Effect of nitric oxide on gain and output power of a non-self-sustained electric discharge pumped oxygen-iodine laser

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This letter discusses the effect of nitric oxide on gain and output power of a pulser-sustainer discharge excited oxygen iodine laser. Adding small amounts of NO to the laser mixture (a few hundreds of ppm) considerably increases gain and output power due to (i) O atom titration and resultant slower I* atom quenching and (ii) improved stability of the dc sustainer discharge, which allows stable operation at significantly higher discharge powers. Gain on the 1315 nm iodine atom transition and laser power in the $M=3$ transverse laser cavity are 0.049% /cm and 1.24 W, at a flow temperature of $T=100$ K. © 2007 American Institute of Physics. [DOI: 10.1063/1.2771535]

Increasing small signal gain and output power is one of the main objectives of the development of an electric discharge pumped chemical oxygen-iodine laser (DOIL).1–6 The highest gain and cw laser power reported so far remain rather low, 0.022% /cm (Ref. 6) and 1.47 W,7 respectively. In the present letter, we explore the effect of adding nitric oxide to an oxygen-helium flow in a high-pressure pulser-sustainer electric discharge on the DOIL laser performance. Previous experiments1–3 suggested that adding NO to the laser mixture may result in gain and laser power increase due to a reduction of reduced electric field $E/N$ in the discharge, and possibly due to titration of O atoms produced in the discharge by a rapid chemical reaction NO+O→NO$_2$→NO$_2$+hv.2 O atoms are known to decrease iodine population inversion by rapid quenching of excited iodine atoms, I*+O→I+O, $k_O=3.5×10^{12}$ cm$^3$/s.$^2$

In the present work, we use two overlapping transverse electric discharge in a rectangular geometry.4–6 In this approach, ionization is produced by a high voltage, high repetition rate nanosecond pulse discharge, while the dc discharge couples power to the plasma. The main advantages of this discharge are independent control of the dc reduced electric filed $E/N$ and stability at high pressures and power loadings.5 The experimental apparatus, discussed in detail in Ref. 6, is shown in Fig. 1. Briefly, a premixed O$_2$/NO/He mixture is flowing through a $5×2$ cm$^2$ cross section discharge section. At baseline conditions, $P_0=107$ torr and 15% O$_2$ in He, the flow rates are 54 mmole/s of O$_2$ and 308 mmole/s of He. Two dc electrodes and two pulsed electrodes are flush mounted in the side walls and in the top/bottom walls of the channel, respectively, to form a crossed pulser-sustainer discharge. The pulsed electrodes are powered by a high voltage (17 kV peak), short pulse duration (5 ns full width at half maximum), and high pulse repetition rate (up to 100 kHz) FID Technology plasma generator. The dc electrodes are connected to a 5 kV and 4 A dc power supply through a $R=1$ kΩ ballast resistor. A mixture of iodine vapor and helium (I$_2$ flow rate up to 70 μmole/s) is injected into the flow downstream of the discharge (see Fig. 1). The discharge section, which serves as a nozzle plenum, is followed by a $M=3$ nozzle and a supersonic cavity with two arms attached to the side walls (see Fig. 1). For gain measurements, wedged and antireflection coated glass windows are attached to the end of the arms. For laser power measurements, the windows are replaced with laser mirrors (99.99% reflectivity at 1315 nm and curvature radius of 1 m), forming a stable resonator. The transverse cavity length is about 40 cm with a gain path of 5 cm. Small signal gain at 1315 nm in the cavity is measured by tunable diode laser absorption spectroscopy using an PSI iodine scan probe.10 In the absence of excited iodine atoms I* the sensor measures absorption by the ground state I atoms. Positive gain is measured when population inversion is achieved in the flow $n_{I*} > \frac{1}{2}n_I$. The laser output power is detected using an infrared card and is measured by a Scientech power meter.

