PRAMANA — journal of physics
© Indian Academy of Sciences
Vol. 82, No. 1
January 2014
pp. 165–171

Design and performance characteristics of a krypton chloride ($\lambda = 222$ nm) excimer laser

N S BENERJI*, N VARSHNAY, A SINGH and BIJENDRA SINGH
Excimer Laser Section, Laser Material Processing Division, Raja Ramanna Centre for Advanced Technology, Indore 452 013, India
*Corresponding author. E-mail: nsb@rrcat.gov.in

DOI: 10.1007/s12043-013-0657-6; ***e*Publication:** 7 January 2014

Abstract. Development of a discharge-pumped krypton chloride (KrCl) laser operating at 222 nm wavelength is demonstrated. In this paper the design, successful realization and operating characteristics of KrCl excimer laser are reported. The laser is driven by a simple and efficient excitation technique using automatic UV pre-ionization with discharge-pumped self-sustained capacitor–capacitor (C–C) energy transfer circuit. The experimental investigations including output laser energy, temporal pulse parameters, emission spectra and beam profile of the KrCl laser were recorded. For high repetition rate operation, in-built, compact gas circulation system using tangential blower was incorporated. The laser was operated at 25 kV discharge voltage, gas mixture of 5 mbar HCl, 160 mbar kypton and neon as balance with a total gas pressure of ~2.5 bar. These experiments produced an efficient and reliable output energy of 25 mJ from an active volume of 60 cm^3.

Keywords. Excimer laser; krypton chloride; UV pre-ionization; gas circulation.

PACS No **42.55.Lt**

1. Introduction

Excimer lasers are powerful coherent sources with various applications in research, medicine and industry [1,2]. Among various types of excimer lasers, krypton chloride (KrCl) excimer laser with a short wavelength of 222 nm has potential applications in material processing and photochemistry [3–7]. Due to its shorter wavelength, it bears a significance for material processing with higher efficiency because absorption of most materials increases towards shorter wavelengths in the UV [8–12]. Excimer lasers with operating wavelength ranging from 157 nm to 351 nm of UV region of electromagnetic spectrum are gas discharge lasers containing a mixture of noble gas, such as Kr or Xe and halogen donor, like fluorine and chlorine. Among various excimer laser gases, the F_2-based lasers provide the shortest wavelength of 157 nm. However, the fluorine gas

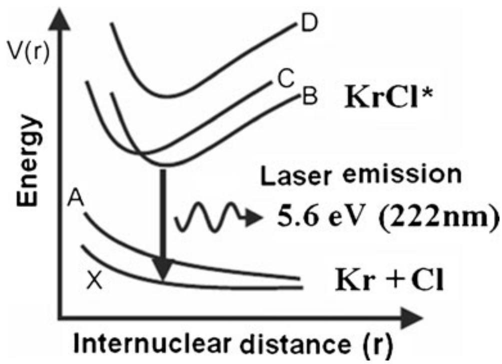

Figure 1. Energy levels and emission spectra of KrCl.

is highly reactive and involves relatively higher degree of technological challenges compared to chlorine as halogen donor for excimer lasers. Moreover, lifetime of the single fill gas is higher in chlorine-based excimer lasers. KrCl laser with its emission wavelength of 222 nm is the lowest wavelength excimer laser in UV using chlorine/HCl-based mixtures. KrCl lasers are characterized by low gain and in order to achieve high laser intensities it is necessary to deposit one order higher input electric power into gas medium than those required for XeCl and KrF lasers. In this paper, we describe the design and operating characteristics of a KrCl excimer laser using simple discharge circuit. For this KrCl laser, we have designed and developed aluminum chamber, subsystems and excitation circuits. The excitation circuit has very low loop inductance to couple the switched energy into gas medium rapidly. The experimental investigations of the energy, temporal parameters and laser beam characteristics of KrCl laser are reported here.

