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Hybrid Electric Oxygen–Iodine Laser Performance Enhancements and Measurements

G. F. Benavides*
CU Aerospace, 2100 S. Oak Street, Suite 206, Champaign, Illinois 61820

J. W. Zimmerman and B. S. Woodard
University of Illinois at Urbana–Champaign, 306 Talbot Laboratory,
104 S. Wright Street, Urbana, Illinois 61801

A. D. Palla, D. L. Carroll, J. T. Verdeyen, D. M. King,
J. K. Laystrom-Woodard, and T. H. Field
CU Aerospace, 2100 S. Oak Street, Suite 206, Champaign, Illinois 61820

and

W. C. Solomon
University of Illinois at Urbana–Champaign, 306 Talbot Laboratory,
104 S. Wright Street, Urbana, Illinois 61801

Recent experiments have led to improvements in the hybrid electric oxygen–iodine laser (ElectricOIL) system that significantly increased the discharge performance, supersonic cavity gain, and laser power output. The continuous-wave laser operating on the $I(^2P_{1/2}) \rightarrow I(^2P_{3/2})$ *transition of atomic iodine 1,315 nm was pumped by the production of* $O_2(a^1\Delta)$ *in a radio frequency (RF) discharge in an* O_2*/He/NO gas mixture. Results with both molecular iodine injection and partially predissociated iodine are presented. Flow temperatures were maintained at reasonable levels even with RF powers of around 2 kW. More than 30% of the discharge power is now being coupled into the active oxygen gas flow. A gain of 0.10%* cm^{-1} *and a laser power of 6.2 W are reported. Modeling with the BLAZE-IV model is in good agreement with data.*

KEYWORDS: DOIL, ElectricOIL, Electric oxygen–iodine laser, EOIL, Singlet delta oxygen

1. Introduction

The classical COIL first reported by McDermott et al.[20] operates on the electronic transition of the iodine atom at 1,315 nm, $I(^2P_{1/2}) \rightarrow I(^2P_{3/2})$ (denoted hereafter as I* and I, respectively). The lasing state I* is produced by near-resonant energy transfer with the singlet oxygen metastable $O_2(a^1\Delta)$ [also denoted hereafter as $O_2(a)$]. Conventionally, a

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*Corresponding author; e-mail: benavides@cuaerospace.com.

chemical two-phase process is used to produce the $O_2(a)$ at the interface of liquid basic H_2O_2 and Cl_2 gas. Zalesskii[32] and Fournier et al.[14] made early attempts to use electric discharges for $O_2(a)$ production and transfer energy to iodine for lasing but did not obtain positive gain. Since then, various groups[9,10,17,18,25,28] have investigated other continuous flowing systems and have measured $O_2(a)$ yields in excess of 15%, a necessary condition for gain at room temperature. Carroll et al.[13] achieved a low level of gain and obtained the first lasing data in subsequent work.[12]

One key difference between the traditional chemical excitation route and the electrical one is the presence of atomic oxygen levels on the same order as the $O_2(a)$ in the "active oxygen" mixture. Atomic oxygen depletes the upper laser level,[1,2] I*, and must be controlled.[11,21] This was accomplished by the use of NO_2 titration made downstream from the discharge or by adding NO to the discharge flow or downstream of the discharge; all of these approaches resulted in the oxygen atoms being depleted to a level such that there were still enough oxygen atoms to dominate the I_2 dissociation process, but low enough such that the power loss through the $I^* + O$ quenching channel is not prohibitively detrimental.

Subsequent efforts have demonstrated gain[16,26,31] and lasing[16,31] in other ElectricOIL configurations since the first demonstrations.[12,13] ElectricOIL discharge models,[3,18,22–24,30] have been developed, and postdischarge kinetics-gain-laser modeling[9,21,22] has been performed. For an excellent and comprehensive topical review of discharge production of $O_2(a)$ and ElectricOIL studies, see Ionin et al.[18] In the work presented herein we discuss recent developments in ElectricOIL technology that have produced significant increases in discharge performance, supersonic cavity gain, and laser power, as well as some temperature measurements at high radio frequency (RF) powers.

2. Experiments

Use of the precisely calibrated gas laser facility at the University of Illinois allowed advanced concepts to be economically implemented, compared directly against less sophisticated methods, and examined in detail. This effort leveraged advanced discharge technologies and diagnostics developed over the past several years to produce an efficient intermediate demonstration of our small-scale ElectricOIL laser devices. The ability to implement critical advanced technologies into the ElectricOIL laser testbed enables the community to more clearly understand the highly complex system questions involved and to advance the applicability of this technology.

2.1. Experimental setup

CU Aerospace (CUA) and the University of Illinois at Urbana–Champaign (UIUC)'s ElectricOIL research is carried out with a quartz discharge flow tube utilizing either internal hollow aluminum electrodes or external copper electrodes to couple RF power into a primary discharge flow comprising oxygen, an inert diluent (typically helium), and a sensitizer gas (typically nitric oxide, NO). Two different supersonic laser cavities were used for this work. One generation of hardware that we will denote as "Cav2" was used in the early ElectricOIL gain and laser demonstrations.[12,13] Third-generation hardware, denoted as "Cav3" hereafter, was designed and fabricated to have considerably more flexibility than the Cav2 hardware. In the Cav2 hardware, the locations for iodine and cold tertiary gas injection were somewhat restricted, which has been significantly limiting both gain and laser power enhancements (as will be discussed below). In the Cav2 assembly, an iodine–helium gas mixture was injected

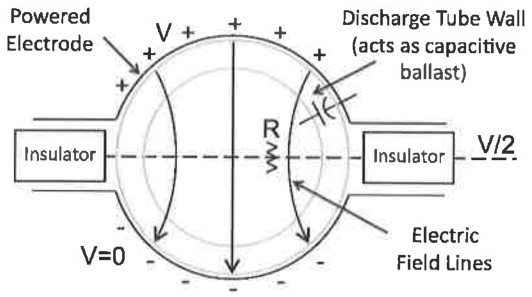

Fig. 1. Cross-sectional illustration of transverse dipolar discharge showing capacitive ballasting. Gas flow is into the paper.

