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A S Kaye and A C Walker

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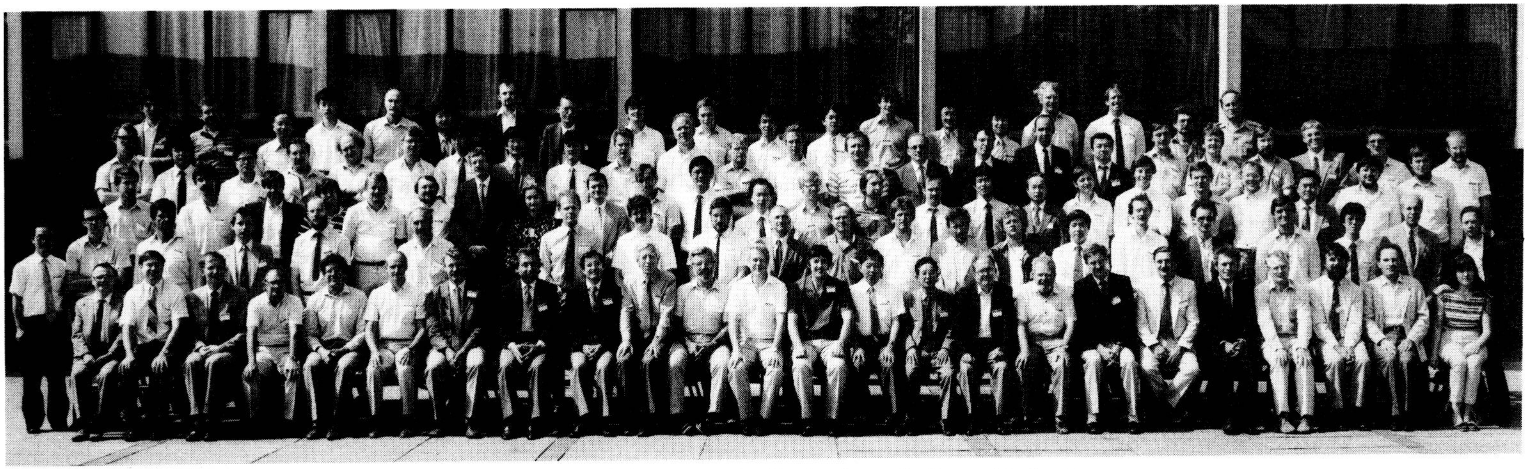

Symposium participants at St Catherines College, Oxford.
Photograph by Gillman & Soame, Oxford.

Preface

The biennial International Symposia on Gas Flow and Chemical Lasers have now become well established with this 1984 meeting being the fifth in the series. As with previous meetings, this symposium once more demonstrated a truly international flavour with the total of 87 presented papers breaking down as: 37 from Europe, 19 from the USA, 14 from Japan, 10 from the USSR, 5 from Israel and 2 from China. This volume is a compilation of 82 of these papers.

In general the papers have been grouped together as they were presented in the sessions but with the poster papers added to the relevant sections. The titles of these sections reflect the scope of the conference and highlight the changes from the previous years. Thus, although the traditional reports on gas-dynamic lasers and fast-flow chemical (vibrational transition) laser systems continue to form a large part of the meeting, the rapidly growing field of electronic-transition chemical lasers stands out as another major topic this year. It is also notable that with the growing deployment of high mean-power lasers in industry, increasingly sophisticated studies, both theoretical and experimental, are being undertaken to fully characterise laser–material interactions.

The number of symposium participants again increased with the total this year reaching 160, representing 13 countries. The city of Oxford provided an ideal ambience for both enthusiastic exchange and discussion of scientific advances as well as social interaction and relaxation. The latter included a very successful programme for accompanying persons arranged by the wives of the Culham Laboratory local organising committee.

In conclusion, we wish to express our thanks to all those concerned with the meeting organisation, to the members of the Scientific Advisory Committee for their support and encouragement and to the sponsors for their financial support. We look forward to the 6th GCL Symposium planned for 1986 in Israel.

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Inst. Phys. Conf. Ser. No. 72
Paper presented at 5th GCL Symp., Oxford, 20–24 August 1984

High power industrial CO_2 lasers

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Abstract. A 20 kW class industrial CO_2 laser, which is equipped with a new discharge electrode system for exciting a large mode volume, has been developed in Japan's national R&D project. This article summarizes the operating characteristics of the laser, and those of other high power CO_2 lasers developed in conjunction with the project.

