CLM - P 425

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Preprint

GAIN CHARACTERISTICS OF A ROGOWSKI ELECTRODE TEA CO_2 LASER AMPLIFIER WITH LARGE ELECTRODE SPACING

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1975

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ABSTRACT

Gain characteristics of a Rogowski electrode TEA CO_2 laser amplifier with large (52 mm) electrode spacing are described. The introduction of small quantities of additives with low photoionisation threshold greatly extends the limit for arc formation allowing significantly higher gain values to be achieved.

(Submitted for publication in Optics Communications)

April 1975
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Of the considerable number of different electrode configurations that have been used in transversely excited atmospheric CO_2 laser systems the Rogowski profiled electrode system has been one of the most successful with regard to high energy output per unit volume, uniformity of gain profile and simplicity of construction. A parametric study of the performance of an oscillator using such a system with a relatively small electrode separation distance (26 mm) has been described previously by Pearson and Lamberton [1]. In building up high energy pulsed CO_2 laser systems it is necessary to use large beam areas in order to maintain an energy density below the damage threshold of optical components and hence transverse discharges between electrodes with a large spacing are required. In the present paper the performance of an amplifier using a larger spacing (52 mm) Rogowski electrode system is described. It is found that the introduction of small quantities of additives with low photoionisation threshold (~ 7 eV) into the CO_2-N_2-He gas mixture, as suggested by Seguin et al [2], greatly extends the useful working range allowing significantly higher gain values to be achieved.

Fig. 1(a) shows details of the electrode system and electrical circuitry. The brass electrodes have a 38 mm wide central flat section and the edges have a Rogowski profile [3], suited to the 52 mm electrode separation, to a depth of 35 mm. A special, full form, profiled milling cutter was used for their manufacture. The active length of the amplifier is 1.8 m and is formed by two pairs of electrodes (see Fig. 1(b)). The ends of the electrodes were shaped by moving the cutter around on an arc of radius 200 mm.

The discharge was driven by a Marx circuit (0.2 μF) operating at up to 90 kV, using low inductance pressurised spark gaps and a parallel plate transmission line connection to the electrodes. The main discharge was initiated by auxilliary discharges between the anode and tungsten trigger wires (dia = 0.5 mm) running parallel to the electrodes and connected to the cathode via 250 pF coupling capacitors at each end. The discharge current, as measured by pick-up coils placed between the transmission lines, was characteristic of an over-damped LCR circuit with a rise time of 300 ns. A mixture of CO_2, N_2 and He was continuously flowed through the discharge region at ~ 4 litres/min, with individual flows controlled by calibrated flowmeters. Small traces of additive could be introduced by bubbling a small fraction of the N_2 through a pool of the additive.

The laser amplifier was used in conjunction with a small, Rogowski electrode, TEA oscillator (electrode spacing 26 mm, active length 700 mm, operating on P20 line only). The optical arrangement is shown schematically in Fig. 1(b). Power levels following the oscillator and amplifier were measured by sampling 5% of the beam and focusing onto photon drag detectors. The oscillator pulse consisted of a sharp initial peak with halfwidth ~ 60 ns followed by a low power tail lasting ~ 500 ns and containing about half the pulse energy.

The peak power gain of the amplifier was measured as a function of voltage, gas mixture, input laser power and timing relative to the oscillator.

Fig. 2 shows the peak power gain as a function of He content, with the $N_2:CO_2$ ratio maintained constant at 1.15:1, for a series of different voltages and for a fixed input laser pulse (4 MWatt peak power, 14 mm beam dia, peak power at 850 ns after start of amplifier discharge). The standard deviation of the gain was typically 8% of the average. As the He content is reduced at any given voltage a transition from a uniform glow discharge to discrete arcs occurs. It was found that when a small quantity of either triethylamine or tripopylamine was introduced into the gas mixture, as suggested by Seguin et al [2], the glow discharge regime was significantly extended to lower He content allowing significantly higher gain. The arcing limits with and without additive present are indicated by the dashed curves in Fig. 2. The arcing limit with the additive present was not found to be critically dependent on the amount of additive (the amount of N_2 passed through the pool of additive was varied from 10 to 100 ml/min) or the type of additive (triethyalamine and tripopylamine had the same effect). The gain was not affected by the presence of the additive under conditions where a glow discharge is obtained without the additive. Similar results were obtained with a N_2:CO_2 ratio of 0.38:1. At a given voltage the peak power gain does not increase monotonically with decreasing He content. In contrast it was found for a Rogowski electrode oscillator (26 mm electrode spacing) [1] that the peak power increased monotonically with decreasing He content at a given voltage. The variation of peak discharge current with He content is plotted in Fig. 3 for a series of different voltages. We note an approximately linear decrease in plasma current with decreasing He content. It is apparently the decrease in plasma current and electrical energy into the discharge that occurs with decreasing He content that leads to the decrease in gain at low He content for a given voltage. For a fixed current level the gain increases monotonically, although not linearly with decreasing He content.