through an aluminum annular injector 63.5 cm downstream from the downstream electrode, followed by injection of cold N_2 tertiary gas flow injected 12.7 cm downstream from the iodine injection plane. This gas mixture then entered the Cav2 supersonic laser cavity with the nozzle throat 24.1 cm downstream from the tertiary N_2 injector. In the Cav3 hardware configuration, the iodine and tertiary flows can be injected as in the Cav2 hardware, but can also be injected at 15 discrete positions ranging from 1.5 to 38.1 cm upstream from the nozzle throat position. In both the Cav2 and Cav3 configurations, the gas flow is expanded through a Mach 2.1 nozzle, based on measured pressure ratios (the nozzle is Mach 2.4 based on geometric area ratio), to lower the temperature of the gas to favor the iodine population inversion for gain and lasing. In both lasing cavities, the gain length is 5 cm.

Pressure measurements throughout the device are achieved via capacitance manometers. Flow rates are monitored by a variety of thermal and coriolis effect mass flow meters. An LN_2-cooled OMA-V InGaAs array detector is used to measure spectra of the $O_2(a \rightarrow X)$ transition at 1,268 nm. A thermoelectric-cooled Apogee charge-coupled device (CCD) is used to measure spectra of the $O_2(b \rightarrow X)$ transition about 761.9 nm and for gas temperature measurements extracted from the rotational spectra. Both instruments are fiber coupled to allow positioning flexibility. Most data are taken in a diagnostic duct fitted with purged window ports, but some data are taken directly through the flow tube walls. Field of view corrections were made to maintain comparable calibrated yields. A Physical Sciences, Inc. (PSI), IodineScan diagnostic[27] was used for the gain measurements. Scientech Astral model AC5000 calorimeters with Scientech Vector S310 readouts were used to measure the laser power. The beam profile was monitored via IR detection cards from New Focus (model 5842).

2.2. Transverse discharge experiments

In prior work by the CUA–UIUC team, we typically utilized either a longitudinal or an inductive 13.56-MHz RF discharge in our ElectricOIL experiments, but this type of discharge has typically resulted in discharge instabilities that would occur at around 500 W in our small system. In an effort to improve the discharge stability, we implemented a "dipolar excitation" (transverse) discharge concept[4,8] (Fig. 1). This concept places contoured capacitive electrodes along the length of the discharge section, similar to experiments being performed at Moscow State University.[24] One significant advantage of this technique at higher pressures is that it provides inherent capacitive ballasting that inhibits current

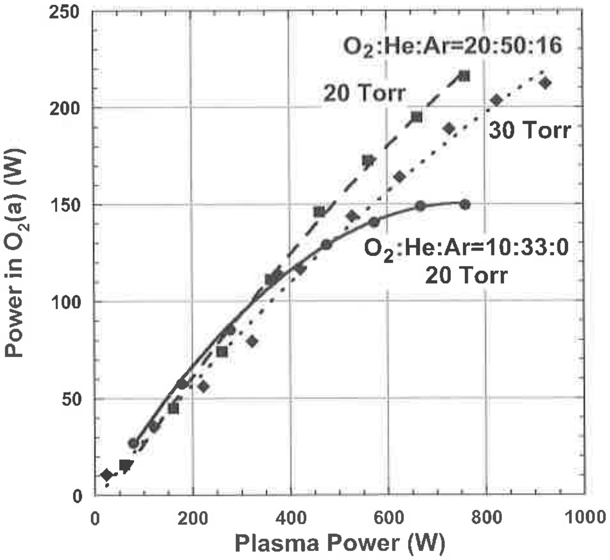

Fig. 2. Power in O_2(a) vs. RF power absorbed by the plasma as a function of flow rate and pressure using an RF transverse discharge (~0.15 mmol/s nitric oxide).

constriction and arcing, thus providing good discharge stability. Hicks et al.[16] have also observed that the transverse discharge provides better stability at higher discharge pressures. Experiments performed in our laboratory with a transverse discharge resulted in significant yields and power coupled into the O_2(a) state at pressures of 20 and 30 torr (Fig. 2); these yields were significantly higher than we had previously been able to obtain with a longitudinal discharge. Additionally, we were able to attain larger fractions of the power deposited into the flow going into the desired O_2(a) state at higher pressures (Fig. 3): >30% at a pressure of 20 torr and >25% at 30 torr. This is a significant improvement over the longitudinal discharge with which we were getting only about 18% of the electrical power into the desired O_2(a) state. Initial experiments with the dipolar exciter discharge enabled a gain of 0.027% cm^{-1} at 20 torr (Fig. 4); these gain numbers were further enhanced with other hardware and flow modifications, discussed in Secs. 2.4 and 2.5.

2.3. Variable nozzle Mach number

At the current stage of ElectricOIL development, the O_2(a) concentration (and yield) and the I_2 flow rate are sufficiently low that the gain zone is stretched farther downstream than occurs in a classic COIL system. In addition, the established $I^* + O$ quenching reaction[1,2] also tends to lower the O_2(a) concentration and thereby further stretches the gain zone. Although a longer gain zone has the advantage of reducing the intensity loading on the laser mirrors, it also requires modifications to efficiently extract the energy optically and new scaling parameters need to be established. The nozzle geometry affects the gain zone and the temperature of the flow. The trade-off between shorter gain zone (mode width) and flow temperature was explored with new geometric Mach 2.67 and 3.0 nozzles and compared with the geometric baseline Mach 2.4 nozzle.[4] A higher Mach number nozzle will provide lower temperature but will stretch the gain zone by increasing the flow velocity.

