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Experimental Optimization of the Output Power of a Copper Vapor Laser Using Air as a Buffer Gas

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Abstract

In order to investigate the effect of the pressure buffer gas and frequency on the output power, a copper vapor laser with active medium length of 60 cm and bore of 16 mm has been operated and optimized using air as a buffer gas. The observed oscillatory behavior of the output power versus frequency is in good agreement with the previous reports. The measured results show the maximum output power of ~1.6W at the optimum pressure of 3.8 torr and frequency of 17 kHz. Abundance of the air and reduction of the system volume due to elimination of the gas handling system as well as the economically benefits are the advantages of the employing air as a buffer gas in the copper vapor laser operation.

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1. Introduction

The lasers are devices that emit light coherently through a process of optical amplification based on the stimulated emission of photons. There are many different kinds of lasers for different and specific uses [1]-[28]. One of the lasers with high average power in the visible region at 510.6 nm and 578.2 nm is the copper vapor laser

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(CVL). Applications of CVL include the research, medicine, industry, high speed imaging, micro-machining, non-linear frequency conversion to the ultraviolet and photodynamic therapy. Furthermore, they have been used extensively as a powerful pumping source for dye lasers by the master oscillator-power amplifier array for higher output powers and beam quality [29]-[34]. In order to increase the output power and improve the laser performance, the buffer gas is used in CVL tube that provides a discharge medium when the discharge tube reaches to the required temperature of copper vapor production. The buffer gas provides the population inversion mechanism by means of energy transfer of the gas, ions or electrons to the metal atoms. On one hand, it shapes the energy distribution function through elastic collisions and on the other hand, it protects the windows against contamination and then transfers heat from the tube axis to the walls. Therefore, the buffer gas causes the increase in impedance of the discharge tube and consequently leads to improving matching by the excitation circuit [30]. In order to minimize the effect of inelastic electron collisions on the energy distribution function, the non-reactive inert gases with high excitation and ionization energies have been employed as the buffer gases such as He, Ne, Ar, Kr, Xe and their mixtures gases. He gives longer and lower discharge current pulses [30]. Neon enables laser oscillation at the highest gas pressure and obtained the highest output power among of them [35]. The weak oscillations are provides with N_2 [36], H_2, and CO_2 buffers [37]. The Ne buffer gas with adding of H_2 extremely improves CVL performance [38] [39]. Recently, we reported the gold vapor laser with Heas a buffer gas to comparison output power and the stability [40]. In this work, a CVL has been operated using air as a buffer gas and the behavior of the laser output power versus discharge frequency and gas pressure have been investigated to obtain the optimum conditions. Furthermore, formed layer and pollutions on the tube laser has been analyzed by XRD instrument and FTIR spectrometer to find layer compositions. Affluence of the air and reduction of the system volume due to eliminating of the gas handling as well as the thriftily benefits are the advantages of the using air as a buffer gas in the CVL operation in some researchers or educational cases. The paper is organized as follows: the experimental setup is described in Section 2. Section 3 presents the obtained results and discussion. The concluding remarks are given in Section 4.

2. Experimental Setup

The material of discharge tube is Alumina that its inner diameter and active medium length are 16 mm and 60 cm, respectively. It surrounded by a fibrous alumina insulation covering with a Pyrex tube and an external stainless steel jacket. In order to discharging, two molybdenum cylindrical electrodes are used. The back and front mirrors are consist of the couple of flat-flat resonator with reflectivity of 98% and 4%, respectively. As illustrated in **Figure 1**, the standard driven circuit is coupled to the laser tube. By the discharge of a 1.65-nF main capacitor (C_s) through the TGI1-1000/25 Thyratron, the tube gas is excited. A 0.68-nF peaking capacitor (C_p) is connected between the tube electrodes as well as the 0.15 mH inductance (L_2).

The experimental characteristics of the laser output are measured by a Tektronix^{TM} oscilloscope; model TDS-1250, a Molectron^{TM} PM500D powermeter, and a semiconductor detector model pbx-65. A FTIR spectrometer and XRD instrument are exploited to determine the chemical elements level to study the composition of the formed layer at the ends of laser tube.