2. Experimental set-up and results

The energy level diagram and emission spectra of KrCl are briefly shown in figure 1. The bound-free emission of krypton chloride has a strong emission peak at 222 nm. The

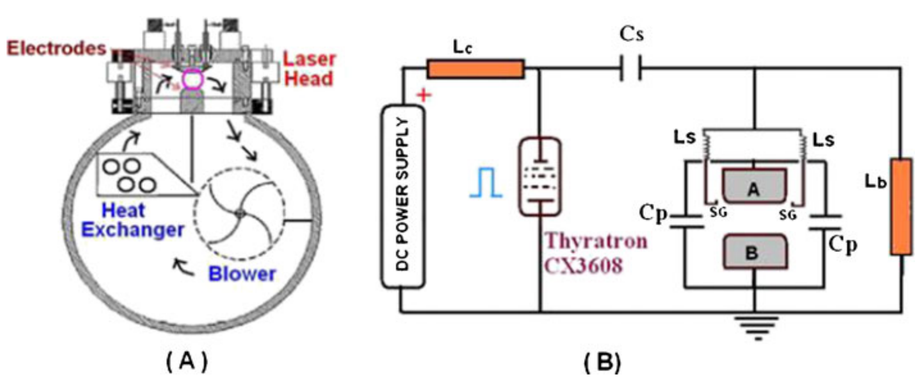

Figure 2. Schematics of (**A**) laser head and (**B**) excitation circuit.

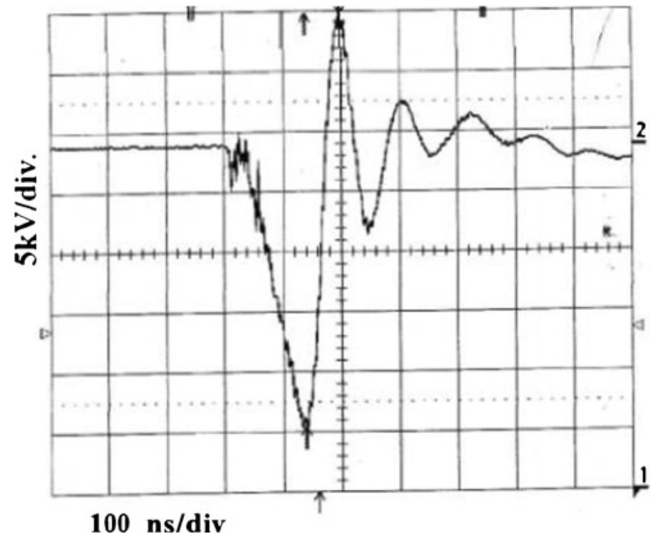

Figure 3. Discharge voltage waveform.

cross-sectional view of the laser system is shown in figure 2A. The system mainly consists of a cylindrical vessel that contains laser head, a tangential blower and heat exchanger. The laser housing is made of aluminum alloy and it can withstand an internal gas pressure of 5 bar. The laser head consists of a pair of Chang-profiled nickel electrodes, which are placed 15 mm apart. These discharge-profiled electrodes have been designed and fabricated based on Chang profile with an empirical constant $k = 0.18$. This arrangement leads to the formation of discharge of volume 50 cm $\times$ 1.5 cm $\times$ 0.8 cm (vol. $\sim$60 cm^3).

Figure 2B shows the excitation circuit of the laser with thyratron CX3608 as the main switching element. Storage capacitor bank Cs is charged with DC power supply through suitable charging inductor Lc and bypass inductor Lb. On switching the thyratron, the stored energy is transferred to peaking capacitors Cp through Ls and spark gaps (SG), which create effective pre-ionization in the discharge volume. The pre-ionization of the active discharge volume is by spark UV radiation created adjacent to both sides of the

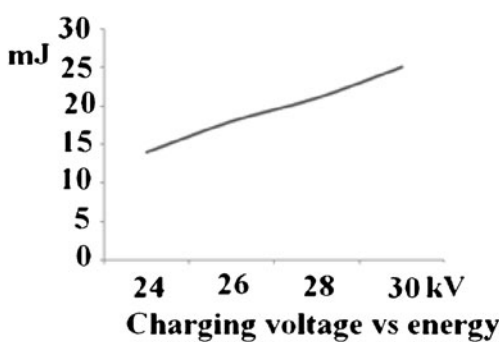

Figure 4. Output laser energy with charging voltage.