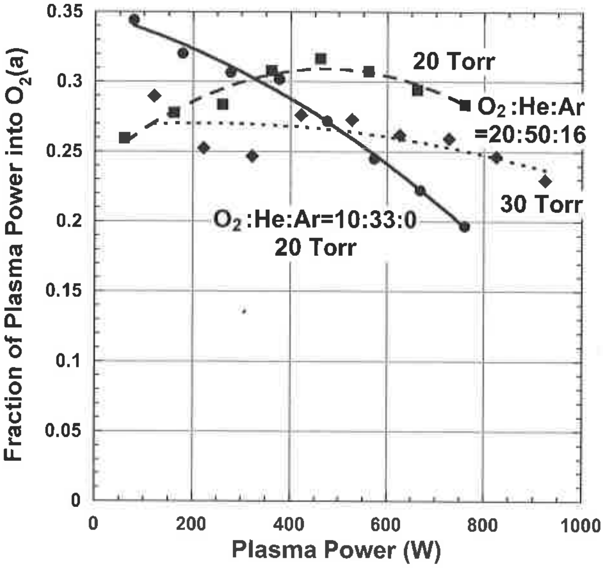

Fig. 3. Fraction of plasma power deposited into $O_2(a)$ vs. RF power absorbed by the plasma as a function of flow rate and pressure using an RF transverse discharge (~0.15 mmol/s nitric oxide).

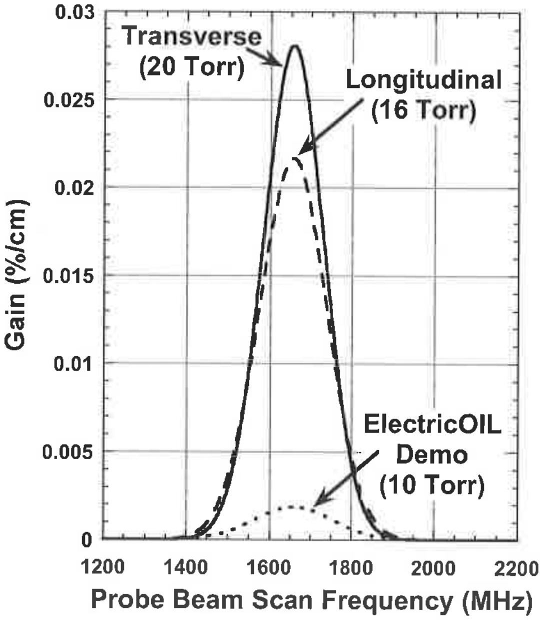

Fig. 4. Digitally filtered gain signal in the supersonic cavity as a function of probe beam scan frequency for O_2:He = 4:10 mmol/s with 10-torr longitudinal discharge from the initial ElectricOIL demonstration,[13] O_2:He = 10:33 mmol/s with 16-torr longitudinal discharge,[19] and O_2:He = 10:33 mmol/s with 20-torr transverse dipolar discharge (this work).

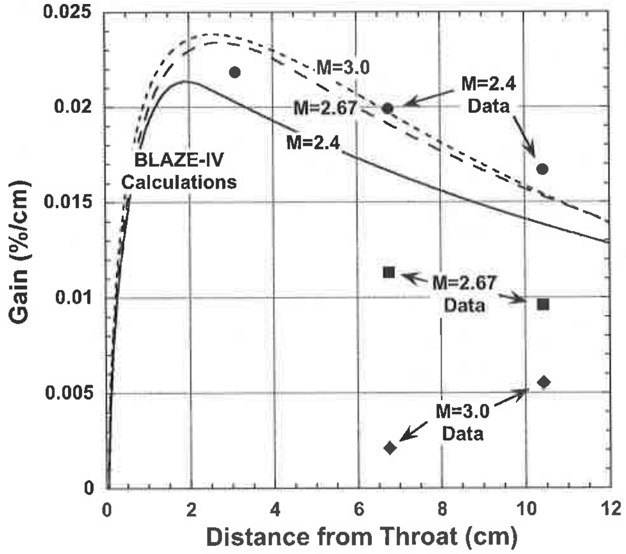

Fig. 5. Gain data and BLAZE-IV predictions vs. distance from the throat (inches) for three different nozzles having geometric Mach numbers of 2.4, 2.67, and 3.0. Flow conditions were a gas mixture of O_2:He:NO = 10:33:0.15 mmol/s with 16 torr in a longitudinal 550-W RF discharge.

Pressure and gain testing were performed with the baseline Mach 2.4 nozzle and the new Mach 2.67 and 3.0 nozzles using the Cav2 hardware. Comparison of the experimental results indicates that the Mach 2.4 nozzle gave higher gain (Fig. 5) than did the higher Mach number nozzles when the injected N_2 gas was cooled. However, when compared with results from our BLAZE-IV model (discussed in Sec. 3) (Fig. 5), it is clear that the model is in reasonable agreement with the Mach 2.4 data but that it predicts performance dramatically different from the Mach 2.67 and Mach 3.0 nozzle data. In fact, BLAZE-IV predicts slightly higher gain (about 10% higher) with the Mach 3.0 nozzle than with the Mach 2.4 nozzle. However, power extraction calculations were also performed for these cases and the predicted laser powers were 1.40, 1.29, and 0.88 W for the Mach 2.4, 2.67, and 3.0 nozzles, respectively. So, whereas the Mach 3.0 nozzle is predicted to have slightly higher gain, the laser power extracted with 1-in.-diameter mirrors is predicted to drop by approximately 40% because of the higher flow velocity in the cavity. This could potentially be alleviated, at least in part, with a longer resonator in the flow direction.

We believe that the primary reason for the stark difference between the experimental data and BLAZE-IV predictions for the two higher Mach number nozzles is that our pumping system is not sufficient to properly pump the Mach 2.67 or 3.0 nozzles at the lower total pressures. This is evidenced by the fact that for total pressures between 10 and 16 torr, the cavity pressures never fell below about 0.75 torr regardless of nozzle. As we drive the total pressure to higher values, the Mach 2.67 and 3.0 nozzles will perform closer to their design point because it is a low pressure limitation that we are encountering, not a flow rate limitation. Our conclusion from this testing was that we should continue to use the Mach 2.4 nozzle for gain and laser testing with the Cav3 hardware (Sec. 2.4), primarily because our current pumping system is not adequate for the higher Mach number nozzles. An improved diffuser section is recommended in future research.

