimental conditions {Chapter 3, 4, 5 and 6}. This section briefly explains the techniques adopted in ICCD (4 Picos Stanford Computer Optics, Inc.) for its high speed operation and image amplification.

Fast imaging cameras consist of a high performance CCD camera and an image intensifier that is mounted in front of it {22}. The incoming light is first amplified by the image intensifier. The intensified image is then transmitted from the intensifiers phosphor screen where the multiplied electrons from the micro channel plate convert back into photons. This image is then projected onto the CCD
sensor by means of a coupling lens. Thus, an ICCD camera directly amplifies the incoming light, thereby supplying the CCD sensor with a light intensity far above the thermal noise level of the sensors.

2.3.2.1. The image intensifier

The image intensifier is the key system element of an ICCD high speed camera, besides the CCD sensor itself. The main function of the image intensifier is the amplification of the incoming light signal, i.e. the multiplication of the incoming photons. This permits the ICCD camera to take images at extremely low light conditions and/or at exceedingly short exposure times down to 200 ps, when the integral of the photon flux over the exposure time is very small.

The image intensifier module basically consists of the following three functional units:

- The photocathode that converts the incoming photons to photo electrons,
- The micro channel plate (MCP) that strongly multiplies these photo electrons,
- The phosphor screen that converts the multiplied photo electrons back to photons.

The incoming light first meets the photocathode of the ICCD camera's image intensifier. The photocathode converts the incoming photons to photo electrons by collisional ionization. To obtain a maximum signal to noise ratio in the images the spectral sensitivity of the photocathode should be well suited to the applications light spectrum. A maximum number of photoelectrons per incoming photon are generating in this way. The MCP multiplies the incoming electrons from the photocathode. It can be considered as a matrix of tiny linear channeltrons in which the single channels are arranged by an angle of a few degrees towards the axis of the image intensifier. MCPs are available as single stage, double stage or triple stage. The typical electron multiplication factor of one MCP stage is 1000 secondary electrons per incoming electron. Thus, a two stage MCP will give a
multiplication factor of 1000 x 1000 = $10^6$. In the case of a triple stage MCP, the maximum multiplication factor is limited to less than $10^8$ due to saturation effects.

2.3.2.2. High speed shutter

It is the image intensifier that provides the so called gating capability of the ICCD camera, i.e. the shutter function.

![Representation of the ICCD gating operation](image)

*Figure 2.3 Representation of the ICCD gating operation (A) Shutter open (B) Shutter closed*

A unique advantage of the gateable ICCD camera over all other kinds of cameras is the ability of ultrafast gating, i.e., exposure times in the range of less than 5 ns can be achieved with gateable ICCD cameras. There are three voltages applied to the image intensifier as shown in the Fig.2.3. If the voltage between photocathode and micro channel plate is negative (Fig.2.3(A)), the photoelectrons are accelerated towards the MCP. This means that the ICCD high speed camera is gated, i.e. the shutter is open. If the voltage applied is positive, the photoelectrons are kept at the photocathode which means that the ICCD camera is not gated, i.e. the shutter is closed and no light is transmitted to the CCD sensor (Fig. 2.3(B)). There are triggering options for the ICCD, where the camera can be synchronously triggered to ultrafast events.
2.3.3. Ion probe diagnostics

A movable charge collector (ion probe) is used to study the plume propagation dynamics at longer distances from the target where the optical emission signals are almost undetectable [15]. The length of the probe, which is exposed to the plasma and separation between the probe and target plate are set as 3 mm and 45 mm respectively.

![Schematic of the ion probe assembly](image)

**Figure 2.4 Schematic of the ion probe assembly**

The ion probe consists of a 10 mm diameter stainless steel disk (Fig. 2.4). A pair of high transmission (~80%) stainless steel grids is mounted in front of the collector. The separations between the grids $G_1$ and $G_2$ between the second grid ($G_2$) and collector are 8 and 5 mm, respectively. The whole assembly is mounted on a Wilson feed-through for scanning the beam cross-section. The first grid $G_1$ is kept at ground potential. To collect the positive ions, negative bias voltages are applied to the second grid $G_2$ and collector. The potential between $G_1$ and $G_2$ prevents the plasma electrons from reaching the collector. A 2 μF capacitor is used to decouple the measuring circuit from the applied bias voltage. The collector signal is terminated on a 50 Ω resistor through a potential divider and signals are recorded on a fast digital oscilloscope.
The applied voltages on the grid $G_2$ and the collector, and distance between the charge collector to the target plates ‘z’ require critical optimization to avoid breakdown due to high plasma density. It was found that at distance $z \geq 40 \text{ mm}$, the bias voltages $-70 \text{ V}$ and $-40 \text{ V}$ to the collector and second grid $G_2$ respectively give the undistorted time of flight spectrum of the ion current in the saturation region. The potential difference $(-30 \text{ V})$ between the collector and $G_2$ is sufficient to prevent the escape of secondary electrons, emitted by the collector.

