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HIGH-POWER CO LASER AND ITS POTENTIAL APPLICATIONS

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The R & D program for the development of a high-power CO laser and its application technologies is described. Based on a self-sustained discharge excitation scheme, the available laser output has been successfully scaled to over 20 kW. The CO laser cutting experiments for thick metals have been performed in association with the decommissioning technologies development. Other potential applications, which include those based on photo chemical process, are reviewed. Recently demonstrated high-power tunable operation and room-temperature operation are also reported.

Keywords: CO laser, cutting, decommissioning, tunable operation
room-temperature operation

1. INTRODUCTION

The CO laser can produce scalable output with high operating efficiency in the 5-μm-band spectrum region. Its shorter output wavelength, when compared with 10.6-μm CO_2 laser, offers higher laser-to-materials coupling, and therefore, more efficient processing can be achieved especially in the field of metalworking such as cutting, welding, and surface treatment [1]. Potential of glass-fiber-based laser power delivery, which provides flexible processing, is another attractive issue in the CO laser applications [2]. The CO laser is featured, by not only its capability of producing high laser output but also, by its unique spectral characteristics. By introducing a line-selective cavity, tunable operation can be attained in the range of 4.9 - 6.3 μm, which includes special lines used for isotope separation, crystal growth, etc.

Although various excitation schemes have been investigated so far to obtain high laser output [3,4], only a limited number of apparatus have materialized for practical use. In our CO laser program, we first developed a 5-kW-class CO laser based on a self-sustained discharge excitation scheme [5], and this scheme has been scaled up to obtain a 20-kW-class output. In an early work with the 5-kW prototype laser, we demonstrated higher processing efficiency in cutting mild steel and stainless steel, with the CO laser than with CO_2 laser [6]. Attractive results were also obtained in processing of nonferrous metals [7]. Based on its excellent cutting capability, we consider that the CO laser can be an effective tool for decommissioning of nuclear power plants. For this purpose cutting of thick metals are now under test with the 20-kW CO laser developed.

This paper reviews the current status of the MHI / IRI CO laser program and potential applications of the CO laser. Recently demonstrated high-power tunable operation and room-temperature operation are also reported.

2. HIGH-POWER CO LASER DEVELOPMENT

As mentioned above, we first developed a 5-kW-class CO laser and collected performance data [5], based on which we designed and constructed a scaled-up version ,i.e. a 20-kW-class laser. The specifications are given in Table I and the schematics of this apparatus are shown in Fig. 1. In the system, all components for gas circulation are installed in a 2.3-m-diameter, 6.8-m-long cylindrical vacuum chamber. Laser gas mixture is circulated with four axial blowers operating in parallel and cooled through two heat exchangers operating with liquid nitrogen (LN_2) as coolant . The laser is excited by a transverse, self-sustained dc glow discharge which is produced between two-array hollow cathodes and a flat anode. An interelectrode gap length was selected to be the same as that of the 5-kW prototype laser, i.e. 6 cm, while a discharge length was scaled to around 4 m. Both a stable and an unstable resonators were tested, and it was confirmed that a steady, long-term operation was achievable at a 20-kW output power level even with a stable resonator. This is presumably due to lower absorption losses, both in bulk and coating of the ZnSe output coupler, at the CO-laser wavelength than at the CO_2-laser wavelength. The output performance is shown in Fig. 2. The output increases almost linearly with increasing discharge input and an output of 21 kW, which we believe to be the highest ever pure-cw CO laser output, is achieved with an electrical conversion efficiency of 22%.

3. APPLICATIONS OF HIGH-POWER CO LASER

In early experiments with the 5-kW laser, we investigated cutting capability of the CO laser, and compared the results with that of the CO_2 laser. Figure 3 shows relations between maximum cutting speed and plate thickness for carbon steel and stainless steel [6]. A higher cutting performance is demonstrated with the CO laser than with the CO_2 laser. Although there is an uncertain factor relating to the difference in the beam quality of the lasers used in the experiment, higher cutting performance with CO laser has been confirmed in subsequent experiments conducted by other groups [8,9]. Cutting of nonferrous metals was also performed and high quality cutting has been obtained for, e.g. a 10-mm-thick copper plate [7].

