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A repetitively pulsed xenon chloride excimer laser with all ferrite magnetic cores (AFMC) based all solid state exciter

N.S. Benerji [a,*], N.K. Varshnay [a], D.V. Ghodke [b], A. Singh [a]

[a] Excimer Laser Section, LMPD, Raja Ramanna Centre for Advanced Technology, Indore 452013, India
[b] PLSCD, Raja Ramanna Centre for Advanced Technology, Indore 452013, India

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ABSTRACT

Performance of repetitively pulsed xenon chloride excimer laser (λ∼308 nm) with solid state pulser consisting of magnetic pulse compression circuit (MPC) using all ferrite magnetic cores (AFMC) is reported. Laser system suitable for 100 Hz operation with inbuilt pre-ionizer, compact gas circulation and cooling has been developed and presented. In this configuration, high voltage pulses of ∼8 μs duration are compressed to ∼100 ns by magnetic pulse compression circuit with overall compression factor of ∼80. Pulse energy of ∼18 J stored in the primary capacitor is transferred to the laser head with an efficiency of ∼85% compared to ∼70% that is normally achieved in such configurations using annealed met-glass core. This is a significant improvement of about 21%. Maximum output laser pulse energy of ∼100 mJ was achieved at repetition rate of 100 Hz with a typical pulse to pulse energy stability of ±5% and laser pulse energy of 150 mJ was generated at low rep-rate of ∼40 Hz. This exciter uses a low current and low voltage solid state switch (SCR) that replaces high voltage and high current switch i. e, thyratron completely. The use of solid state exciter in turn reduces electromagnetic interference (EMI) effects particularly in excimer lasers where high EMI is present due to high di/dt. The laser is focused on a thin copper sheet for generation of micro-hole and the SEM image of the generated micro hole shows the energy stability of the laser at high repetition rate operation. Nearly homogeneous, regular and well developed xenon chloride (XeCl) laser beam spot was achieved using the laser.

1. Introduction

With the increasing of engineering applications such as micromachining and surface modifications of polymers, ceramics, glass and metals, the use of excimer lasers in advanced technology has grown rapidly [1–6]. The potential for excimer lasers in the workplace has been expanding dramatically recently because of their unique beam properties such as short wave length, high photon energy and output power. The excimer lasers capable of generating photons of energy between 4 eV and 6.4 eV, cause a direct interaction with the degree of freedom of the electrons of the radiated material without exciting rotational and vibrational energy levels. By breaking the covalent and ionic bonds, these lasers generate contour with well-defined edge sharpness. With high photon energy, short duration pulses the excimer lasers are among most precise optical processing tool. The thermal interaction on the target material reduces with the use of the excimer laser in material processing. Excimer laser systems with discharge pumped excitation with moderate laser output pulse energy and repetition rate of about 100 Hz are generally preferable for most of the scientific, material processing applications and studies of various atmospheric science [7–11]. Compared to other laser sources in UV (higher harmonics of infrared and visible laser sources), the excimer lasers have important features like ruggedness in design, scalability, large homogenized beam cross-section, cost effectiveness, easy operation and maintenance.

The major challenges in excimer laser systems have been of depositing high and fast input electrical pulse energy for efficient excitation of the laser energy levels due to very short inversion time. The discharge pumped excitation of medium power high repetition rate excimer lasers is normally operated with C-C charge transfer circuits using thyratron as high voltage switch. This switch has to be capable of switching tens of kA peak current at high operating voltage with high di/dt values. The thyratron switch is either operated as a single component or in combination with pulse compression circuits to reduce the load (switching current) through it. As the thyratrons are costly components with limited operational life, it is desirable to completely replace them with all solid state pulser involving semiconductor switches and

* Corresponding author.
E-mail address: nsb@rrcat.gov.in (N.S. Benerji).

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magnetic pulse compression circuits. The semiconductor switches are inferior to thyratrons in switching voltage, switching current and di/dt. But, their life time is considerably long. All solid state power supplies in combination of semiconductor switches with MPC have been used for gas lasers such as CVL, TEA CO_2 and excimer laser [12–28]. These schemes have been demonstrated in past by many authors in excimer lasers without the use of thyratrons under various pulser configurations. In many such cases, MPC circuits using met-glass and combination of met-glass with ferrites have been demonstrated with overall energy transfer efficiency of ~65–70%. Though high transfer efficiency and compression ratio have been demonstrated using met-glass as core material, such saturable inductors necessitate complicated fabrication. Besides, they have higher losses and more material degradation compared to those made of Ni-Zn all ferrite toroidal cores. Also, the air gaps formed between layers of core in met-glas lead to reduced heat transfer efficiency.

Here, in this short paper, we report a simple, rugged, cost-effective and easy to assemble solid state pulser consisting of 4 stage MPC circuit based on all Ni-Zn ferrite core material with pulse energy of 150 mJ from a UV pre-ionized XeCl laser. The energy transfer efficiency, T~85% was achieved and this is a significant improvement of about ~21% in its performance compared to T~70% achieved using all met-glass reported previously [14]. To the best of our knowledge, there has not been any report on such high energy transfer efficiency in a repetitively pulsed XeCl excimer laser driven all solid stage exciter using all ferrite cores. Increased overall reliability, simple circuit, easy to assemble and nearly homogeneous beam spot are other features of the work reported here. High current discharge switching normally associated with thyratrons is completely eliminated and single SCR is used as a low current primary switching (before the pulse transformer) in the pulser, thus completely eliminating high current, high voltage switching (discharge) in the laser. In this simple circuit, SCR has been used as a switching device. Since SCR is current driven, it is immune to noise triggering.