2.4. Development of system for pulsed magnetic field

It is well known that the presence of magnetic field during the expansion of laser-produced plasma may induce several interesting physical phenomena, including plume confinement, plume splitting, ion acceleration, emission enhancement and plasma instability \{23-26\}. The behavior of plasma streams produced by intense laser irradiation of a target made from various materials in an external magnetic field has been the subject of studies at numerous laboratories in the world for many years \{27-32\}. Taking this into account, we have conducted experiments to investigate the effect of pulsed magnetic field on plasma generated from LiF-C thin film and Li solid targets.

In order to study the effect of uniform magnetic field on laser-induced plasma, a system has been developed. It is required that the magnetic field should be uniform throughout the plume dimension and the field duration longer than the duration of the plasma plume (> few microseconds). The pulsed power system consists of a capacitor bank and wire wound solenoid to produce magnetic field. In this design, the capacitor energy is drained through two identical coils, mounted in parallel resulting in the generation of pulsed magnetic field. The amplitude of the magnetic field depends on the amplitude of time dependent current (flowing through the coil) and the geometrical configuration of the coils.

The schematic diagram of the pulsed power system to produce the magnetic field is shown in Fig. 2.5. A pair of magnetic field coils was constructed using 8
mm diameter multi-stand shielded copper wire. Each coil having 22 turns (two layers of 11 turns each) were wound on the top and bottom port of the vacuum chamber.

![Figure 2.5 Schematic diagram of the capacitor bank pulsed power system.](image)

A forma made of hylam was used to hold the coil perfectly parallel to each other. Average diameter of each of the coils is 14 cm and they were 23 cm apart. Figure 2.6 shows the photograph of the coils on the upper and lower part of the chamber. Due to limitations from experimental setup, coils could not be mounted in exact Helmholtz configuration. Both coils were connected in parallel in such a way that the direction of current flow was identical in both the coils. To reduce the input impedance of the discharge circuit, which results in more current through the coil, we have chosen the parallel connection instead of series connection of the coils. The measured inductance and resistance of the coil in parallel configuration were 45 μH and 0.054 Ω respectively.
The pulsed power system consists of parallel combination of two capacitors (700 $\mu$F and 500 $\mu$F, CSI K-Film, USA) and can store a maximum energy of 15 kJ at the maximum charging voltage of 5 kV. For charging the capacitor bank, dc voltage up to 5 kV was derived by using a combination of step-up transformer and the rectifier circuit. An ignitron ($BK506$, maximum peak forward anode voltage and current 25 kV and 100 kA, respectively) controls the current flow between the capacitor bank and the coil. During the instant discharge of the capacitor bank, it will recharge in the opposite polarity. To avoid reverse charging of the capacitor bank, a high power fast recovery diode (2.5 kV–4 kA at 10 ms) was connected across the coil circuit \cite{19}. A current transformer (0.01 V/A) was used to measure the coil current. A thyristor-based triggering circuit was also developed to initiate the switching of ignitron. To fire the thyristor, a +12 V pulse generated from the time synchronization circuit was applied to the gate terminal of thyristor via, a
transformer coupling and an optocoupler. The transformer and optocoupler protect the malfunctioning of time synchronization circuit.

2.4.1. Operation and optimization of field

For the generation of magnetic field, the capacitor bank is charged upto the preset voltage, depending on the required magnetic field strength in the experiment. After ensuring all setup including detectors and laser are ready, a firing pulse from the driving circuitry will apply to the ignitor for discharge the capacitor through the pair of coils wound (Fig.2.6) over the hylum sheet placed on the top and bottom of the vacuum chamber. As a result, a heavy current of few tens of kA flows in coils which was directly proportional to the induced field intensity. The temporal evolutions of the coil current and magnetic field measured by the current transformer and pickup coil, respectively, were used to optimize the design parameters of LCR system, magnetic field penetration time, uniformity, and strength of the magnetic field. Characteristics of the generated pulsed magnetic field are discussed as follows.

