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High-power transverse flow CW CO_2 laser for material processing applications

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Abstract

A transverse flow transversely excited (TFTE) CW CO_2 with a maximum output power about 15 kW has been developed. This is excited by pulser sustained DC discharge applied between a pair of multi-pins anodes and a common tubular cathode. Though the laser power in convective cooled CO_2 laser scales proportionally with the volumetric gas flow, it did not increase in this laser when the volumetric gas flow was increased by increasing the electrode separation keeping the flow velocity constant. The discharge voltage too remained almost unchanged with increase of the electrode separation. These observations are explained considering the electrical discharge being controlled by ionization instability. Laser materials processing applications often demand programming facilities for laser power modulation. A four-stage cascaded multilevel DC–DC converter-based high-frequency switch mode power supply has been developed to modulate the output power of the laser. Laser was operated up to 15 kW output power in four different modes viz. continuous wave mode, pulse periodic mode, single shot mode and processing velocity-dependent power mode with 1.2 kHz modulation bandwidth. We describe briefly the laser system, the SMPS, and the temporal behavior of laser beam.

Keywords: CO_2 laser; Transverse flow; DC excitation

1. Introduction

High-power CO_2 lasers, because of their high efficiency and high-power capability are widely used for laser materials processing (LMP) applications such as cutting of metallic and non-metallic sheets, welding, surface hardening, surface alloying and cladding, etc. In fact, CO_2 laser is the workhorse in the industry for laser power above 5 kW. Several different schemes for multi-kilowatt CW CO_2 laser such as fast axial flow CO_2 lasers excited by DC [1,2] and RF [3,4] discharge, transverse flow lasers excited by either DC [5,6], RF [7] and silent discharge [8] and the more recent one, diffusion-cooled extended electrode discharge [9,10] have been developed. We have adopted the transverse flow configuration and created the active volume between a pair of multi-pin anodes and a common tubular cathode with the pulser sustained DC discharge because of its simple design and relatively low cost [6,11]. The pair of anodes is placed across the gas flow (Fig. 1). We had developed laser models of 2.5 and 5 kW [11,12] and based on the experience we have developed laser of power about 15 kW. In convective cooled CO_2 laser the laser power scales proportionate to volumetric gas flow. In this discharge configuration, we found that the laser power did not increase when the volumetric gas flow was increased by increasing the discharge electrodes separation at a constant flow velocity [13]. The discharge voltage too did not increase with the increase of electrodes separation. In fact, the maximum input electrical power per unit electrode length that could be deposited in a stable and uniform discharge remained almost constant with the increase of electrode separation at a constant flow velocity. And, the maximum laser power too remained almost constant for different electrodes separations at a constant flow velocity. However, when the gas flow velocity was increased, both the discharge voltage and the laser power

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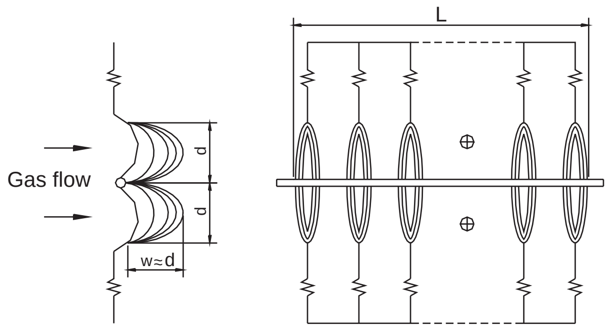

Fig. 1. Schematic diagram of the resistance ballasted multiple pins anode and tubular cathode.

increased. Thus, the laser power could be increased by increasing the discharge length and/or the gas flow velocity. And, the electrode separation needed to be increased for producing laser beam of size for which the laser power density is below the damage threshold of the intracavity optical components. Based on these considerations, the discharge length and electrodes separation for 15 kW laser power at about 50 m/s gas flow velocity were determined as 5.2 and 0.065 m, respectively [13]. LMP applications often demand programming facilities for laser power modulation. Conventionally, DC power supplies are used for creating electrical discharge in multi-kilowatt transverse flow CO_2 lasers, and these power supplies are controlled by either an autotransformer or phase-controlled rectifier. The dynamic response of these power supplies are poor; therefore, they cannot be used for very fast discharge current modulation or switching in the kHz range. The vacuum tube-based power supplies can give fast dynamic response, but their efficiency is poor because of the large power dissipation in the vacuum tube due to the linear mode operation of tube. A more efficient and versatile method of laser power modulation and switching is to use high-frequency current-controlled switch mode power supply (SMPS) for laser excitation. We developed a four-stage cascaded multilevel DC–DC converter-based high-frequency SMPS for this purpose. This allowed us to operate the laser at 15 kW output power level in four different modes viz. continuous wave mode, pulse periodic mode, single shot mode and processing velocity-dependent power mode. The laser power modulation bandwidth was 1200 Hz. In the optimum condition, we obtained over 15 kW maximum laser power with ~17% electro-optic efficiency. The operation of the laser in pulse-periodic mode was found advantageous for cutting metal sheets and materials of high reflectivity such as aluminum, copper and brass and also in some specialty of welding. In this paper, we discuss the laser power scaling in this type of TFTE CO_2 laser and briefly present the construction and operation of the laser and SMPS.

2. Laser power scaling in TFTE laser

In a convective cooled laser, the laser power scales up with the laser gas flow velocity as

$$P_L = [\eta/(\eta-1)]\rho C_p \Delta T v d L \tag{1}$$

$$\approx 120 M^{\bullet}, \tag{2}$$

where η is the electro-optic efficiency, ρ is the laser gas density, C_p is the specific heat of laser gas, ΔT is the rise in the laser gas temperature, v is the gas flow velocity, d is the discharge height (~ electrodes separation), L is the discharge length (Fig. 1) and $M^{\bullet}$ is the mass flow rate of the gas. This is with the assumption that maximum electrical input power limited by the rise in laser gas temperature ($\Delta T \sim 200^\circ$C) without the bottlenecking at the lower laser level can be dissipated in a stable and uniform discharge. In fast gas flow lasers, where the gas residence time is too small for any discharge instability to grow and deteriorate the discharge quality, the input electrical power is limited by bottlenecking at the lower laser level.

From Eq. (1) one would expect that the laser power would increase with the increase of electrode gap d. We carried out experiment in a TFTE laser for different electrode separations and gas flow velocity. In the first set of experiments, the gas flow was kept constant at ~35 m/s and laser power was maximized for three different electrode separations. It was observed that the maximum discharge current, discharge voltage and the laser power remained almost constant for different electrodes separations. However, the optimum gas mixtures for the maximum laser power were different. The nitrogen partial pressure was more for smaller electrodes separation. The maximum discharge current, discharge voltage, input electrical power density, laser power, laser gas mixture and electro-optic efficiency are presented for different electrode separations and gas flow velocity in Table 1. For the estimation of input power density, the discharge cross-section was assumed to be equal to the laser beam size. When gas flow velocity was increased, both laser power and electro-optic efficiency increased.

From the above experimental results the following observations can be made:

1. One would expect that the discharge voltage would increase with the electrodes separation and the discharge electrical field would remain constant to maintain the same discharge current. But the discharge voltage does not increase proportional to the increase in electrodes separation.
2. Maximum discharge current that can be flown through discharge without the onset of discharge instability remains nearly constant. It has slight tendency of reduction with the increase of electrodes