3. Results and Discussion

The CVL has been operated by employing the air as a buffer gas to investigate and optimized the output power in terms of the various parameters at the constant input power of ~1.4 kW. At first, the behavior of the output power versus frequency has been studied at constant air pressure. The experiments are repeated at some various air pressures. The obtained results at some typical pressures of 2, 3.8, 5.3, 6.2 and 7.8 torr are shown in **Figure 2**. There is an optimum pressure and frequency for each CVL, which gives maximum output power. The optimum pressure is due to rate of collision between air molecules and copper atoms, which at optimum pressure, the population inversion and so gain of Laser would be increased, as for the other conventional buffer gases has been occurred. The optimum frequency and oscillatory behavior comes from geometrical structure of tube only, and independent of kind of buffer gas. The maximum output power of ~1.6 W is obtained at 3.8 torr of air pressure and 17 kHz of frequency. The noticeable point is the oscillatory behavior of the output power in terms of the frequency, which is in agreement with the previous reports [41] [42]. The effect arises from the laser tube which performs both as an optical and an acoustic resonator at some frequencies. In fact, the discharge energy extracted by optical and acoustical channels due to radiative and non-radiative decays, respectively. It is shown
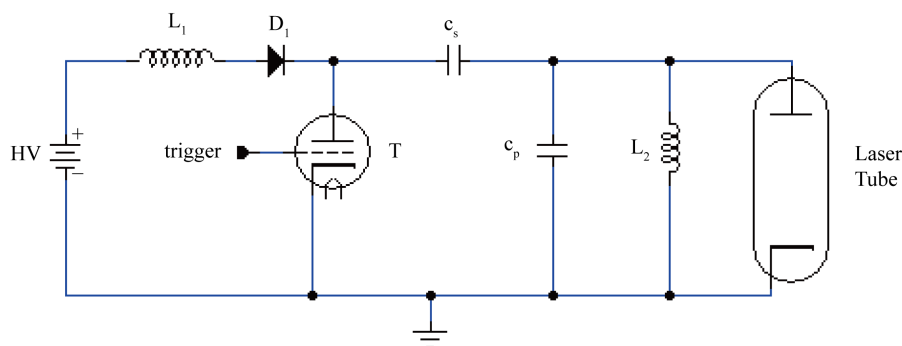
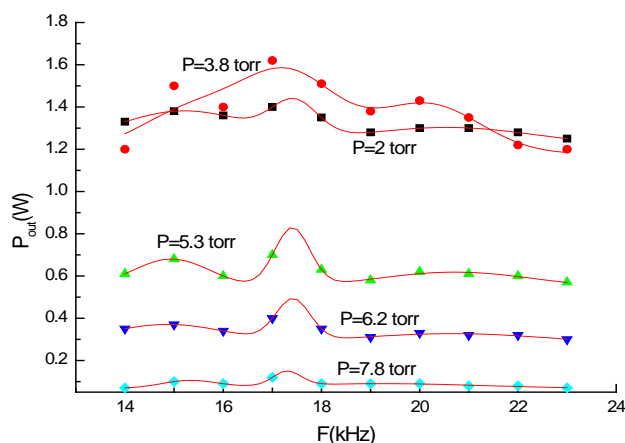**Figure 1.** Schematic layout of standard driven circuit of CVL.

Figure 2. The output power versus frequency at some various air pressures.

that the non-radiative deactivation vastly increases, when the excitation frequency is equivalent to the acoustic resonant mode of laser tube [41].

