Development of automated ultraviolet laser beam profiling system using fluorometric technique

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ABSTRACT
This paper describes the development of laser beam monitoring system for excimer laser. As excimer lasers become more attractive for industrial and medical applications such as photolithography, stereo lithography, material processing, lasik surgery etc, it is necessary to characterize and control the beam quality of the laser. Conventional characterization techniques use burn paper, scanning system in which a knife-edge, wire, pinhole or slit is moved across the beam and the transmitted or reflected energy is measured. Solid state array camera system is also used to spatially sample the energy distribution. Each of these techniques suffers from limitations. To circumvent these limitations, we have developed a diagnostic tool to monitor the beam characteristics using fluorescent glass plate. When the glass plate is illuminated by UV radiation it gives fluoresces in visible region. This approach allows high incident beam fluence, good signal to noise ratio, high spatial resolution and linear response to input energy. The benefit are fast, accurate and repeatable measurements improved consistency and quality and cost effective design.

Keywords: fluorescence, spatial profile, beam shape

1. INTRODUCTION
Many laser applications viz. photo lithography, stereo lithography, lasik surgery etc. require the 2 D intensity profile across the beam to be in specific uniform or non-uniform profile. Before the illumination / irradiation of laser in such application study and control of beam shape is very important. To study the beam shape and intensity distribution, common methods like burn paper study (Subjective Densitometry), slit or knife-edge measurement (single axis scan), aperture and pinholes scan (single or dual axis) type instrumentation are generally employed. Each of these methods suffers from limitations. For example burn paper is a thermal paper which offers a convenient means for detecting the beam shape from single laser pulse and is more convenient for alignment of the laser. These papers have small dynamic range and non-linear thermal property. Due to this it can give a tentative idea about the beam shape of incident radiation but it is unable to provide actual intensity profile. The Beam scanning systems generate a profile by mechanically moving a slit aperture or knife-edge across the beam. Scanning type system is quite good for CW systems but they are unable to provide a intensity profile of single shot laser systems. The knife edge profilers measure the portion of the beam that is not blocked by the knife and differentiate the results. Slit profilers measure the amount of light passing through a narrow slit and integrate the results. A calculated beam profile is then displayed, based on the raw power data and assumptions about the nature of the beam. The scanning system gathers two-dimensional data and uses topographical algorithms to sort of fill in the blanks. These scanning systems need several laser pulses to produce the beam profile and provide the integrated intensity profile.

In modern systems solid state array cameras are used to spatially sample the energy distribution. The heart of CCD imager is an array of minute photodiodes (pixels), each of which produces output directly proportional to the amount of light incident upon it. By shining a laser beam onto the array and correlating the output of each pixel with their position in the array, the intensity can be determined at any point in the beam. The main advantages of CCD based systems are their relative low cost and their ability to provide profiles of pulsed (down to 1 Hz) and CW beams without making any assumption on the nature of the beam. The CCD imaging system can also provide positional information. The main limiting factor of a CCD system is pixel size. The smaller and more closely spaced the pixels, better is the resolution. Currently the smallest pixels available are 4.65 x 4.65 µm for instruments operating in 350 - 1100 nm. Within the limits of their resolution CCD system capture complete three-dimensional data (intensity, X and Y). The array camera systems have low damage thresholds for short wave length radiation. The performances of these cameras degrade continuously.

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by short wavelength radiation. For example, sensitivity of vidicon camera exposed to 193nm wavelength radiation intermittently over a one month period was found to change by 30 percent due to ablation of photocathode.

To overcome limitations offered by these techniques, we have developed our own diagnostic tool to monitor the beam characteristics using fluorescent glass plate.

2. THEORY

Fig 1 shows schematically the UV beam incident normally upon the crystalline plate and the fluorescence induced at typical point within the plate. The fluorescent light propagates in all directions from the chosen point. This emanating visible fluorescence can be seen by naked eye from all points within the UV irradiated volume as respective beams passes through the plate. Since the intensity of the visible fluorescence at each point is proportional to that of input UV radiation reaching that point, we get the facsimile of the UV intensity distribution within the plate. The temporal shape of the fluorescent pulse differs from that of UV laser pulse because of the time required for energy storage and release within the atoms of the crystalline plate. When this fluorescent glass (which contains rare earth ions) was illuminated by XeCl excimer laser (pulse width 12 ns FWHM, 308 nm), its fluorescence duration was 18 µS FWHM as shown in fig 3. The laser pulse width is measured using biplaner photodiode and fluorescence duration has been measured by MRD500 (having response time less than 1 ns) which has been biased in photo conductive mode. The laser pulse width and fluorescence duration are shown in fig 2 and fig 3 respectively.