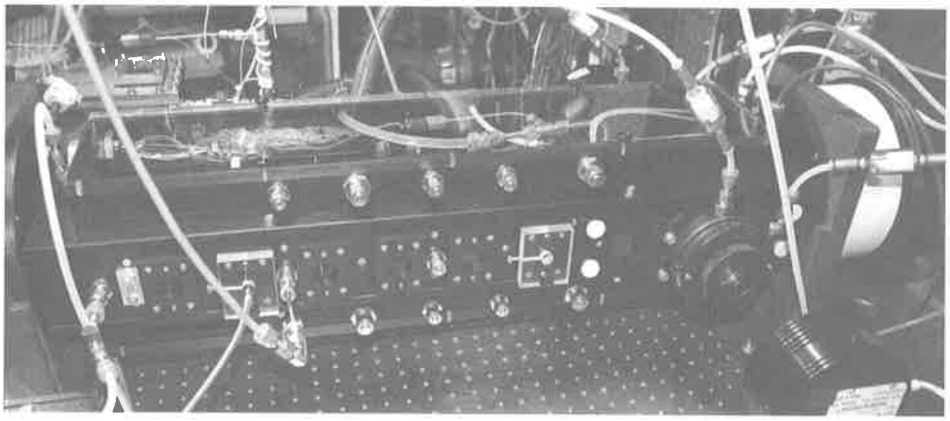

Fig. 6. New third-generation Cav3 ElectricOIL diagnostic-laser housing. The 5-cm gain length is expandable to 15 cm and multiple discharge tubes for future scaling experiments.

It is also interesting to note that Hicks et al.[16] have found their best performance with a Mach 3.0 nozzle and that they recommend moving toward a Mach 4.0 nozzle. For their flow and discharge conditions, this may be necessary because of their low yields (5%–6%), but as yields are improved we do not recommend such a high Mach number nozzle. As was pointed out by Hicks et al., and in agreement with theoretical analysis of COIL flows by Hager et al.,[15] the residence time in the laser cavity decreases with flow velocity, and a significant competition occurs between residence time in the resonator and the time required to repopulate the upper laser level, and thus it becomes difficult to efficiently extract the flow energy optically. Further, various kinetic quenching mechanisms will have a larger detrimental impact on performance with longer gain zones. As the BLAZE-IV modeling above indicates, because the gain curves were similar for the three Mach numbers investigated but the laser power was highest for the Mach 2.4 nozzle case, we conclude that for our flow conditions with much higher yields, a Mach 2.4 nozzle is preferable to a higher Mach number nozzle even with a better diffuser section.

2.4. Third-generation ElectricOIL experiments

Building on results from Secs. 2.1–2.3, we implemented a planned progression of knowledge into a third-generation "Cav3" ElectricOIL system to increase the laser power output to 4.5 W. The hardware for the more flexible Cav3 device geometry was completed, and all of the aluminum pieces were anodized to minimize chemical interactions with the Cav3 housing while at the same time providing a solid structure with which to perform adaptive experiments (Fig. 6). Based on results of Sec. 2.2, a transverse RF capacitive discharge was chosen. Based on results of Sec. 2.3, a geometric Mach number of 2.4 was selected for the new supersonic nozzle.

The Cav3 ElectricOIL was tested and the hardware available was optimized for gain and laser performance. One of the key improvements with the Cav3 hardware was the capability to place the I_2 and cold N_2 injection points at different positions. Previous modeling with the BLAZE-II code[6,21,29] indicated that it was important to have more flexibility in the placement of these injectors to optimize performance. The older Cav2 hardware did not

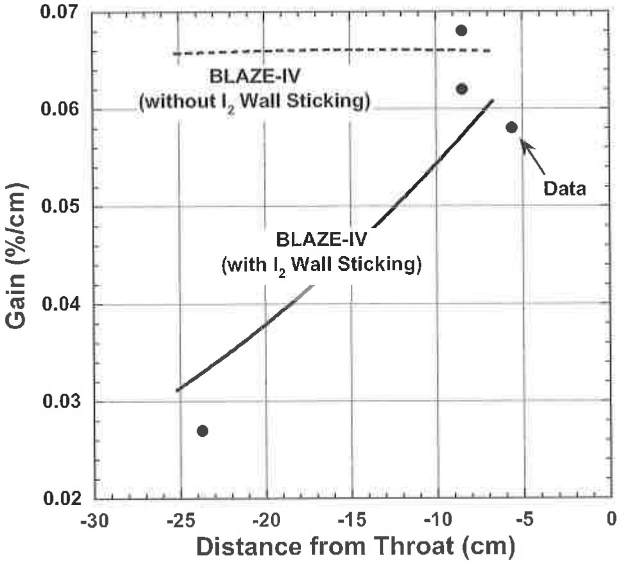

Fig. 7. Gain data and BLAZE-IV predictions vs. position of iodine injector holes relative to the nozzle throat (negative distance indicates distance "upstream" from the nozzle throat). Data taken with the Cav3 hardware and cold N_2 injectors downstream from the I_2 injectors. Flow conditions were O_2:He = 10:33 at 20-torr pressure and 1,000-W RF power. BLAZE-IV calculations performed with and without iodine wall sticking.

have this capability, and the I_2 injectors were essentially fixed at a position 36.8 cm upstream from the nozzle throat and the N_2 injectors fixed at a position 24.1 cm upstream from the nozzle throat. Figure 7 shows the dramatic improvement obtained by moving these injectors much closer to the throat. For these cases, the cold N_2 injectors were always placed downstream of the I_2 injectors. Injecting the I_2 downstream of the cold N_2 consistently resulted in large deposits of iodine along the cavity wall, which is not desirable and results in a lower gain system. Iodine coatings were also observed on the walls for cases in which the iodine was injected far upstream of the nozzle throat; BLAZE-IV calculations show that it is very important to account for this mechanism of iodine loss from the gas flow (Fig. 7) through the addition of a wall sticking term.