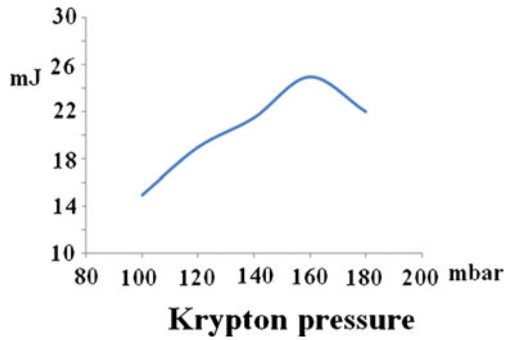

Figure 5. Output energy dependence on krypton pressure.

HV electrode, all along its length and spatially modulated to ensure uniform irradiation of the gas volume. In order to get effective pre-ionization, the current into the pre-ionizer is given by $I \sim C(\mathrm{d}V/\mathrm{d}t)$, which has been optimized for efficient lasing. Gas mixture is circulated in the discharge volume using a tangential blower, which is magnetically coupled to the driver motor outside the chamber. In this arrangement, there is no direct contact between the driver and the blower. This arrangement leads to minimum mechanical vibrations and prevents any possibility of gas leakage from the laser system. Finned tube heat exchangers are used to remove heat from the gas medium in the chamber during laser operation. Since KrCl has low gain compared to other excimer lasers (XeCl and KrF), it needs input power an order higher than other excimer lasers to get reasonable output energy. This requires an efficient excitation circuit that drives the electrical input power ($\sim$10 MW/cm^3) into the gas discharge medium rapidly. The design presented by us here is based on minimum discharge loop inductance which meets such criterion.

Excimer KrCl* was formed when gas mixture consisting of krypton, chlorine and neon/helium at a pressure of a few bars was excited by transverse electric discharge. The

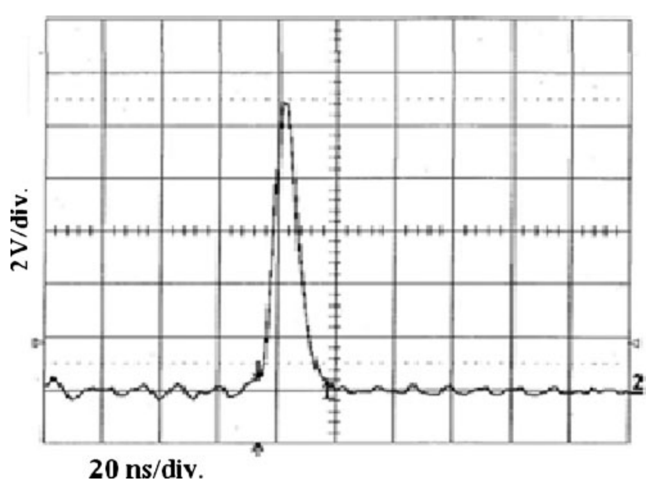

Figure 6. Laser pulse shape.

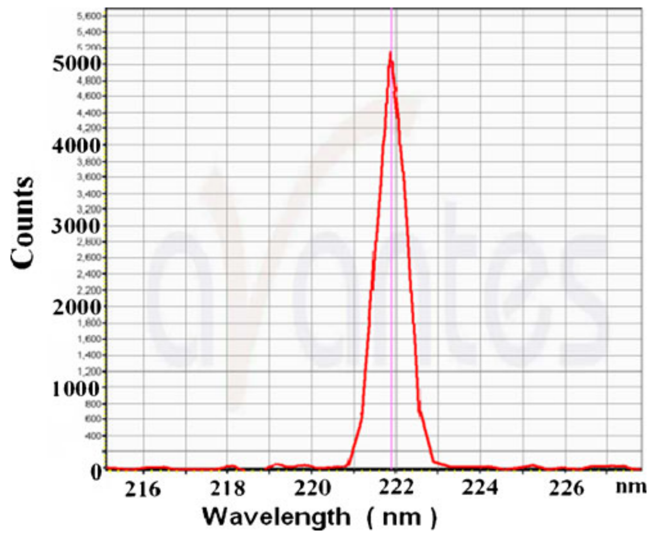

Figure 7. Laser emission at wavelength 222 nm recorded by spectrophotometer Aventis make.