The reason for the extension of the arcing limit by the additive is an increase in the photo-preionisation level produced by the auxilliary discharge prior to initiation of the main discharge. Microwave measurements of the photoionisation level produced by a spark UV source in a CO_2-N_2-He gas mixture have shown an increase in electron density of four orders of magnitude when these additives were introduced [2].

Fig. 4 shows peak output power P_o and gain plotted as functions of peak input power P_s for an 85% He content and 78 kV operation. To obtain an estimate of the small signal gain coefficient α and the saturation power P_s of the amplifier we assume the peak power gain to equal the energy gain and apply the gain equation for a uniform beam intensity, i.e.

$$P_o = P_s \ln \{1 + \exp(\alpha L) [\exp(P_i/P_s) - 1]\}$$

where P_i and P_o are input and output peak powers and L is the length of the amplifier discharge. Fitting this equation to the experimental result of Fig. 4 gives $\alpha \sim 2.0\ m^{-1}$ and $P_s = 15$ MW.

The peak power gain was measured as a function of the timing of the input pulse relative to the start of the amplifier discharge. The peak amplified output occurred when the input pulse occurred at ~ 900 ns after the start of the amplifier discharge. When the amplifier discharge was initiated at earlier times relative to the input pulse the oscillator output was affected by optical interaction from the amplifier which led to a premature gain switch in the oscillator with the result that the oscillator peak power was decreased by a factor of up to 2.5 (at 1.1 μs). This phenomenon has been described previously [4] for the case where the present amplifier feeds into a small spacing (26 mm) Rogowski electrode amplifier.

No detailed measurements of the gain profile were made. However time integrated photographs of the discharge taken from the side and end showed a uniform luminosity between the electrodes and a width of discharge ~ 60 mm. Burn patterns on exposed polaroid film formed by expanding the oscillator beam to fill the full aperture and passing it through the amplifier indicated a uniform gain profile.

The effect of introducing the additives to the oscillator gas mixture was not tried because energy densities capable of damaging germanium optical components could readily be achieved without the use of additives. It is likely however that the use of additives would greatly increase the efficiency of a 26 mm Rogowski amplifier or an oscillator with a short discharge length.

References

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[3] J.D. Cobine, in 'Gaseous Conductors' DOVER (1958) 178.

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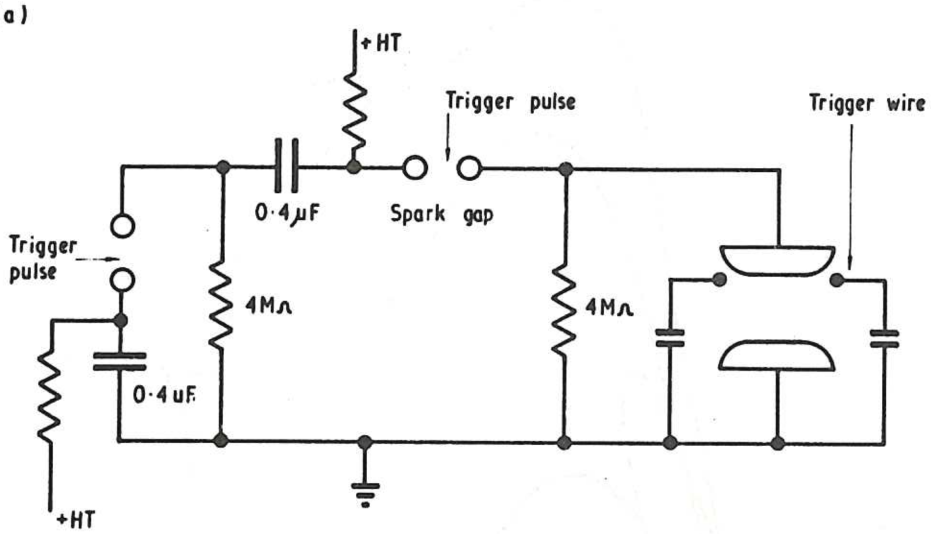
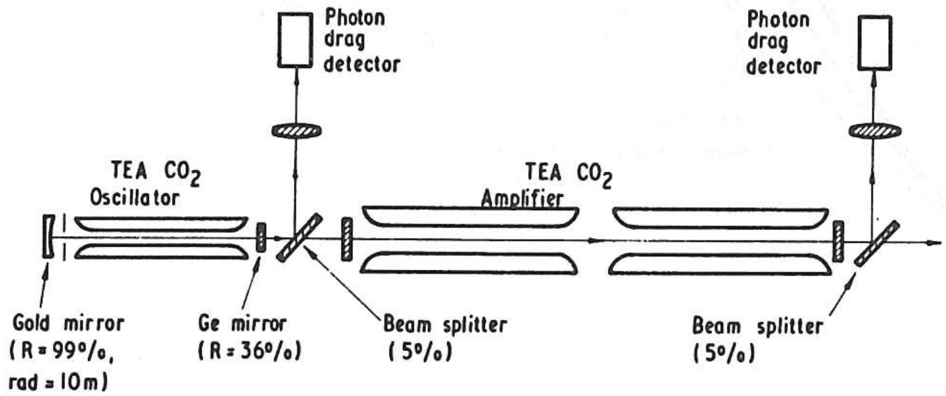
(a)

