PRAMANA — journal of physics
© Indian Academy of Sciences
Vol. 82, No. 1
January 2014
pp. 153–157

Enhanced performance of a repetitively pulsed 130 mJ KrF laser with improved pre-ionization parameters

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DOI: 10.1007/s12043-013-0655-8; ***e*Publication:** 5 January 2014

Abstract. Studies related to the effect of pre-ionizer on laser output energy of a repetitively pulsed KrF laser are presented. The dependence of laser output energy, spectral width and beam spot homogeneity on pre-ionization parameters, namely its current and voltage rise time are reported here. Here, effectiveness of pre-ionization is optimized by improving pre-ionization current and rise time of the pump pulse of the automatic UV pre-ionizer KrF laser. It is observed that by increasing pre-ionization current from 6 kA to 10.6 kA, the output energy increases by about 30% (from 100 to 130 mJ). It is also observed that the emission spectral width reduces by almost 60% by increasing the pre-ionization current. Regular homogeneous and well-developed beam spot (nearly Hat-Top profile) was achieved under these optimized conditions.

Keywords. Excimer; krypton fluoride; pre-ionization; spectral width; beam profile.

PACS No. **42.55.Lt**

1. Introduction

Excimer lasers are pulsed gas lasers which produce ultraviolet radiation in the range of 351 nm to 193 nm depending upon the composition of the gas mixture used [1,2]. Fluorine-based excimer gas lasers are powerful sources of coherent radiation in the ultraviolet region of the EM spectrum. For practical reasons, discharge-pumped krypton fluoride (KrF) laser systems operating at 248 nm are the most widely used laser systems for possible laser material processing applications [3–8]. These excimer lasers have found numerous uses in a broad range of applications in research, micromachining, manufacturing of semiconductor devices, precision machining, medical therapy and photochemistry. Short-wavelength excimer laser beam can be focussed onto a smaller spot size than any other laser source in visible or IR region. UV lasers have enormous advantage in microstructuring, laser ablation, marking and drilling applications [9–11]. Self-sustained high repetition rate KrF lasers generally operate at high voltages and high buffer gas pressure (2–5 bar). In these lasers, maintaining glow discharge for efficient pumping is a challenging task over the entire discharge volume. The electron density required in these discharges is of the order 10^{14}–10^{15}/cm^3 for efficient operation of KrF excimer lasers. If stored energy in the capacitor is directly coupled to the gas medium, it will lead to an arc formation which is not desirable for uniform laser pumping. Therefore, an efficient pre-ionization is an extremely necessary requirement prior to the main laser discharge. Efficient pre-ionization not only improves the homogeneity of the discharge but also increases the width/cross-section of the discharge. In a typical excimer laser, the spacing of the discharge electrodes leads to a multimode output beam with conventional plane–plane cavity that has a typical rectangular cross-section of 10 mm × 20 mm. Most applications require good beam homogeneity and therefore require laser gas discharge plasma uniformity, which is ensured by an efficient pre-ionizer coupled to the laser system. In this short paper, the enhanced performance of the KrF laser output energy and beam characteristics by improving the pre-ionization parameters are presented.

2. Experimental set-up and results

The KrF laser system developed mainly consist of laser head, UV spark pre-ionizer, magnetically coupled tangential blower, finned tube heat exchanger and electrostatic precipitator. The excitation circuit is primarily the C–C transfer circuit using high capacity thyratron as the switch element.

The laser-profiled nickel electrodes and an in-built automatic UV pre-ionizer are incorporated in the laser system. This arrangement leads to a discharge volume of 50 cm × 2 cm × 1 cm. The pre-ionizer assembly of the laser consists of inductively ballasted spark pins placed through HV electrode with proper insulation. There are 49 pins placed in two rows along the length of the HV electrode, besides each pin is inductively ballasted. For generating pre-ionizing sparks, a gap of 2 mm is left between the tip of the pin and the high voltage electrode surface.