1. Introduction

A national R&D project, named as "Flexible Manufacturing System Complex Provided with Laser (FMSC with Laser)" will have been finished by next March after eight years of activities. One of the most important targets of this project is the development of high power CO_2 and YAG lasers (20 kW and 300 W, respectively) for industrial use (Kimura et al 1980). The lasers are expected to provide new manufacturing processes in FMS with various metal working capabilities, such as cutting, drilling, welding, surface-treating and deburring.

Until the fiscal year of 1980, three kinds of 5 kW class CO_2 lasers had been developed as the interim objects toward the final target of a 20 kW laser. The first was a type in which the discharge direction and the gas flow direction are parallel to each other, and perpendicular to the laser beam axis. (Takahashi et al 1982). The laser was operated under conditions of (1) low gas pressure below 6.65 kPa and (2) high gas flow rate above 80 m/s. The second was a type in which all of the discharge direction, the gas flow direction and the laser beam axis are orthogonal to each other (Nagai et al 1982). This laser was operated under conditions of (1) high has pressure above 13.3 kPa and (2) low gas flow rate below 45 m/s. Each of these lasers has achieved high reliability and durability together with high efficiency and good beam quality. The third was compatible with both lasers with respect to the main structure and operated under various conditions (Kasamatsu et al 1981 & 1982). The control technology of high power lasers has been developed by using this laser.

A 20 kW industrial CO_2 laser has been developed on the basis of the results obtained in operations of the 5 kW lasers mentioned above. We had decided that the 20 kW laser should be the type to be operated under medium high gas pressure and high gas flow rate. The operating conditions are mixtures of the two types described above, but we had to develop two new techniques for power increase to 20 kW. One is a silent-discharge assisted DC glow excitation (SAGE) method (Hishii et al 1983) and the other a transparent window system for high power beam extraction (Kotani 1983 &

Miyata 1982). We are confident that the 20 kW laser has become suitable for industrial use by adopting these new techniques.

The Tsukuba test plant of FMSC has been constructed as part of the project, where a 10 kW CO_2 laser for metal processing has been installed. One of the 5 kW lasers mentioned above has been remodelled into the 10 kW laser by making use of the SAGE method.

In this paper, we describe the details of the structure and operating characteristics of the 20 kW CO_2 laser, and also summarize the characteristics of other high power CO_2 lasers developed in conjunction with the national R&D project in Japan.

2. Structure of 20 kW laser

The 20 kW laser is a transversely excited type and has a size of 3.4 m in length, 1.8 m in width and 1.7 m in height (Fig. 1). The electrode system for gas excitation is about 3 m in length and 70 mm in discharge gap width. The laser gas is sealed-off under a pressure of 10.6 kPa and circulated at a flow rate of 80 m/s (i.e., at a volume flow rate of about 20 m^3/s) through the discharge region perpendicularly both to the directions of discharge current and optical axis. An annular beam out of an unstable resonator is extracted into the air through a KCl or ZnSe window.

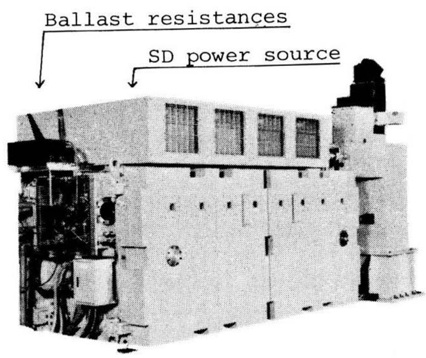

Fig. 1 20 kW industrial CO_2 laser

2.1 Electrode System

In Fig. 2, we show a configuration of electrodes for the SAGE method, which was developed for exciting a large discharge space densely and homogeneously. The electrode system consists of DC glow discharge electrodes with planar anodes and an array of 300 molybdenum pin cathodes and silent discharge (SD) electrodes for pre-ionization. The SD electrodes are installed at a pertinent position upstream from the array of multi-pin cathodes and feed ions and electrons into the main discharge gap by high frequency silent discharge (25-100 kHz).