Figure 3 illustrates the behavior of the output power versus the pressure of air buffer gas at some frequencies. At first, the output power increases by increasing the air pressure for all frequencies. After reaching to a maximum value, it reduces at higher pressures. The reduction of the output power is due to increases in collision and relaxation of excited copper atoms. It is seen that the maximum output power at all frequencies occurs at ~3.8 torr of the air pressure. Compared with other buffer gases like He and Ne, the output power of CVL with air as buffer gas is decreased in the same discharge frequency due to exuberance of impurities in air, which alter the condition of population inversion. Meanwhile the optimum Ne pressure for this laser is about 25 torr that is 6 times more than that of air one. Furthermore, it is observed that the peak power is reduced from 1.6 to 1.27 W by increasing of frequency from 17 to 22 kHz due to the increasing in the inter pulse population of the lower laser level and the inter pulse electron density.

Abundance of the air and reduction in volume of the laser system due to elimination of the gas handling as well as the economic benefits are the advantages of the air where is using as a buffer gas in the CVL operation, in some research or educational specific cases. However, the laser tube is polluted after some operation such that some populace in red color are deposited at one of the tube end and a black color one is deposited at the other side, as shown in **Figure 4**. The Laser tube is polluted after some operation, which causes the lifetime of the tube would decrease the output power of CVL, and no effect on frequency operation. However, pollution can be eliminated by cleaning of tube through removal of pollutant.

The deposited samples at each ends of the laser tube are analyzed by FTIR spectrum and XRD instruments to determine the component of composition. **Figure 5** displays FTIR spectrum before and after some laser operation.

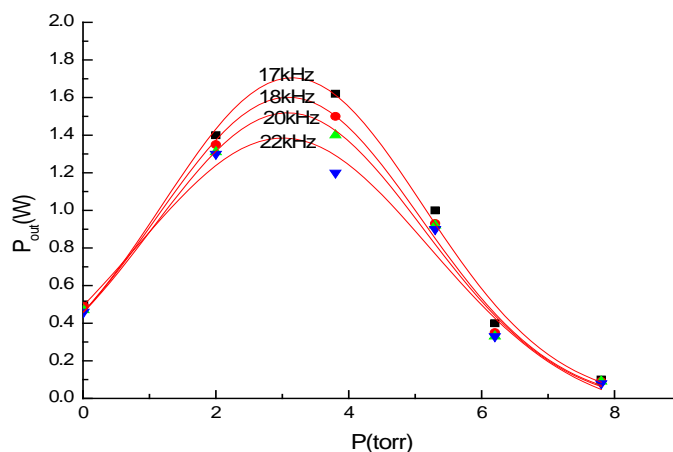Based on the FTIR spectrum, the component of composition in formed layer at the ends of the tube can be

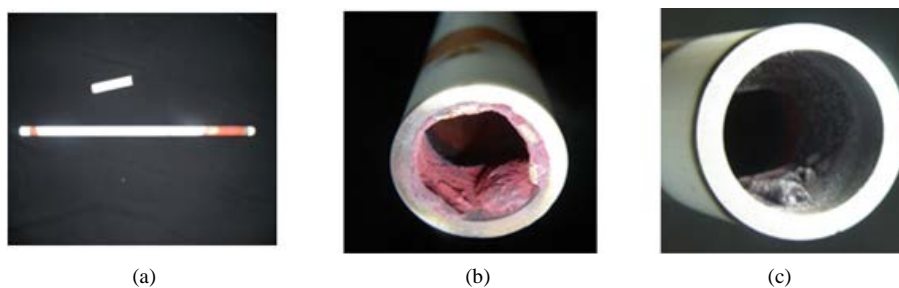**Figure 3.** The output power versus air buffer gas pressures at some frequencies.