We have used LUMILASS SERIES of new luminescent glass that can convert wide range of ultra violet light into visible light. LUMILASS - G9 emits green fluorescence (540 nm, emission spectrum is shown in fig 4). It converts wide range (200 - 390 nm for LUMILASS-G9 as depicted in fig 4) of UV radiation into visible light.

This fluorescent glass is highly sensitive and is capable to change faint UV ray (less than 1 µW/ cm²) into visible light and can be observed by naked eye. It has better durability than organic fluorescent materials and inorganic phosphors. The fluorescence is linear over several orders of magnitude of input UV irradiance. We could test linearity of lumilass G9 fluorescent glass, upto three order in our laboratory and the obtained curve is depicted in fig 5. The damage threshold of this material depends on irradiation wavelength and light source. The damage threshold of this crystalline fluorescent plate is quite high. For our XeCl laser maximum energy density is 100 mJ/ cm² and the pulse could be used easily without any damage.
3. EXPERIMENTAL SETUP

Fig. 4 Excitation and emission spectra of lumilass G9 glass

Fig. 5 Linearity of lumilass G9 glass

3. EXPERIMENTAL SETUP

Fig 6 Experimental Setup

Fig 7 fluorescent glass illuminated by XeCl laser
Figure 6 depicts the actual experimental setup. The figure 7 shows the experimental condition when fluorescent plate is illuminated by laser beam. The schematic of the experimental setup is shown in fig.8

The experimental setup incorporates the beam splitter, fluorescent crystalline plate, interference filter for 540 nm having bandwidth of 10 nm FWHM, Neutral density filter, imaging lens and CCD camera. The UV laser beam is splitted into two parts with the help of beam splitter. The reflected part is used to monitor the beam diagnosis system whereas transmitted beam is used for laser based application. In this setup we have used transmitted beam for beam profile scanning using a pinhole aperture (to observe the variation between these two methods). We are using a pinhole of 1 mm diameter. The transmitted beam falls on pin photodiode having response time less than 1 ns, which is biased in photo conductive mode. The reflected beam falls on fluorescent glass and produces a facsimile image on it. The fluorescent plate also can transmit some UV radiation. To save the CCD camera from UV radiation it is necessary to filter out this radiation. For this the fluorescence light is being passed through interference filter of 540 nm. To prevent the camera from getting saturated, we have used ND filters. Finally the image formed on fluorescent plate it imagined on CCD camera using iris and imaging lens.

The electronic image generated at CCD video camera is captured by PC with the help of frame grabber card. Since the excimer laser is pulsed laser system, it is necessary to synchronize the frame grabber with output laser pulses. To synchronize the frame capture we have developed an interfacing circuit, which provides synchronized trigger pulses to frame grabber card. This circuit takes optical trigger pulse through optical fiber to prevent EMI pickups from laser system. Fig.9 shows the synchronization circuit. The video image can be observed in real time or monitored or stored in videotape with a conventional VHS Video Cassette Recorder.

4. BEAM ANALYSIS

The captured beam is analyzed by the help of in house developed image processing software. This software is capable of online display of beam characteristics. This software can do much operation regarding image processing viz. averaging, filtering, binning, 1D, 2D and 3D plotting, FWHM calculation, pixel wise energy calculation etc.
In this paper we have measured the intensity profile of the XeCl excimer laser beam by 1. Burn paper, 2. Pinhole scanning and 3. By fluoremetric technique as described in this paper. In the following figures we show the results of our experiment.

Fig. 10 shows the burn pattern on a thermal paper. The measured width of the laser is 6 mm.

In fig 11 A shows the intensity profile with pinhole scanning whereas B shows the measurement of the same beam with the technique developed by us. In pinhole scanning, the transmitted laser light falls on MRD500 pin photodiode and the measured FWHM is 5.08 mm. In fluorometric technique, the FWHM is 4.959 mm. if you compare these, we can easily recognize that the fluoremetric method is more suitable and accurate.

The fig. 12 shows the laser beam. The 3D plot depicts the intensity variation of entire beam, which is of much interest when the beam shape of specific type is required for laser based application.

Fig 11 Intensity profile of XeCl laser by , A. pin hole scanning,  
B. Fluorometric technique

Fig 12 laser beam and its 3D plot
5. CONCLUSION

We have developed a low cost diagnostic tool for UV laser beam profiling system using fluorometric technique. This technique eliminates the performance degradation of CCD camera caused by UV laser. Experiment also proves its superiority over conventional methods as it can analyze the profile over a single laser shot. This setup will be invaluable for the study of the excimer laser beam properties with time, due to variations of the resonator, due to mechanical changes, due to impurities developed in the laser gases and change of discharge property. By this technique we can also monitor the pulse-to-pulse stability of laser system and beam quality being delivered by system and take corrective steps to reshape and homogenize the laser beam.

REFERENCES