The maximum stable discharge current is tripled with an extra power consumption of only 5 % of the total discharge power for preionization. It is also emphasized

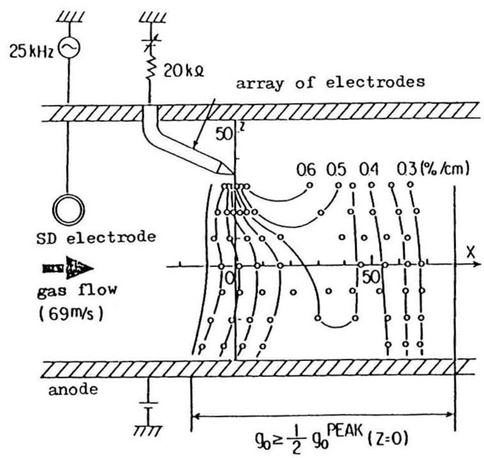

Fig. 2 Configuration of the SAGE electrode system with a contour map of small signal gain.

that the SAGE method enhances homogeneous excitation in the large mode volume to attain good beam quality.

2.2 Resonator and Beam Extraction Window

The resonator of the 20 kW laser is a positive branch unstable resonator with a magnification factor of 1.5 and a cavity length of 3.7 m. An annular beam coupled out of a scraper mirror of the resonator is extracted through a transparent window into the atmosphere. Stable extraction of the high power laser beam was one of the most important problems to be resolved, since an aerodynamic window could not be applied to gas sealed-off lasers. Analytical and experimental investigations on thermal stresses made it possible to use a transparent window of either KCl or ZnSe with an appropriate cooling device for 20 kW laser beam extraction. An AR-coated KCl window has been developed and is now being improved to use for extracting a laser beam above 20 kW in the project.

3. Operating Characteristics of 20 kW Laser

The dependence of laser power on discharge power for a few gas pressures is shown in Fig. 3. The maximum output power obtained was 26.5 kW with an efficiency of 16.5 % under conditions of a gas pressure of 10.6 kPa and a SD input power of about 7 kW. In this case, an annular beam was extracted through a ZnSe window, where the outer diameter of the laser beam was about 80 mm. The ZnSe window has a good mechanical strength, which can stand against the thermal stress arising from absorption of the laser beam, but is not free from the optical distortion (i.e., thermal lens effect). Therefore, the ZnSe window has been replaced by a KCl window and a stable output of 20 kW has been obtained continuously for over 30 minutes. The output characteristics of the laser did not change by the replacement, but the optical distortion was much reduced. It is true that a concave lens effect was observed in the case of the KCl window. But it is too slight to cause any harm for practical use.

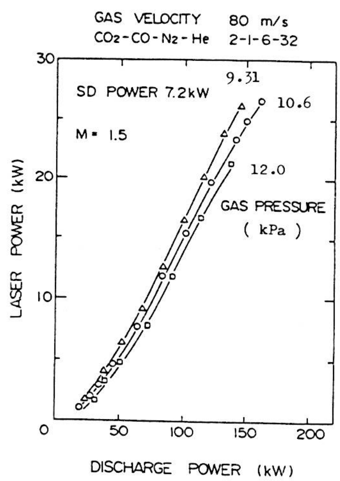

Fig. 3 Dependence of laser power on discharge power.

Fig. 4 shows a burn pattern of the 20 kW laser beam at near field. The intensity distribution of the beam has good homogeneity. The diffraction angle of the beam is 1.7 mrad without a thermal lens effect, which is close to the theoretical value of 1.3 mrad.

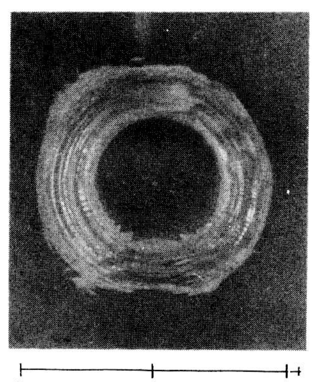

Fig. 4 Beam pattern at near field.