1.1. Laser system

For stable and long life operation of a repetitively pulsed excimer laser, a compatible laser head is a challenging requirement and must be ensured before applying the excitation voltage for laser action. One of the main requirements for RGH lasers is a low inductance electrical circuit to provide very rapid current rise times for the laser discharge. In order to deposit excimer energy into the gas medium between the electrodes rapidly, the inductance has to be kept as minimum as possible to generate short pulses. To achieve this requirement, special care has been taken in the design of compact laser head, selection and geometrical arrangement of conductors and circuit components. The elements of this circuit are chosen individually and collectively for their low inductance characteristics in order to achieve rapid current rise times. The compact of laser head, arrangement of conductors and exciter circuit components need to be geometrically arranged in a compact way, so that it results into low inductance for current path thereby leading to rapid deposition of energy stored in the final circuit into the laser gas medium rapidly. Excitation of the active medium of the laser was accomplished using a capacitor charge transfer circuit (based on all solid state exciter) and automatic pre-ionization of the gaseous mixture by UV radiation. With such an excitation method, we do not need complicated synchronization systems and the design of the laser is significantly simplified. Besides this ensures its high reliability in operation. Schematic diagram of the repetitively pulsed xenon chloride excimer laser system with its sub-systems is shown in Fig. 1. The excimer laser system demonstrated here mainly consists of laser head, compact gas circulation and cooling unit, all solid state high voltage pulser for excitation and stable plane-plane optical cavity. The laser head also consists of a pair of main discharge electrodes and pre-ionizer assembly. One of the electrodes is high voltage electrode having semi-cylindrical shape with inbuilt spark pre-ionizer and other electrode is profiled ground electrode. The profiled discharge electrode has been designed and fabricated based on Chang profile with an empirical constant k=0.12. The use of compact electrodes resulted in aspect ratio of electrode width to discharge width of 3:1.2. This allowed us to place the pre-ionizer close to discharge zone and also enabled us in placing peaking capacitors very close to the laser electrodes. Subsequently, this has resulted in establishing low inductance laser head. The profiled electrode is located along a central position within the cavity and is grounded to the housing structure and high voltage electrode mounted on a main insulator member with a spacing of 23 mm between them. The electrical connection on the two plates was provided by side feedthrough arrangement to minimize the inductance. Here, the peaking capacitors have been distributed both the sides of electrodes along their length. In order to decrease the inductance of the discharge circuit, we have placed the peaking capacitors C_p between the caps, flush against the discharge chamber, as close as possible to the electrodes. The capacitors used are low equivalent series inductance Murata make 700 pF, 30 kV and N4700 series capacitors (Strontium Titanate as dielectric) and these are made as parallel capacitor banks (individual capacitors of these banks are of 0.7 nF for peaking and 2 nF for main storage) so that the value of the collective inductance decreases further. These electrodes with inbuilt pre-ionizer are mounted in a halogen gas compatible and UV non-degradable insulator chamber. This arrangement results in a discharge of 1 cm × 2.3 cm × 50 cm dimensions. The discharge volume was uniformly pre-ionized with UV sparks light from both sides along the electrode length. The pre-ionizer is based on sparks produced between tips of a HV pins inserted in electrode with required insulation and electrode. For uniform distribution of UV pre-ionization, a total of 50 pins have been equally spaced and staggered all along the electrode on both sides with a gap of 2 mm between the tip of the pin and electrode. Each pin is ballasted by an inductor (~20 nH) to ensure uniform flow of current through all sparks.

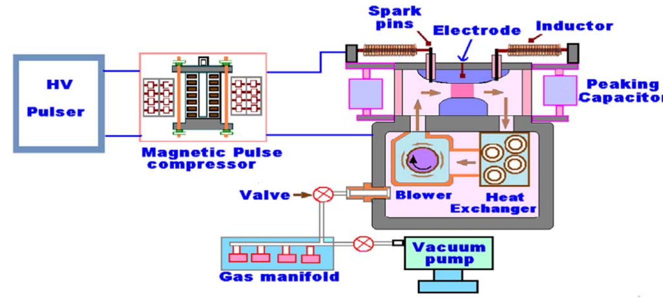

Fig. 1. Excimer laser system with subsystems schematics.

The gas replacement between electrodes within successive discharge pulses at high rep-rate of ~100 Hz is ensured by the uniform flow provided along the electrodes by the tangential blower. The velocity of gas flow in the discharge region was measured in neon gas at 2.5 bar pressure by tachometer and was found to be sufficient for clearance ratio of 4 for 100 Hz laser operation. These sub-assemblies were rigidly mounted inside the compatible laser chamber made of aluminum alloy with high vacuum integrity. Finned tube heat exchanger has been integrated with the gas flow system in the laser chamber for gas cooling during longtime operation of the laser at 100 Hz. The resonator for the laser is a plane high reflecting dielectric coated mirror and