A gain of 0.067% cm^{-1} was achieved (Figs. 7 and 8) with the aforementioned hardware improvements. Two 2-m-radius-of-curvature, 2-in.-diameter laser mirrors from AT Films with a reflectivity of approximately 99.997% were used as the optical resonator; the mirror separation was 34 cm. The resulting laser power was 4.52 W with the laser cavity gain length held fixed at 5 cm. Note that if mirror/absorption scattering losses were accounted for (which typically account for greater than a 20% loss in such low gain stable resonators), the power optically extracted from the flow would be greater than 5 W. The beam profile was elliptically shaped with a major axis of ~3.5 cm and minor axis of ~1.9 cm at the mirror.

2.5. Power enhancement of ElectricOIL through iodine predissociation

Building upon results from Sections 2.1–2.4 and modeling results that indicated that the use of predissociated iodine should result in enhanced gain and laser power,[7,9] we

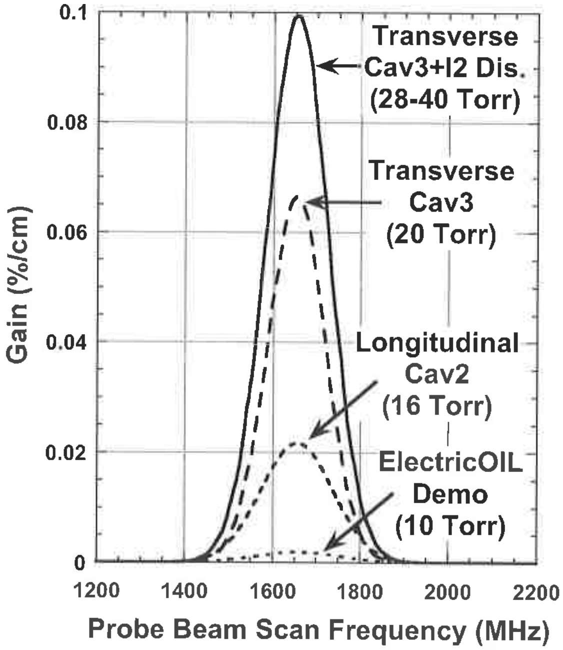

Fig. 8. Digitally filtered gain signal in the supersonic cavity as a function of probe beam scan frequency for O_2:He = 4:10 mmol/s with 10-torr longitudinal discharge from the initial ElectricOIL demonstration with Cav2 hardware,[13] O_2:He = 10:33 mmol/s with 16-torr longitudinal discharge from prior work with Cav2 hardware,[19] O_2:He = 10:33 mmol/s with 20-torr transverse dipolar discharge resulting from the Cav3 ElectricOIL hardware, and O_2:He = 10:50 mmol/s with 28–40-torr transverse dipolar discharge, the Cav3 ElectricOIL hardware, and an iodine predissociation discharge.

implemented an RF discharge at the exit of our iodine injection holes using electrodes imbedded in injector blocks fabricated out of Macor®. In ElectricOIL experiments at lower pressures, we relied on O atoms to provide the dominant mechanism for iodine dissociation. However, with the desire to push the system to higher flow pressures, fewer O atoms are available due to recombination; e.g., Zimmerman et al.[33] have measured that an O atom to O_2 ratio at 20 torr of ≈16% (measured 5 cm from the exit of the discharge) decays to ≈8% over a 30-cm flow distance, but in a 50-torr flow the O atom fraction is only ≈2.5% and decays to ≈0% over the same 30-cm flow distance. Thus, to achieve more complete dissociation in ElectricOIL, the use of an iodine predissociator is of particular importance at higher flow pressures. The flexible third-generation Cav3 hardware was again used for these experiments. Summarizing results from Benavides et al.,[5] with the iodine predissociation discharge turned on, the gain was increased from 0.067% cm^{-1} to 0.10% cm^{-1} (Fig. 8) and the laser power was improved to 6.2 W. This is a 50% increase in gain and a 38% increase in laser power relative to a case without the iodine predissociation discharge (Sec. 2.3). Further, the use of the iodine predissociator permitted higher pressure operation. The 28-torr, 0.10%-cm^{-1} gain, 6.2-W laser case was obtained with 700 W of RF discharge power applied to the primary flow and 100 W of RF power applied to the iodine predissociation discharge. Note that the dissociator has resulted not only in additional gain and laser power

Table 1. Experimental test matrix for measurements of gas flow temperature as a function of pressure, flow rate, and discharge RF power for a fixed inlet gas flow velocity of approximately 1,520 cm/s[a]

Total pressure (torr)	O_2 flow rate (mmol/s)	He flow rate (mmol/s)	RF powers (W)	eV/molecule	Gas temperature (K)
3.1	1.3	3.2	39, 77, 115, 150	0.32–1.22	314–323
10.5	4.5	10.4	130, 260, 390, 500	0.30–1.16	367–433
20	8.9	20.5	260, 520, 775	0.30–0.90	402–473
30	13.7	31.3	390, 779, 1,147	0.30–0.89	350–527
51	22.3	52.7	649, 1,298, 1,949	0.30–0.91	451–638

[a] Temperature measurements from $O_2(b)$ rotational spectra were made 28 cm downstream from the exit of the discharge.

enhancement but a total RF power savings of 20% compared with the nondissociator 1,000-W case (Sec. 2.4). Applying power to dissociate the iodine at the dissociator is more energy efficient than applying additional power in the primary discharge to produce sufficient O atoms to dissociate the iodine. Further improvements to the iodine dissociator are expected to provide additional power savings over the current design. Note that these results represent approximately a 50-fold improvement in gain and laser power since the initial demonstrations in 2004–2005. Experiments to determine the iodine dissociation fraction, to better understand the performance of our electrical predissociator, are planned for the future. We anticipate that continued work will result in a steady progression in performance enhancement of gain, laser power, and electrical-to-optical efficiency.