Table 1. Characteristics of high power CO_2 lasers developed

type of excitation	TE (DC glow)	TE (DC glow)	TE (DC glow)
reference	Takahashi et al 1982	Nagai et al 1982	Kasamatsu et al 1982
output power	5.4 kW	8.7 kW	9.2 kW
discharge power	52 kW	60 kW	55.7 kW
discharge length	1.5 m	1.5 m x 2	1.35 m
discharge gap	10 cm	4 cm	13.5 cm
discharge volume	∿15 ℓ	∿5 ℓ	∿20 ℓ
gas mixture	CO_2-N_2-He	CO-CO_2-N_2-He	CO_2-N_2-He
total pressure	4.6 - 6 kPa	13.3 kPa	5 - 6 kPa
gas flow rate	14.4 m^3/s	7 m^3/s	7 m^3/s
resonator	Z-type unstable	unstable	stable
cavity length	7.5 m	5.6 m	2 m
efficiency	10%	14.5%	16.5%
beam mode	annular	annular	multi
BD at near field	OD 50 mm	OD 40 mm	85 mm
diffraction angle	0.7 mrad*	< 3 mrad	not reported

* value at the 1st intensity minimum

4. Other High Power CO_2 Lasers

The 10 kW CO_2 laser for the Tsukuba test plant was remodeled from one of the 5 kW lasers developed in the project by using the SAGE method. The laser has a main frame size of 2.3 m in length, 2.0 m in width and 2.0 m in height. The electrode system in the main chamber is about 1.5 m in length and 70 mm in discharge gap width. The resonator is a positive branch unstable resonator with a magnification factor of 1.5 and a cavity length of 3.2 m. A silent discharge power source for the SAGE method is put on the main chamber. An annular beam with an outer diameter of 80 mm is extracted through an AR-coated KCl window into the atmosphere. A maximum output power of about 11 kW was obtained with good beam quality. The details of this laser will be reported in the near future.

Besides these lasers, commercial 5 kW CO_2 lasers have been developed on the basis of technologies developed in the project. One of them incorporates the SAGE electrode system and transparent window system. It will be the most compact 5 kW laser for industrial use throughout the world.

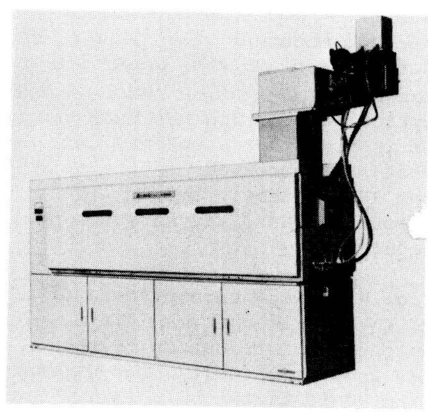

Fig. 5 Commercial 5 kW CO_2 laser with the SAGE electrode system.

Table 1 shows the sizes and charac-

SAGE	SAGE	SAGE
		Hishii et al 1982
20 kW	10 kW	5 kW
125 kW 3.0 m 7 cm ∿15 ℓ	74 kW 1.5 m 7 cm ∿7.5 ℓ	46 kW 1.3 m 4 cm ∿2.0 ℓ
CO_2-CO-N_2-He 10.6 kPa 20 m^3/s	ditto to left 10.6 kPa 10 m^3/s	ditto to left 13.3 kPA 3 m^3/s
unstable 3.7 m	unstable 3.2 m	unstable 2.5 m
16% annular OD 80 mm 1.7 mrad	13.5% annular OD 80 mm not measured	13.3% annular OD 40 mm <3 mrad

teristics of high power CO_2 lasers developed in conjunction with the project in Japan.

5. Concluding Remarks

High power CO_2 lasers for material processing have been developed in the national R&D project sponsored by the Agency of Industrial Science & Technology in Japan. These are two 5 kW lasers, a 20 kW laser and a 10 kW laser. The 20 kW and 10 kW lasers incorporate two new techniques, that is, the silent discharge assisted glow excitation (SAGE) method for exciting a large mode volume densely and homogeneously and the transparent window system for extracting a high power laser beam. The 20 kW laser is a compact and economical laser with high efficiency, good beam quality, high reliability, easy operation and easy maintenance.

Commercial models of 10 kW and 20 kW lasers will be developed in the near future. After the 5 kW lasers were put on the Japan's market, high power CO_2 lasers seem very promising for use in steel and heavy industries. Typical examples are current applications at two plants in a steel company. Each plant successfully uses a 5 kW laser as a flexible welder with the shortest setup time for various kinds of plate steel in a line of strip mill (Japanese Newspapers NIKKEI SANGYO SHINBUN etc. Aug. 30, 1983). The success of these applications would stimulate potential demand for high power CO_2 lasers in various industries.