Figure 2 shows peak absorption and gain signals measured during each run at baseline flow conditions, with up to 0.6 mmole/s of NO added to the flow. Gain is the positive part and absorption is the negative part of the vertical axis. In Fig. 2, I$_2$ flow rate is 60 μmole/s, pulse repetition rate is $ν=34$ kHz, dc power supply voltage is $U_{DC}=2.8$ kV, and discharge current is $I=1.3–1.4$ A. As discussed in Ref. 6, when the pulser alone is operating, O atoms are produced by electron impact dissociation of O$_2$ during high voltage pulses, while no significant singlet delta oxygen is produced. At these conditions, absorption is observed on the I(2P$_{3/2}$)→I(2P$_{1/2}$) transition (see Fig. 2), since O atoms generate I atoms in the cavity by rapid chemical reactions with iodine, I$_2$+O→I+I and I+O→I+O$_2$.2 When both the pulsed discharge and the dc discharge are in operation, both O$_2$($^3$Δ)$^a$ and O atoms are generated in the discharge section, which results in additional iodine dissociation, nO$_2$(a' Δ) + I$_2$→⋯→nO$_2$I$^+$, as well as iodine atom excitation in the cavity by energy transfer from singlet delta oxygen.

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FIG. 1. Experimental setup.
O$_2$(a $^1\Delta$) + I $\rightarrow$ O$_2$ + I$^*$. This produces population inversion and results in optical gain, $\gamma = \sigma(n_1 - \frac{1}{2}n_0)$, where $\sigma$ is the stimulated emission cross section.

Figure 4 shows time dependent absorption/gain signal measured during a single run at baseline flow conditions, $\nu=34$ kHz, $U_{PS}=3.1$ kV ($U=1.56$ kV), $I=1.54$ A, discharge power of 2.4 kW, NO flow rate of 0.2 mmole/s (NO mole fraction of 550 ppm), and somewhat higher I$_2$ flow rate of 70 mmole/s (iodine mole fraction of 190 ppm). As in Fig. 2, in Fig. 4 gain is the positive part and absorption is the negative part of the vertical axis. It can be seen that peak gain reaches 0.049% /cm. Figure 5 shows gain line shape at these conditions, with a Doppler fit indicating translational temperature in the cavity of $T=100\pm10$ K. Further increase of I$_2$ flow rate was limited by the iodine delivery system.

At these discharge and flow conditions, cw lasing was detected by both the infrared card and the power meter. The laser beam produced a nearly circular spot approximately 2 cm in diameter on the infrared card, placed 10 cm away from one of the laser mirrors. The highest power achieved during these experiments, 1.24 W, exceeds our previous re-
The results of the present work demonstrate that adding small amounts of NO to the laser mixture (on a few hundreds of ppm level) considerably increases gain and output power due to (i) O atom titration and resultant slower \( \text{I}^\text{+} \) quenching and (ii) improved stability of the dc sustainer discharge, which allows operation at higher discharge powers. The results also suggest that gain may be limited by the relatively low iodine vapor concentration in the flow. We believe that gain may be further increased by iodine vapor dissociation in an auxiliary electric discharge, prior to injection into the main flow. This would reduce the fraction of \( \text{O}_2(a^1\Delta) \) yield lost to dissociate iodine, \( n\text{O}_2(a^1\Delta)+\text{I}_2 \rightarrow \cdots \rightarrow n\text{O}_2+\text{I}^++\text{I} \), where \( n \approx 4 \) and increases at low \( \text{I}_2 \) concentrations. Studies of iodine dissociation, as well as increasing gain path and flow residence time in the discharge, i.e., scaling the pulser-sustainer discharge volume, are currently underway.

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\[ \begin{align*}
\text{FIG. 5.} & \quad \text{(Color online) Gain line shape at the conditions of Fig. 4, at } t=5.1 \text{ s. Doppler fit indicates the flow temperature of } T=100\pm 10 \text{ K.}
\end{align*} \]