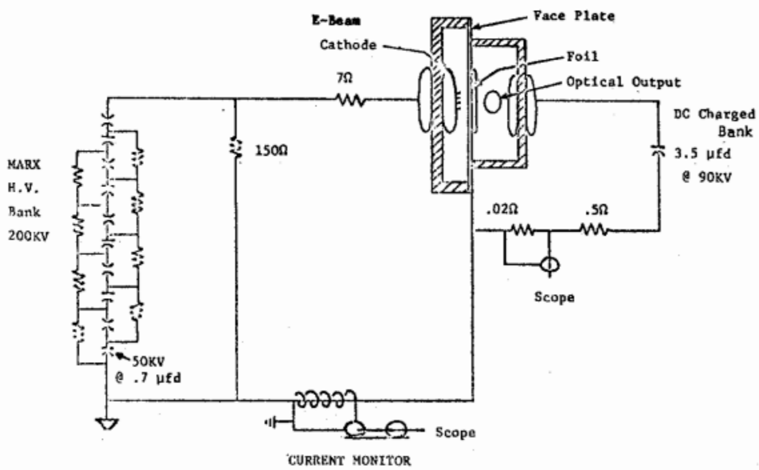

Fig. 1. Electrical schematic.

TABLE I
OPERATING PARAMETERS

	E Beam			Discharge			
	Voltage (kV)	Width (µs)	Current (A/cm)	Length (cm)	Electrode Spacing (cm)	Height (cm)	Capacitor (µF)
L(long)	200	0.2	1–3	100	1	1.5	1.4
S(short)	200	1.0	1–3	30	3	3	2.5
B(big)	200	0.5	1–3	100	4	4	3.5

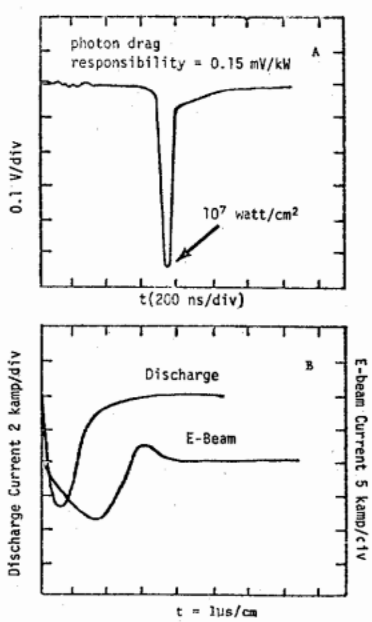

Fig. 2. Time-resolved trace of *E* beam and discharge currents *B* and optical *A* from laser *L*.

sures to test the high efficiencies predicted[1] at kilojoule/liter-atmosphere loading levels, while longer pulse guns capable of attaining such loadings at 1 atm are being developed.

[1] J. E. Brau, "The efficiency of the 300°K pulsed CO TEA laser," *Laser Div. Dig.*, LRD 72-2.

11.4 High-Pressure Self-Sustained Laser Discharges in CO, L. D. Pleasance and L. A. Weaver, *Westinghouse Research Laboratories, Pittsburgh, Pa. 15235.*

(15 min)

Recently it has been found that stable uniform self-sustained discharges between planar electrodes can be initiated over a wide range of pressures, gas mixtures, and electrical power inputs suitable for gas lasers. Besides being attractive as possible alternatives to electron-beam-initiated discharges, triggered planar electrode configurations offer a simple geometry for investigating the fundamental processes of self-sustained laser discharges. Towards this end we have studied high-pressure self-sustained discharges in pure CO and mixtures with He, N_2, and Xe; this paper describes the experimental results and the gas discharge kinetic model employed to explain them.

The planar electrodes were fabricated from OFHC copper with edges contoured to a modified Bruce profile.[1] The active discharge dimensions were 2 × 2 cm in cross section with a 50-cm length giving a discharge volume of 200 cm.[3] The discharge was driven by a single storage capacitor and a pressurized spark gap. The discharge circuit had a loop inductance of ~500 nH. The laser glow discharge was triggered by an array of arcs along the sides of the main electrodes. Stable discharges were obtained in CO and N_2 at pressures of up to 300 torr, in He at pressures up to 1000 torr and in mixtures at reduced partial pressures. Specific energy inputs of greater than 250 Jl^{-1} atm^{-1} were obtained in 150 torr of pure CO. Discharge current and voltage were monitored with fast-response probes and the infrared output was measured with a 0.5-m Ebert spectrometer fitted with an InSb detector.