2.4.2. LCR circuit analysis

The current through the coil in equivalent LCR circuit is governed by the second order differential equation:

\[ L \frac{d^2 i}{dt^2} + R \frac{di}{dt} + \frac{i}{C} = 0 \]  

In our system \( L > \frac{1}{4CR^2} \), that is system is under damped.

In this case, the solution of above equation is

\[ V(t) = \frac{2\alpha V_0}{\omega_d} e^{-\alpha t} \sin \omega_d t \] , and

\[ I(t) = V(t) / R \]

where, \( V_0 \) is the voltage across the charged capacitor,
L and R are the inductance and resistance of the coils, $\alpha = \frac{R}{2L}$ and $\omega_d = \left[\left(\frac{1}{LC}\right) - \left(\frac{R}{2L}\right)^2\right]^{1/2}$.

Simulated temporal evolution of the coil current for the measured parameters, $C = 1200 \mu F$, $L = 45 \mu H (\sim 500 \text{ Hz})$, $R = 0.014 \Omega$ and $V_0 = 300 \text{ V}$ are shown in Fig.2.7. A typical current profile with crowbar diode is also shown in Fig.2.7.

**Figure 2.7** Field profile measurements: Simulated profile and measured profile using current transformer (CT)

Output current waveform of the LCR circuit shows the damping nature because of the reverse charging of the capacitor. To avoid the reverse charging of the capacitor, we have used high power fast recovery diode (2.5 kV- 4kA @ 10 ms) across the coil circuit \cite{33}. This will overcome the damping of the LCR circuit, where induced reverse voltage across the inductor coil bypasses through the diode. The experimentally observed current profile measured by the current transformer (CT) is also shown in Fig.2.7. The effect of diode across the coil (crow-bar protection) is clearly seen in the current transformer (CT) profile. Due to the
addition of extra resistance of connecting wire, the magnitude of the observed current is slightly lower than the calculated value.

2.4.3. Magnitude and uniformity of the field

A high frequency Gauss-meter (F. W. Bell, U S A, Model: 9900) was employed to measure the actual magnetic field profile in the region of interest. For a specific coil current, the calculated and measured magnetic field at the center of the chamber is presented in Table 2.1. The discrepancies (~ 20%) between the calculated and measured field arises mainly due to two reasons. Firstly, field is attenuated by the chamber 34} and secondly errors 35} in measurements of current and geometrical dimensions of coil assembly such as insulation thickness are reflected in field calculation.

<table>
<thead>
<tr>
<th>Capacitor charging voltage (Volt)</th>
<th>Coil current (Amp)</th>
<th>Calculated magnetic field (Gauss)</th>
<th>Measured magnetic field (Gauss)</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>1180</td>
<td>920</td>
<td>598</td>
</tr>
<tr>
<td>600</td>
<td>2400</td>
<td>1872</td>
<td>1216</td>
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<td>900</td>
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<td>2798</td>
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<tr>
<td>1500</td>
<td>5936</td>
<td>4630</td>
<td>3009</td>
</tr>
</tbody>
</table>

Table 2.1 Magnetic field calculated theoretically and measured experimentally for a fixed charging voltage of the capacitor

Further, to ensure the uniformity of the magnetic field, the Gauss meter probe was mounted on X-Z translator having a resolution of 5 μm. The transverse components of the magnetic field has been measured as a function of distance along the plume expansion (along z-axis) and radial (perpendicular to the plume expansion., i.e. along y-axis) directions at different positions along the x-axis. It was found that, the magnetic field was almost uniform in the region of slab 30 x 20 x 20 mm. So, the target was placed at a distance where the uniformity start in expansion.
direction. This leads to plume expansion in a uniform field at least 30 mm distance along expansion direction.

![Graph](image)

**Figure 2.8** Temporal profiles of induced voltage in pick-up coil and CT current with respect to photodiode signal.

The typical current and hence the magnetic field profile obtained is shown in Fig.2.8. It is clearly seen that magnetic field is nearly constant for ~ 40 μs duration. The length of flat top portion of the magnetic field is much larger than the laser-plasma lifetime, which is few microseconds. In order to study the dynamics of plume in uniform magnetic fields, it is necessary to ensure that flat top portion of the field and the formation of plume are well synchronized.