The peaking capacitors are charged through these spark pins. The pre-ionization current is measured at the charging loop of the peaking capacitors externally. The main

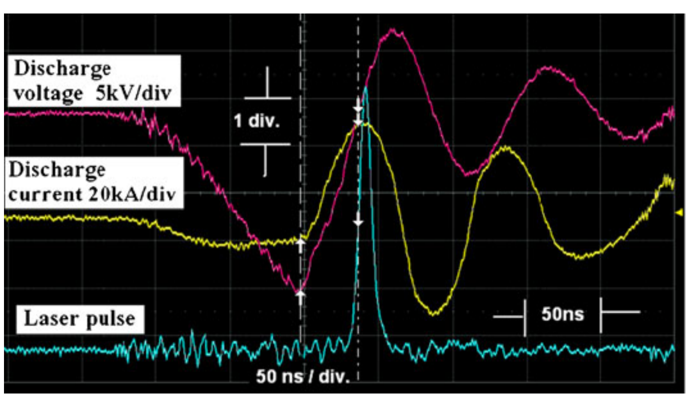

Figure 1. Discharge voltage, current and laser pulses of the KrF laser.

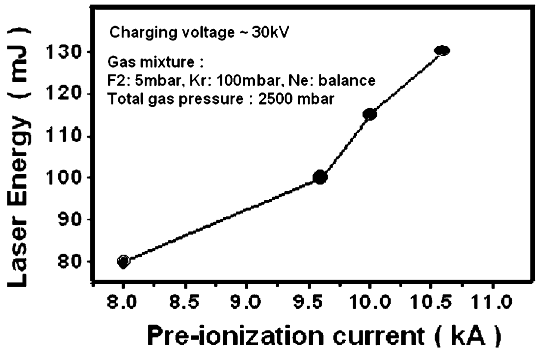

Figure 2. Variation of laser energy with pre-ionization current.

storage capacitors are charged up to required voltage of ~30 kV using home-built resonant charging power supply and switched by thyratron E2V CX 3608. A low inductance discharge loop has been incorporated for achieving fast discharge voltage pulses and high voltage pulses with ~90 ns rise time have been achieved (figure 1). With a view of keeping minimum loop inductance required for achieving fast rising voltage pulses for these particular lasers, due care has been taken for discharge loop. The circuit is capable of generating high voltage pulses ~30 kV and 90 ns rise time.

On triggering the thyratron, the energy of the main storage capacitor bank is transferred to the peaking capacitors via pre-ionization spark gaps. The intensity of the ultraviolet light that is used for pre-ionizing the gas medium is proportional to the pre-ionizer current. The amount of pre-ionization current depends on the capacitance (Cp), spark gaps, rise time and amplitude of the voltage pulse. By optimizing these parameters, the pre-ionizer current improves the laser performance. Weak and poor pre-ionization leads

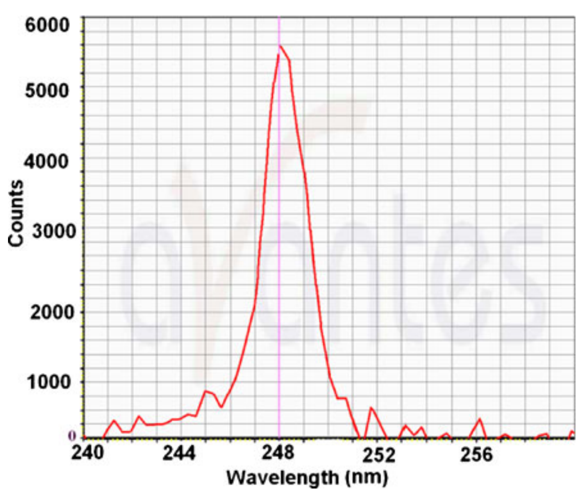

Figure 3. Emission spectra of KrF laser with weak pre-ionization.

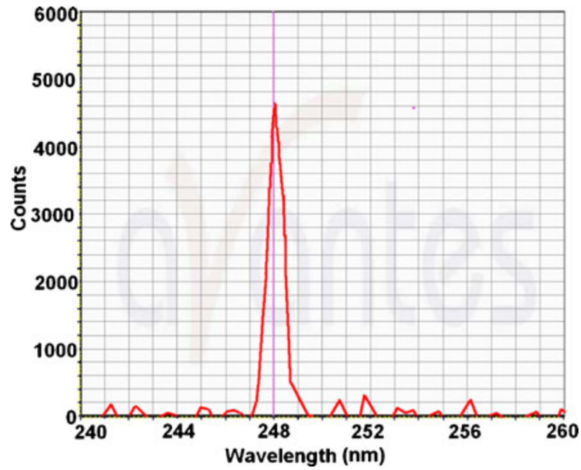

Figure 4. Emission spectra of KrF laser with efficient pre-ionization.

to inhomogeneous beam spot and drastically reduced laser energy. The effect of pre-ionization current on the output energy was studied and the results are given in figure 2. The pre-ionizer current was increased from 8 kA to 10.6 kA by improving the rise time from 130 ns to 90 ns as a result of reducing the circuit inductance, optimizing the peaking capacitor values and spark gaps.