2.6. Temperature measurements at high RF power

An important issue for any oxygen–iodine laser system is temperature. In anticipation of our research and development efforts to go to progressively higher power systems, we experimentally determined the effects of RF power on gas flow temperature. To perform a broad range of measurements, we chose five different flow pressures having a fixed input gas flow velocity of approximately 1,520 cm/s and a fixed O_2:He ratio of approximately 3:7. The inside diameter of the quartz flow tube was 4.9 cm. The test matrix is shown in Table 1 and in Fig. 9. Gas flow temperature measurements were extracted from the rotational spectra of the $O_2(b \rightarrow X)$ transition about 761.9 nm. The measurements show that the gas flow temperature remains quite reasonable (<650 K) at high pressures even for RF powers of nearly 2 kW. For a fixed energy per molecule, the temperature of the flow is observed to increase with pressure (Fig. 9). Quenching and recombination (e.g., three-body reactions) kinetic processes will release heat into the flow, and these processes will occur more rapidly in higher pressure flows. Thus, it is reasonable to expect higher temperatures at higher pressures for a fixed energy per molecule.

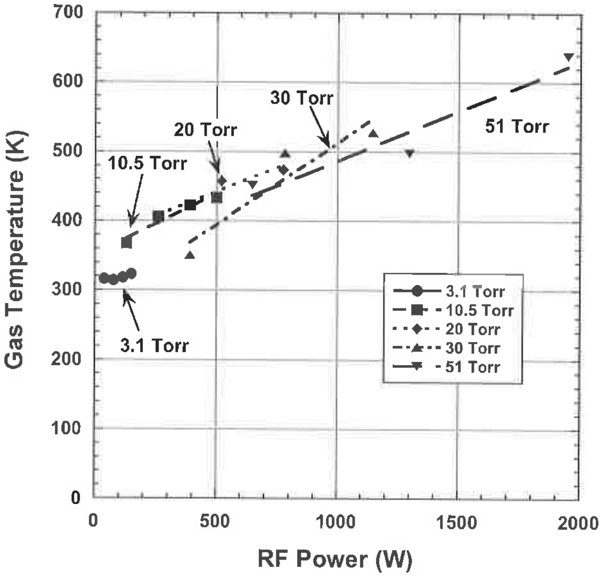

Fig. 9. Experimental measurements of gas flow temperature as a function of pressure, flow rate, and discharge RF power for a fixed inlet gas flow velocity of approximately 1,520 cm/s. Temperature measurements from $O_2(b)$ rotational spectra were made 28 cm downstream from the exit of the discharge.

3. Modeling

To help guide and understand experiments, the new advanced BLAZE-IV electrodynamics-fluids-laser model[22] was employed. BLAZE-IV is a one-dimensional, fluid-dynamic, chemical-kinetic, nonequilibrium plasma-dynamic flow model that was developed to investigate the physics critical to the production of $O_2(a)$ in ElectricOIL devices and the downstream kinetics and predictions of gain and lasing. BLAZE-IV is a new model based partially on BLAZE-II,[6,21,29] the one-dimensional, fluid-dynamic, chemical-kinetic model from which the nonmixing, fluid-dynamic equations used in BLAZE-IV were derived. BLAZE-IV was developed using the C++ programming language in order to simplify the coding of complex physics by taking advantage of object-oriented programming techniques and appropriate data encapsulation. BLAZE-IV utilizes the one-dimensional momentum, continuity, energy, and species concentration equations (neutral and charged) and an implicit Newton iteration scheme. For more details on the BLAZE-IV model see Palla et al.,[22] in which the model was validated and baselined to other experimental data.

For the studies in this work, we wanted to demonstrate the unique capability of the BLAZE-IV model to simulate the discharge region, carry the flow into and through the nozzle, and accurately compute gain in the supersonic region of the flow. Figure 10 illustrates a single complete calculation that demonstrates these unique capabilities of our new BLAZE-IV code. For this simulation, the yield was predicted to be approximately 18% for this 20-torr condition; experiments indicate a slightly lower yield of around 17%, but this is quite reasonable agreement for the one-dimensional BLAZE-IV model. As has been observed in the past, there is a yield loss once the I_2 is injected (axial position 90 cm),

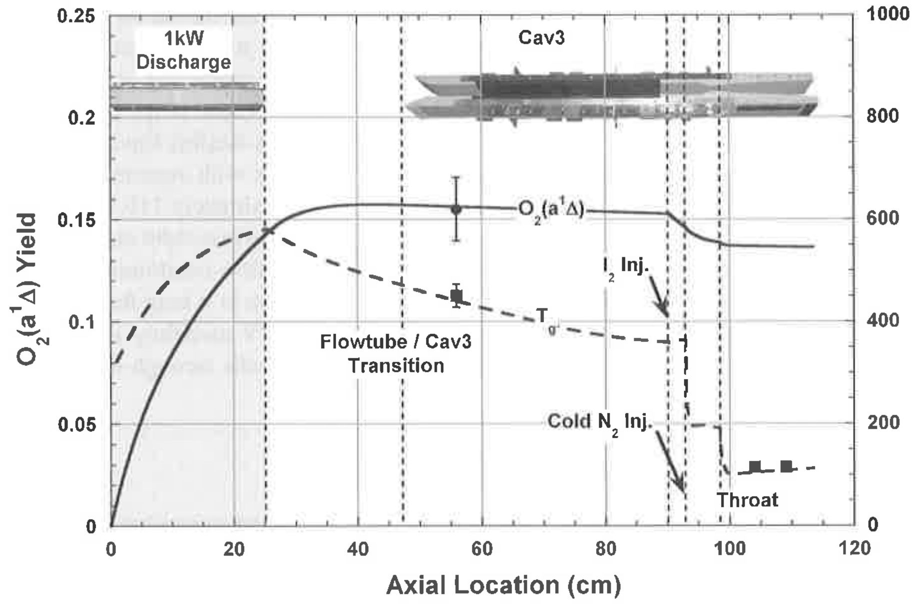

Fig. 10. BLAZE-IV simulations of the Cav3 ElectricOIL 5-cm gain length diagnostic-laser nozzle (Sec. 2.4). The transverse discharge section and the Cav3 nozzle are shown for clarity. Available experimental data for these flow conditions are shown.