The experimentally observed electrical characteristics of the discharge were compared with predictions of a model in which the discharge was included as a time-varying resistive element in the pulse circuit. The plasma and pulse circuit were coupled by the requirement that the voltage across the discharge and the current in the loop be self-consistent. The resistivity, ionization rate, and vibrational excitation rates were calculated as a function of electric field using a non-Maxwellian electron energy distribution function. This distribution function was obtained from a quasi-static solution of the Boltzmann equation for a spatially uniform plasma. This model has been used for CO and CO:He mixtures and its predictions are in agreement with the experimental measurements within 30 percent. This is consistent with the limitations of the model and with uncertainties in the CO electronic excitation cross sections. This model predicts that the discharge should operate at relatively constant E/N and more importantly, that the peak electron density in the discharge is primarily a function of the characteristics of the external pulse network and decreases with increasing gas pressure.

Laser output was observed in pure CO and correlated with the electrical discharge characteristics. Lasing was observed after cessation of the current pulse on several rotational lines around the $P(18)$ transition of the $v = 6 \rightarrow 5$ and $v = 5 \rightarrow 4$ bands, moving to higher vibrational bands in a series of cascades. The laser output initially rose with increasing pressure, peaked and then fell as critical damping of the pulse network was approached. The initial rise is attributed to improved matching of the discharge to the pulse network and to the increasing effect of V–V pumping on the vibrational population in the region of the Treanor minimum. At higher pressures for the relatively constant vibrational excitation rate implied by a decreasing electron density, the V–V process tends to deplete the population inversion by redistributing it over a larger number of vibrational levels for the same electron density. The observed decrease in laser output at higher CO pressures is attributed to this effect.

[1] F. M. Bruce, *J. Inst. Elec. Eng.*, vol. 94, pt. 2, p. 139, 1947.

11.5 High-Power Transverse Discharge CO_2 Lasers (*Invited*), M. C. Richardson, *Division of Physics, National Research Council of Canada, Ottawa, Canada.*

(30 min)

The adoption of transverse electrical excitation techniques in high-pressure molecular gas mixtures has resulted in rapid progress being made in the development of high-power high-energy gas lasers. As a consequence, there is considerable interest in the possible application of such lasers to the production and heating of high-density plasmas, particularly with a view to the initiation of controlled thermonuclear fusion. Until recently, the two most promising approaches to the development of large-aperture uniform high-pressure gas discharges were those of the double discharge techniques of Dumanchin *et al.*[1] and Laflamme,[2] and the use of high-energy electron-beam-controlled discharges.[3] However, within the past year an alternative method of exciting large volumes of CO_2, N_2 and He gas mixtures has been reported, and successfully incorporated into a laser system capable of delivering pulses of several gigawatts of power, with total energies of $\sim$300 J[4]. This technique utilities UV radiation from an auxiliary two-dimensional array of high-current arcs as a means of producing an initial degree of volumetric preionization in the active region, prior to the onset of the main discharge. Initial studies of this preionizing radiation indicate that it can have an effective range of >30 cm and can produce the required conditions for the occurrence of uniform arc-free discharges for times >12 μs. This discharge scheme, which is relatively simple in construction, permits the uniform excitation of large volumes of various mixtures of CO_2, N_2, and He, including pure CO_2, with input energies of >300 J/l, resulting in energy extraction efficiencies of >10 percent and small signal gain values of 0.04–0.05 cm^{-1}. In particular, discharges between electrodes separated by up to 30 cm have successfully been produced, making possible the construction of gas-laser modules with beam apertures in excess of 1000 cm^2. Since the maximum radiation density that can be sustained by the excited gas medium without the occurrence of optical breakdown is $\sim$13 J/cm^2 (for a 50-ns pulse),[4] such large-aperture discharges are a prerequisite for the fabrication of multikilojoule laser systems suitable for the production of high-temperature plasmas. Various features of the excitation scheme will be discussed and a number of electrode configurations described. In particular, details of an oscillator-amplifier laser system capable of delivering high-power laser pulses of short duration will be presented.

[1] R. Dumanchin, J. C. Farcy, M. Michon, and J. Rocca-Serra, presented at the 6th Int. Quantum Electronics Conf., Kyoto, Japan, 1970.

[2] A. K. Laflamme, *Rev. Sci. Instrum.*, vol. 41, p. 1578, 1970.

[3] C. A. Fenstermacher, M. G. Nutter, V. T. Leland, and K. Boyer, *Appl. Phys. Lett.* vol. 20, p. 56, 1972.

[4] M. C. Richardson, A. J. Alcock, K. Leopold, and P. Burtyn, presented at the 7th Int. Quantum Electronics Conf., Montreal, Canada, 1972.