(a) (b) (c)

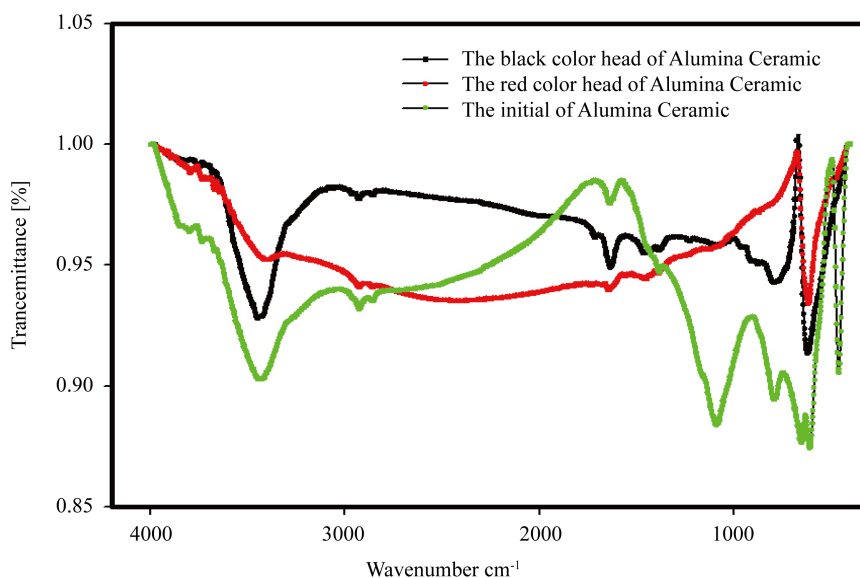**Figure 4.** The laser tube after some operation of CVL using air as a buffer gas.

Figure 5. FTIR spectrum of the laser tube.

determined to be copper oxide in the red side and the copper oxide, the copper aluminum oxide and the copper sulfate hydroxide at the other one. It is emphasized by XRD spectrums, as shown in **Figure 6**.

4. Conclusion

In this work, a CVL laser was employed using air as a buffer gas. The behavior of the output power is investigated
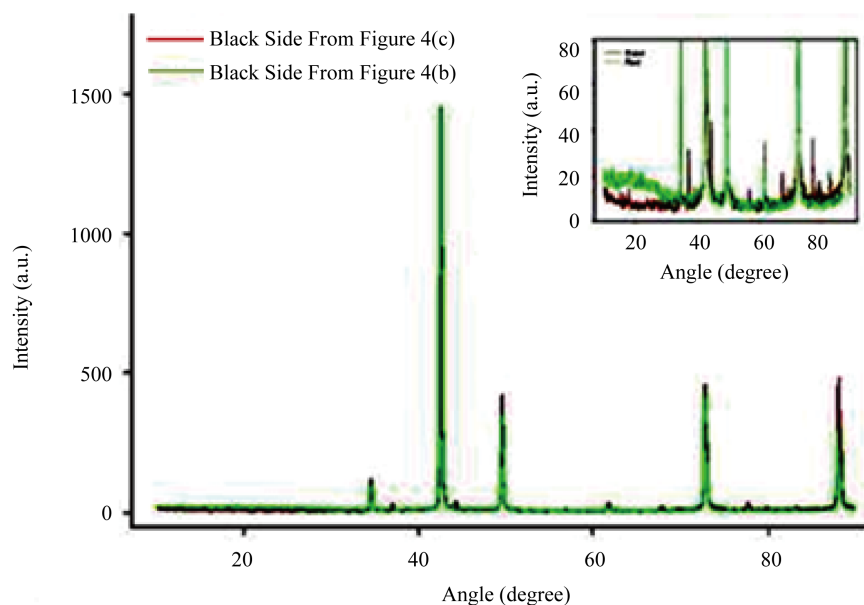
Figure 6. XRD spectrum of the laser tube. Black and redsides indicate copper oxide; and copper oxide and copper aluminum oxide and copper sulfate hydroxide, respectively.

in terms of the discharge frequency and gas pressure to determine the optimum condition. The oscillatory behavior of the output power versus frequency is observed which is in agreement with previous reports. The output power versus pressure is also studied to measure the maximum output power of ~1.6 W at the optimum pressure of 3.8 torr and at 17 kHz of frequency. Abundance and easy access of air as buffer gas and reduction of the weight volume of the laser system due to eliminating the gas handling as well as the economic benefits are the advantages of the air as a buffer gas for some research or educational specific cases. However, by using air as a buffer gas, the lifetime of the tube would be decreased.

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