Due to induced eddy currents in the SS chamber, a time delay is introduced between the peak in coil current and produced magnetic field. To measure this delay (penetration time of magnetic field), we have used the pick-up coil having 100 turns of insulated copper coil made of 0.04 cm diameter wound on a 10 mm diameter Teflon rod. Pick-up coil (P-coil) was placed at the center of the chamber, where
laser-material interactions take place. The induced current (voltage) in the P-coil (which is directly proportional to the dB/dt) was monitored on the DSO without using any integration circuit. Temporal profile of pickup coil voltage along with the CT profile of the main coil current is shown in Fig.2.8. The zero-crossing point of the P-coil voltage shows that at this point magnetic field has maximum intensity. Approximately 120 μs delay was observed from the moment of peak coil current to the moment of peak field at the center of the chamber. Therefore, it was concluded that laser pulse should be delayed by 120 μs from the moment of peak coil current for perfect field-plasma synchronization.

2.5. Time synchronization of the integrated system

In the present setup, three independent diagnostic systems viz optical emission spectroscopy, time resolved imaging spectroscopy and fast charge collector technique are used to characterize the laser-induced plasma. Working principle and specialization of each diagnostic tool has already been discussed in previous sections {Sec 2.3} of this chapter.

The simultaneous use of these diagnostics gives complementary information about the plume dynamics in different experimental conditions. Successful operation of the setup requires the synchronization of diagnostics systems, laser pulse and the magnetic field together. The schematic diagram for synchronization of various subsystems and the corresponding timing sequence are shown in Fig.2.9.

A small fraction of scattered laser light from the focusing lens was detected by a photodiode and this signal served as the time reference (Tref = 0) in the whole experiment. The set position of spectrometer and charge collector does not require any time synchronization. To measure temporal profiles from the optical emission spectroscopy and charge collector, the outputs from these diagnostics were connected to 500 MHz oscilloscope (Tektronix TDS 540 A) directly with 50 Ω
terminations. The oscilloscope was triggered at the rising edge of the photodiode output. The ICCD camera has an inbuilt delay of 130 ns, therefore it should be pre-trigger of above delay in order to capture the image at $T_{\text{ref}} = 0$. Similarly, $70 + 120$ μs (rise time of the coil current profile + field penetration time) pre-trigger field firing pulse was required to coincide with the peak field inside the chamber with the time reference $T_{\text{ref}}=0$.

During the experiment, it was observed that the focused flash lamp light (continuously ON with 30 Hz for laser I and 20 Hz for laser II) partially ablated the thin film target. To overcome this problem, an electro-mechanical shutter was introduced in the laser path (Fig.2.2). The trigger pulses for laser and shutter operation ($T_{\text{ref}} - 65$ ms) was gated in such a way that shutter was open for single flash lamp and laser pulse.

*Figure 2.9 Timing sequence of different sub systems.*
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Laser is operated at 30 Hz in external mode. In this mode, the flash lamp is triggered with a 10 μs pulse at 30 Hz repetition rate and the Q-switch is triggered by a single pulse of same width. Multi-channel function generator provides the continuous flash lamp pulses and master trigger pulse in single burst mode. A programmable microcontroller based timing processor circuit (TPC) is used to control the time sequencing of different systems of the experimental setup. When a master trigger pulse initiated the TPC, sync-out pulse (20/30 Hz) from the laser is locked by the TPC at the negative edge. After locking the sync-out pulse, TPC generate the auxiliary pulse which is the ‘time reference’ for further time sequencing. With respect to this time reference, TCP generate the different trigger pulses and control the required time-sequencing operation of magnetic field, mechanical shutter, ICCD camera and laser system.

2.6. Conclusions

In conclusion, an experimental facility associated with the setup for characterization of plasma from thin film (LBO) as well as solid (LPP) target has been developed. The various elements in the system including, laser systems, vacuum chamber and associated components and generation of variable pulsed magnetic field were briefly explained in this chapter. Technical specifications of the diagnostics, which used in the present study- OES, fast imaging and probe techniques were also included. Since a number of elements have to be synchronized accurately in order to carry out this experiment, we have developed a timing processor unit, which synchronized all the events and produce necessary trigger pulses for the associated instruments. Technical aspects, optimization and performance tests of the developed setup were briefly described.
2.7. References


16. Instruction manual, Quantel Brio laser (www.quantel.com)

17. Instruction manual, Continuum laser (www.continuum.com)


22. Instruction manual, ICCD (www.standfordcompturoptics.com)