laser was achieved by the stimulated emission of KrCl* and sustained by suitable cavity configuration. For this laser, a simple and efficient excitation circuit has been designed, developed and incorporated in the system. Considering the simplicity and reliability of the laser device, automatic pre-ionized discharge pumped excitation has been chosen. This is most advantageous for practical purposes as it can be incorporated in the laser head design and the pre-ionization automatically precedes the main discharge with a time delay determined by the circuit parameters. For minimizing loop inductance required for achieving a fast rising voltage and current pulses for this particular laser, due care has been taken

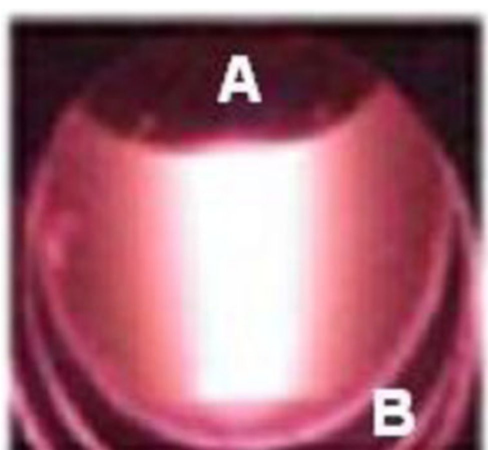

Figure 8. Intense homogeneous laser discharge between profiled electrodes (A, B).

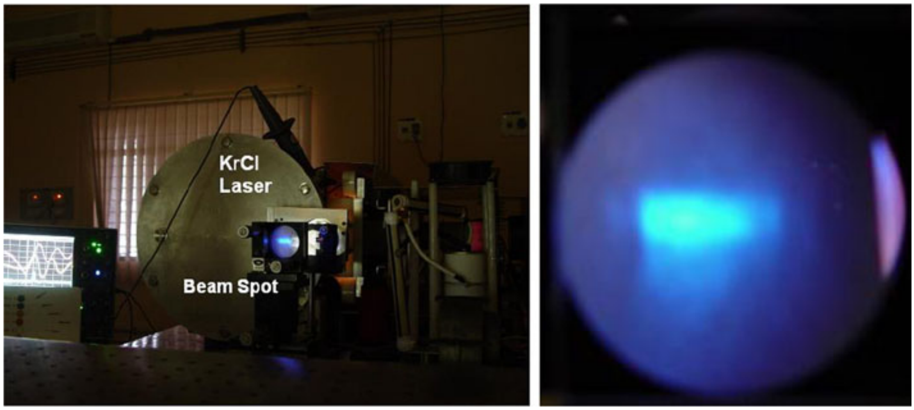

Figure 9. KrCl laser in operation at 25 mJ output laser energy.

in design of the discharge loop. For this, the thyratron was mounted as close as possible to the laser capacitor bank Cs (figure 2B). This arrangement resulted in producing high voltage pulses with rise time less than 80 ns across the laser head (figure 3). The high voltage excitation of the laser was by a C–C charge transfer circuit using storage capacitor Cs (50 nF), thyratron (CX3608 of E2V) and peaking capacitor Cp (40 nF). The peaking capacitor Cp of 40 nF consists of 20 doorknob capacitors placed very close to the discharge head and distributed along discharge length to ensure uniform energy distribution and also to drive discharge rapidly. The discharge chamber was sealed with plane-parallel quartz windows, one of which served as a resonator output coupler. The total system has been assembled in clean environment and the system has been made leak proof both for pressure and vacuum conditions. The leak rate achieved is of the order of 5×10^{-5} mbar l/s. The optical resonator/cavity was formed by a dielectric-coated total reflector with a plane flat quartz window separated by 100 cm. The output radiation energy was measured with a pyroelectric detector ED-200 (Gen Tec), temporal profile with biplanar photodiode (Hamamatsu-R1328U-54) and wavelength with spectrophotometer (Aventis). Initially, the laser performance was examined with different buffer gases (He and Ne), different