11.6 Impurity Effects and Ultraviolet Source Characteristics of a UV Preionization CO_2 Laser, F. Varsanyi, O. P. Judd, and J. Y. Wada, *Hughes Research Laboratories, Malibu, Calif. 90265.*

(15 min)

The use of a plasma-conditioning technique that employs ultraviolet radiation in pulsed electrical CO_2 lasers has been demonstrated by several groups.[1–3] The generation of stable and spatially uniform discharges in atmospheric pressure CO_2 laser gas mixtures at high values of energy input has been achieved. An optical energy extraction of 40 J/l-atm at a conversion efficiency of ≥20 percent and pulsewidth of several microseconds has been achieved. In this paper, we report 1) the measured gas impurity effects on the laser performance, and 2) the UV source and photoionization properties of a UV preionization CO_2 laser.

Briefly, in our devices, the operation occurs as follows. A row of independently controlled auxiliary spark discharges is placed along the length of the main discharge volume at a distance of a few centimeters. This array of auxiliary spark discharges, which are ignited a few microseconds before the initiation of the main discharge, serve as a strong source of hard UV photon radiation which, in turn, photoionizes neutral gas molecules in the main discharge volume. The resulting preionization background of photoionized plasma helps the development of a uniform avalanche glow discharge in a large main discharge volume.

Our measurements of the spectra and photoionization electron densities in a typical CO_2 laser gas mixture have shown that a relatively high efficiency is achieved in the generation of UV photons. Approximately 10 percent of the total spark energy is converted to photons with wavelengths shorter than 2200 Å. A large portion ($\simeq$60 percent) of this radiated power is found in the spectral region below 1100 Å. Our data suggest, however, that only a small fraction ($<10^{-2}$) of these UV photons contributes to photoionization of the laser gases. The measured mean free path of these "effective" photons is about 10 cm at atmospheric pressure in a typical CO_2 laser mix ($He:N_2:CO_2 = 8:1:1$).

In a clean laser environment, the stability of the main discharge is not critically dependent upon the UV preionization parameters. The energy required in the preionizer is typically less than 2 percent of the main discharge energy. The preignition time of 2–10 μs will lead to a preionization plasma density of $\sim 10^9$ electrons/cm^3 and to a stable main discharge of several microseconds. We have also investigated the generation of higher electron densities with more energetic spark discharges as preionizers. An increase of two orders of magnitude of plasma electron density to $n_e > 10^{11}/cm^3$ was observed when the electrical energy of 2 J was dissipated in each preionizer spark. The effect on laser performance and on medium homogeneity of these spark preionizers is presently being evaluated. We have also studied the influence of undesirable impurities on the laser and discharge characteristics. The attainment of stable and efficient laser operation becomes increasingly difficult as the impurity concentration in the laser medium is increased as the result of evaporation of surface contaminants, volumetric gas dissociation, and/or small gas leaks. The threshold condition for the glow-to-arc transition in the main discharge was affected significantly so that the laser output energy was reduced by more than a factor of 2 to 3 when 1 percent air was mixed into the laser gas. The reduction factor increased to about 10 when the air concentration was doubled to 2 percent.

[1] O. P. Judd and J. Y. Wada, *25th Annu. Gaseous Electronics Conf.*, London, Ont., Canada, 1972.

[2] H. J. Seguin and J. Tulip, *Symp. High Power Molecular Lasers*, Quebec, Canada, 1972.

[3] M. C. Richardson, *Symp. High Power Molecular Lasers*, Quebec, Canada, 1972.

11.7 Independent Initiation of a High-Pressure Pulsed Glow Discharge for CO_2 Laser Excitation, G. S. Dzakowic and R. V. Babcock, *Westinghouse Research Laboratories, Pittsburgh, Pa. 15235.*

(15 min)

We describe the performance of a small (55 cm^3) CO_2 laser, excited by pulsed glow discharges between planar electrodes 11 mm apart and 15 mm wide, pulsed by an independent initiation technique. The electrodes (and sustainer capacitors) are maintained at a voltage below the quiescent breakdown value (V_b), but above the characteristic glow voltage (V_g), and glow discharges are initiated by injecting timed bursts of ionization. Within 20–200 ns (shorter for higher initial voltage), the electrode voltage drops to the glow value, remaining there until the sustainer capacitors drain.

In earlier experiments, the independently initiated pulsing provided arc-free glows at input energy densities up to 1 mJ/cm^3-torr; about the same limit applies when the main energy is switched externally. Various initiating methods were studied. The maximum energy per pulse did not depend strongly on the initiation method, but the permissible gas composition and operating voltage range did. For the 55-cm^3 cavity experiments described below, the initiation method adopted was corona showers from blades parallel to the anodes. The chosen gas composition was $CO_2:N_2:He:H_2 = 5:5:40:1$ at 500 torr, which had given optimum efficiency in externally switched operation of the same cavity.

The required initiation pulse was a negative 25–40 kV, rising in <40 ns, and containing 3–7 percent as much energy as the sustainer. For initiation energies below 7 percent, the laser efficiency fell off at low gas flow rates.