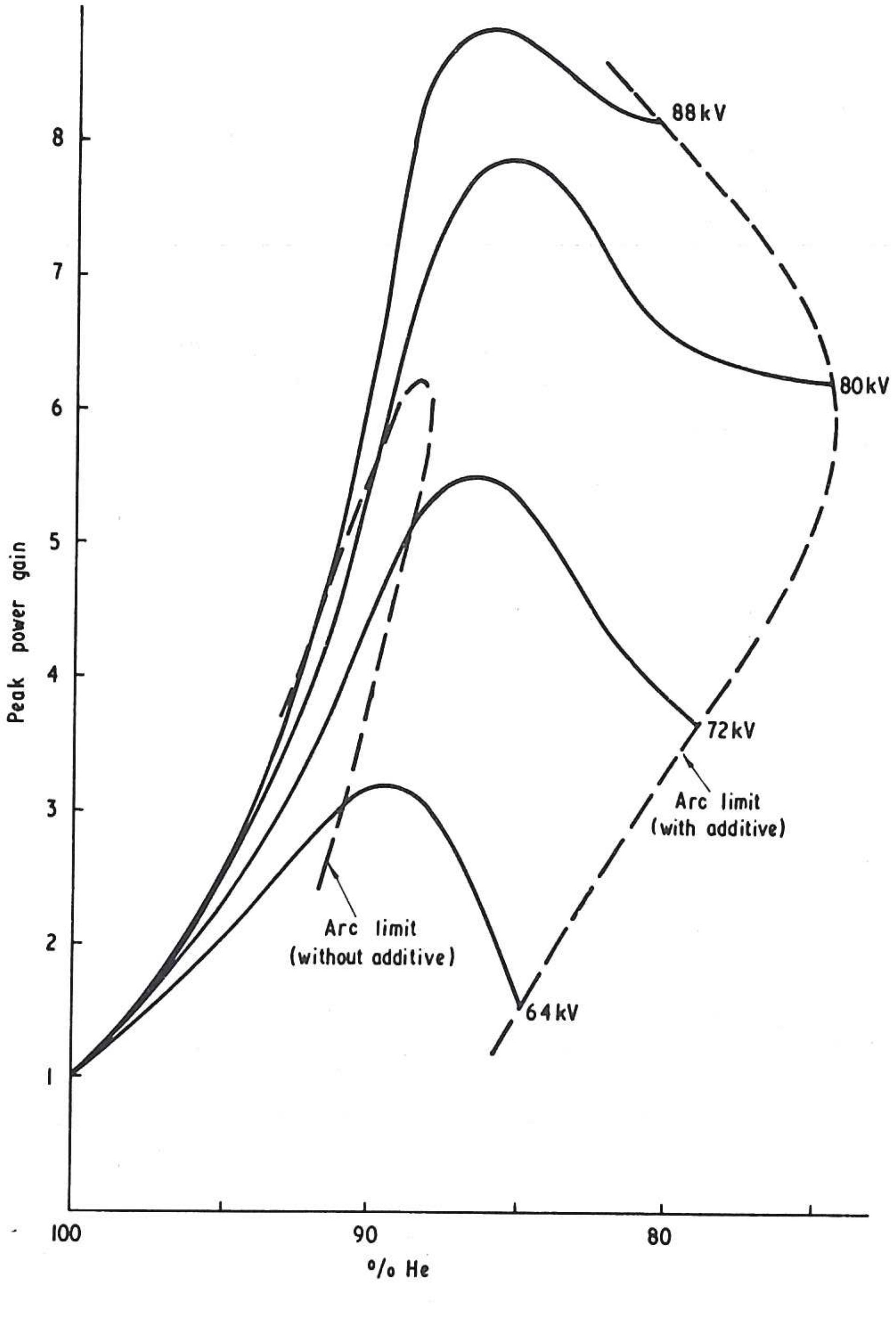


(b)