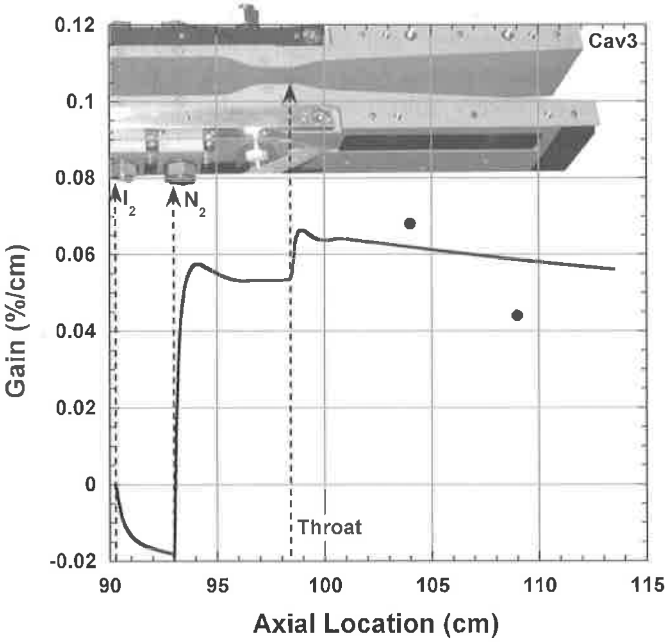

Fig. 11. BLAZE-IV predictions of gain vs. axial position through the Cav3 supersonic nozzle. Data taken with the Cav3 hardware and cold N_2 injectors downstream from the I_2 injectors. Flow conditions were O_2:He = 10:33 at 20-torr pressure and 1,000-W RF sustainer power (Sec. 2.4).

but because the Cav3 hardware permits injection much closer to the throat, we are able to minimize the loss of yield before the optical extraction region that starts at an axial location of around 100 cm. In previous BLAZE-II modeling,[21] we were predicting as much as a 60% drop in yield by the time the iodine reached the resonator because of the much larger distance between iodine injection point and laser cavity in the less-flexible Cav2 hardware. The predicted temperatures are also in very reasonable agreement with experimental data, e.g., the predicted temperature in the laser cavity region is approximately 110 K, which is in excellent agreement with the temperature obtained from the gain linewidth measurement (Fig. 8). Figure 11 shows that the gain prediction for the 20-torr flow conditions is in very good agreement with the measurements. For cases in which there is a long flow distance in slower velocity flows upstream of the nozzle throat, BLAZE-IV modeling also showed that it is important to account for iodine loss to the hardware walls through the use of a wall sticking mechanism (Fig. 7).

4. Concluding Remarks

Over the past three years of research and development, continual improvements in gain and lasing power have been obtained. $O_2(a)$ yields greater than 20% have been demonstrated along with positive gain and continuous-wave laser power in both supersonic and subsonic flow systems. The gain has improved from the initial demonstration of 0.002% cm^{-1} by more than a factor of 50 to 0.10% cm^{-1}, and similarly the outcoupled laser power has risen from 0.16 to 6.2 W (with a 5-cm gain length cavity). We are now obtaining $\approx$30% energy coupling (and for the higher RF power cases more than 200 W of the power) into the desired $O_2(a)$ state, but significant improvements in understanding the role of components of plasma-generated "active oxygen" still need to be made in regard to laser extraction of this energy. Whereas O atoms permit rapid dissociation of the I_2 molecule, they appear to be a major problem for energy extraction (as they also act as a quencher) and alternate I_2 dissociation schemes are required at higher densities. The use of an electrical iodine predissociator increased the performance of the ElectricOIL system by 50%. Modeling with the BLAZE-IV simulation code shows generally good agreement with species, gas temperature, and gain data. For cases in which there is a long flow distance in slower velocity flows upstream of the nozzle throat, BLAZE-IV modeling also showed that it is important to account for iodine loss to the hardware walls through the use of a wall sticking mechanism. Given the amount of power stored in the $O_2(a)$ at the exit of the electric discharge gas flow, it should be possible to extract significantly (an order of magnitude) more laser power from the resonator than we are presently measuring. We believe that this may be due to a combination of diffractive spill losses (from the use of a short gain length cavity and very high reflectivity mirrors) and unknown kinetic processes; we are planning future experiments to investigate both possibilities. We anticipate that ongoing work will result in a steady progression in performance enhancement of gain, laser power, and electrical-to-optical efficiency.

5. Acknowledgments

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The Authors

Mr. Gabriel F. Benavides received his B.S. degree in aeronautical and astronautical engineering from the University of Illinois at Urbana–Champaign (UIUC) in 2001. He then worked for CU Aerospace as a Staff Engineer. In 2003, he returned to full-time study at UIUC, pursuing a M.S. degree in aerospace engineering. He received his M.S. in 2004 and is presently a Ph.D. candidate in aerospace engineering at UIUC. He currently conducts experimental research and component-level design and system-level design in the areas of chemical lasers and electric propulsion.