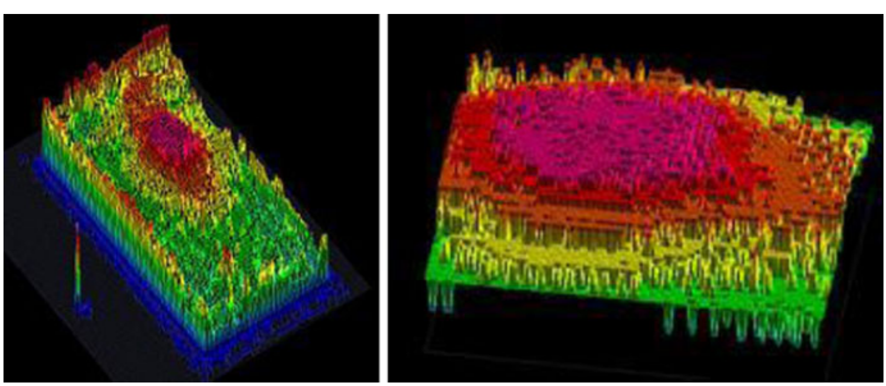

Figure 10. 3D beam profiles of KrCl laser at different graphic levels.

operating pressure and rare-gas pressure for highest laser output energy. The laser pulse energy was measured as a function of charging voltage and the Kr partial pressure and are shown in figures 4 and 5. The measurements were carried out with gas mixture containing partial pressure of Kr from 100 mbar to 160 mbar. A constant HCl partial pressure of 5 mbar was used in the laser. The maximum output of 25 mJ was obtained at charging voltage of 28 kV with a gas mixture composed of 5 mbar HCl, 160 mbar krypton and remaining neon at an operating pressure of 2.5 bar. Further increase in partial pressure of HCl and krypton beyond this optimum value leads to unwanted streamer formations in the discharge. This also results in quenching of excited upper laser states, which reduces the output energy.

The optical pulse length of the laser was observed to be ∼14 ns (FWHM) and is shown in figure 6. The emission spectrum of the laser was recorded at 222 nm with an emission bandwidth of 1.5 nm and is depicted in figure 7. Homogeneous discharge conditions were achieved at optimized conditions with pre-ionization and are shown in figure 8. The KrCl laser system in operating conditions is shown along with laser beam spot in figure 9. The output beam profile was recorded through a semi-transparent screen by the SLR digital camera Nikon D 70 and analysed by a commercial software (shown in figure 10). The output laser beam cross-section was completely filled and the profile was close to Hat-Top.

3. Conclusion

Design and successful realization of KrCl excimer laser operating at 222 nm were presented here. Compact in-built gas circulation system was incorporated in the laser for high rep-rate operation. Output laser energy in excess of 25 mJ was achieved using this laser system. The operating characteristics were recorded and are presented here. Further optimization and other investigations are in progress and will be reported elsewhere.

References

[1] D Basting and G Marowsky, *Excimer laser technology* (Springer, Berlin Heidelberg, 2005)
[2] J J Ewing, *IEEE J. Sel. Top. Quantum Electron.* **6**, 1061 (2000)
[3] L C Caper, H M J Bastiaens, P J Peters, K J Boller and R M Hofstra, *Appl. Phys. B* **88**, 61 (2007)
[4] A M Razhev, A A Zhupikov, E S Kargapol and A V Ryabstec, *Quant. Electron.* **34**, 95 (2004)
[5] E Amandillo, A Lunches, V Nassisi and M R Perrone, *Appl. Opt.* **24**, 18 (1985)
[6] A N Panchenko and V F Tarasenko, *IEEE J. Quant. Electron.* **31**, 1231 (1995)
[7] A M Razhev, A A Zhupikov, *Proc. SPIE* 6938, Atomic and Molecular Pulsed Lasers VII, 693809 (2008)
[8] R D Schaeffer, M J Scaggs and T P McGarry, *Materials processing with excimer lasers. Materials and manufacturing processes* (Taylor and Francis, 2007) **5**, 617 (2007)
[9] Leonard R Migliore, *Industrial lasers in encylopedia of optical engineering* (Taylor and Francis, New York, 2007) 880
[10] Ikeda-Naka, *Radiation Effects and Defects in Solids* **119–121**, 337 (1991)
[11] T Okada, *Mol. Phys.* **86**, 1075 (1995)
[12] P h Delaporte, M Gautand, W Marine, M Sentis, O Uteza, P Thouvenot, J l Arcaraz, J M LeSamedy and D Blin, *Appl. Surf. Sci.* **208**, 298 (2003)