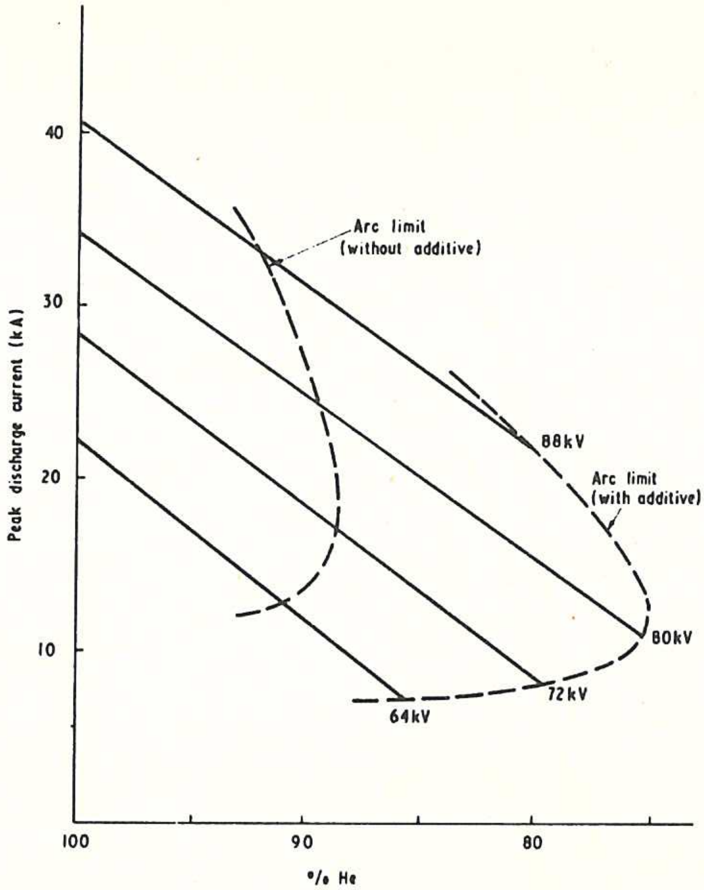


1. (a) Electrode system and electrical circuit.

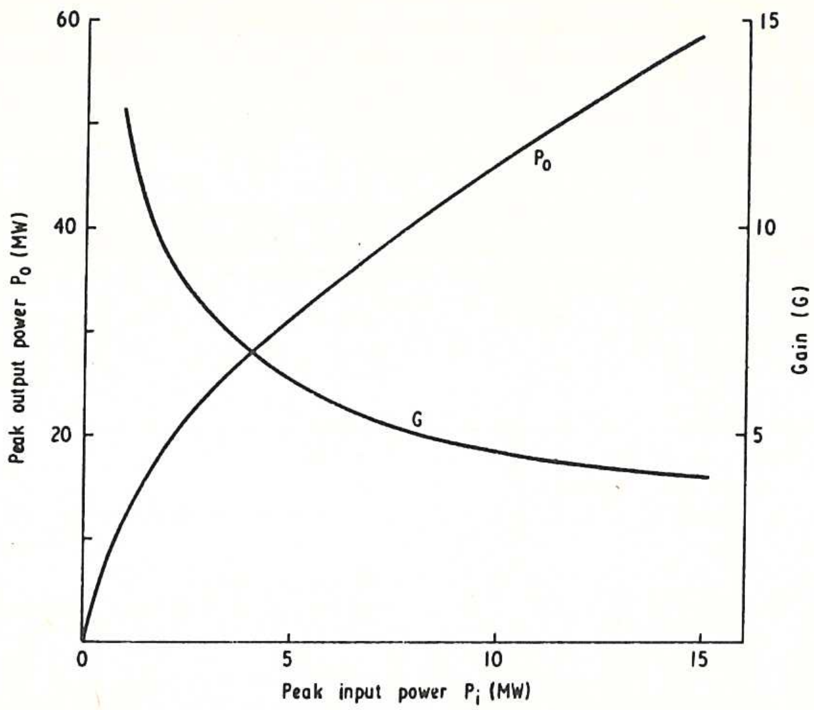
(b) Schematic of optical arrangement.



2. Peak power gain versus He content for a series of different voltages.



3. Peak discharge current versus He content for a series of different voltages.



4. Output power and gain versus input power.