The effect of pre-ionization on the KrF emission spectrum was studied and it was observed that with weak pre-ionization (Ip $<$ 6 kA) the emission spectrum of the output was broader (FWHM $=$ 2.1 nm, base 10 nm) compared to efficient operation of the laser with improved pre-ionization current of Ip $\sim$ 10 kA, with spectral FWHM $\sim$ 0.7 nm as shown in figures 3 and 4. With increased Ip, gain build-up was fast and optical extraction was dominated largely by stimulated emission, increasing the coherence of the laser output, thereby reducing the spectral width considerably. The output beam profile in the case of both weak pre-ionization and improved pre-ionization were recorded through semi-transparent screen by SLR digital camera Nikon D 70 and analysed by a commercial software as shown in figures 5 and 6.

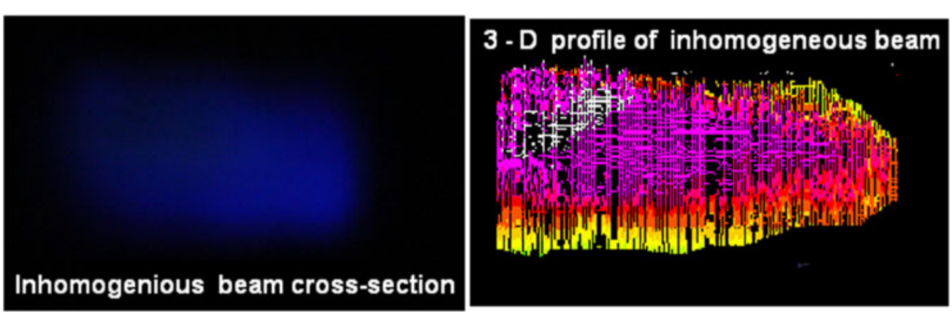

Figure 5. Laser beam cross-section and its 3D profile with poor pre-ionization.

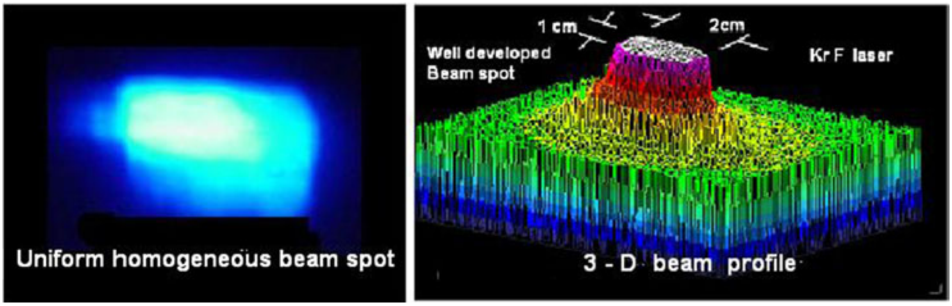

Figure 6. Laser beam spot and 3D profile with efficient pre-ionization.

In weak pre-ionization (low pre-ionizer current) the beam was not completely filled and the beam spot was irregular in shape as shown in figure 5, whereas the output laser beam cross-section in improved pre-ionization was found to be completely filled and the profile was close to Hat-Top (figure 6).

3. Conclusion

In conclusion, enhanced performance characteristics of the repetitively pulsed KrF laser due to increased pre-ionizer current is presented here. Increase in laser energy from 100 mJ to 130 mJ (improvement of ∼30%) was achieved by increasing the pre-ionization current from 8 kA to 10.6 kA. Regular homogeneous and well-developed beam spot (Hat-Top) was achieved under these conditions which otherwise are extremely difficult to maintain in a KrF laser. This also reduces the output emission spectral width by nearly 60%. The improved pre-ionization enhanced the output energy and output laser beam characteristics.

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