Dr. David L. Carroll received his Ph.D., M.S., and B.S. degrees in aeronautical and astronautical engineering from the University of Illinois at Urbana–Champaign (UIUC) in 1992, 1986, and 1985, respectively. He is a founder of CU Aerospace and is its Engineering Director. Other positions he has held through the years include Member of Technical Staff at TRW in Redondo Beach, California, from 1987 to 1988; Postdoctoral Research Associate at UIUC from 1992 to 1995; Research Scientist at UIUC from 1995 to 2000; and Adjunct Lecturer at UIUC in 2001. He has performed in-depth chemical laser system research for more than 20 years including HF and COIL performance and modeling, materials processing experiments with COIL, and issues related to the commercialization of these devices. He has also performed research on stimulated Brillouin scattering (SBS) beam combination and genetic algorithms.

Mr. Tyler H. Field received his B.S. in aerospace engineering from the University of Illinois at Urbana–Champaign in 2005. Since 2007 he has worked for CU Aerospace as a Staff Engineer in the High Energy Laser Laboratory. He currently does research and design for the electrically assisted oxygen–iodine laser and more traditional chemical oxygen–iodine laser projects at CUA.

Mr. Darren M. King received his M.S. and B.S. degrees from the Department of Aeronautical and Astronautical Engineering at the University of Illinois at Urbana–Champaign in 1999 and 1996, respectively. His M.S. thesis was on extensive experimental research with the VertiCOIL device. He is currently a Senior Engineer for CU Aerospace and is an expert with chemical lasers, electronics, power systems, controls, and data acquisition. He has a diverse experimental background and has participated in systems-level as well as component-level design work and testing on chemical lasers, electric propulsion systems, and chemical rockets.

Ms. Julia K. Laystrom-Woodard received her B.S. in aeronautical and astronautical engineering from the University of Illinois at Urbana–Champaign (UIUC) in 2000. Following graduation she worked for CU Aerospace as a Staff Engineer in the electric propulsion and chemical laser laboratories. She then returned to UIUC to pursue a M.S. degree in aerospace engineering and received it in August 2004. Her M.S. thesis and graduate research focused on pulsed plasma thrusters for electric satellite propulsion. She then returned to CU Aerospace, has since become a Senior Engineer, and is currently contributing to the electrically assisted oxygen–iodine laser project.

Mr. Andrew D. Palla received his A.B. degrees in physics and mathematics from the University of Chicago in 2002 and his M.S. degree in aerospace engineering from the University of Illinois at Urbana–Champaign in 2004. He is currently a Senior Physicist and head of the Modeling and Simulation Division at CU Aerospace, where his focus is on the development of multiphysics computational models for the study of laser systems (gas chemical, gas discharge, and solid-state) and other engineering/physics problems of interest.

Dr. Wayne C. Solomon received his Ph.D. in chemistry from the University of Oregon in 1963 and his B.S. in chemistry from the University of Idaho in 1956. He is a Professor Emeritus at the University of Illinois at Urbana–Champaign (UIUC); was a Professor and Head of the Department of Aeronautical and Astronautical Engineering at UIUC from 1988 to 2001; is a founder and President of CU Aerospace in 1998; was Director of Engineering at Bell Aerospace Textron from 1973 to 1988; was a Staff Scientist with the Air Force at Edwards Air Force Base from 1969 to 1973 and 1963 to 1967; and was a Visiting Professor at the Institute fur Physikalische Chemie, Goettingen, from 1967 to 1969. He joined the faculty at the University of Illinois after directing all the high-energy laser activities at Bell Aerospace Textron. His activities include research for several families of high-energy chemical lasers. Several laser systems that were significantly advanced under his leadership included DF–CO_2, HF space laser devices, DF lasers, and COIL devices. Current research includes COIL laser technology with nitrogen diluent and large-scale CFD modeling of COIL devices.

Dr. Joseph T. Verdeyen received a Ph.D. in electrical engineering from the University of Illinois in 1962, an M.S. from Rutgers University in 1958, and the BSEE degree from Rose-Hulman in 1954. He served with the U.S. Army from 1955 to 1957; was Director of the University of Illinois at Urbana–Champaign Gaseous Electronics Laboratory from 1972 to 1974; was Director of the Compound Semiconductor Microelectronics Laboratory and NSF Center for Compound Semiconductor Microelectronics from 1988 to 1989; has been a Professor Emeritus at the University of Illinois since 1994; and consults as a Senior Scientist to CU Aerospace. After undergraduate studies, he worked for Bell Telephone Laboratories at Murray Hill, New Jersey. After completing his graduate studies, he remained at the University of Illinois as a faculty member in Electrical and Computer Engineering. He has been a consultant to Zenith and Lucitron on plasma display technology, General Electric at Nela Park and Applied Physical Laboratories on lighting, Protech, and TEL on RF discharges and plasma processing, and Sandia and Livermore National Laboratories on microwave and RF discharges. His current research interests are lasers (gas, solid state, and semiconductor), optical communications and control, plasma display technology, and gas phase processing of materials.

Mr. Brian S. Woodard received his B.S. in aeronautical and astronautical engineering in 2001 from the University of Illinois at Urbana–Champaign (UIUC). He then worked for the Department of Aeronautical and Astronautical Engineering as a visiting academic professional until the fall of 2002, when he began pursuing his M.S. degree in aerospace engineering at UIUC. He completed his M.S. in 2004 and is currently a Ph.D. candidate in aerospace engineering at UIUC. During his academic and professional careers he has developed and conducted laboratory experiments encompassing all aspects of creating an electrically assisted oxygen–iodine laser.

Mr. Joseph W. Zimmerman received his B.S. (2001) and M.S. (2003) degrees in aeronautical and astronautical engineering from the University of Illinois at Urbana–Champaign (UIUC). His graduate research involved the modeling of gas discharges for use in oxygen–iodine lasers; presently he is performing experimental investigations on a proposed electrically assisted oxygen–iodine laser concept. He has worked as a Staff Engineer for CU Aerospace and is currently a Ph.D. candidate in aerospace engineering at UIUC.