Based on these excellent cutting capability, we consider that the CO laser can be an effective tool for decommissioning of nuclear power plants. Cutting tests for thick metal plates have been performed for this purpose. An example is given in Fig. 4, where the stainless steel of over 100-mm thickness is successfully cut [10]. Cutting of much thicker plates are now under test by using the above-mentioned 20-kW CO laser.

The CO laser has also been used by other groups for welding and surface treatment of metals [1,11] as well as crystal growth for Al_2O_3, YAG, etc. [1,12].

4. RECENT TOPICS

4.1. High-power tunable operation

Another attractive feature of the CO laser is its unique spectral characteristics, in addition to its available high laser output. By introducing a wavelength-selective cavity, tunable operation can be obtained in the spectral range of 4.9 - 6.3 μm. Figure 5 shows the typical tuning characteristics and lines used for some potential applications based on photochemical processes [13-17]. Because there are no other high power laser sources in this wavelength region, we are encouraged to apply CO laser to these valuable applications.

4.2 Room-temperature operation

Although high laser outputs have been achieved with various excitation schemes, operations at cryogenic temperatures have so far been required. However, recent efforts have enabled us to achieve an efficient, high-power room-temperature operation [18-20]. This has been accomplished by combining rf or microwave discharge excitation with convective gas cooling, but dc discharge excitation may be used. High specific laser outputs, which are comparable to those of typical industrial CO_2 lasers, have been achieved. Because of the scalability of the excitation scheme used, construction of a multikilowatt room-temperature CO laser is feasible.

5. SUMMARY

The MHI / IRI CO laser program and the potential applications of the CO laser, as well as some recent topics, have been briefly reviewed. The self-sustained discharge excitation scheme has been successfully scaled up to obtain an output over 20 kW. Such-high power CO lasers should be an effective tool for heavy metal processing, including decommissioning of nuclear power plants. Other applications which use the line-tunability of the CO laser, such as isotope separation, crystal growth, etc. are also promising. The efficient room-temperature operation with high specific output has been demonstrated. Construction of a multikilowatt room-temperature CO laser is feasible.

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Table I Specifications and operating conditions of the 20-kW CO laser.

Target performance	
Output power	> 20 kW
Conversion efficiency	> 20 %
Excitation	
Type of discharge	transverse dc glow discharge
Discharge gap length	6.2 cm
Discharge length	4 m (effective 3.7 m)
Optical cavity	
Type	stable / unstable
Output window	solid / aerodynamic
Cavity length	8 m
Optical aperture	57.5 mm x 72 mm
Operating gas conditions	
Gas mixtures	$CO / N_2 / He / O_2$
Gas temperature	150 K
Gas pressure	40 Torr
Gas flow velocity	20 - 25 m/s

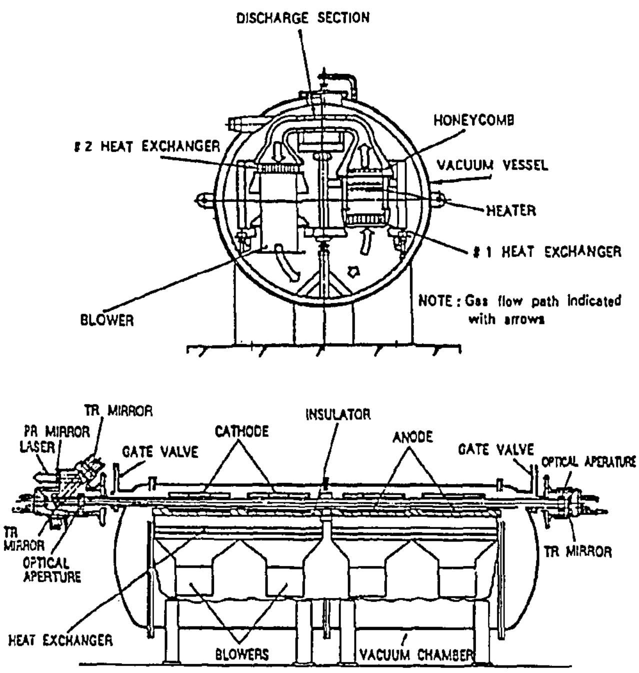


Fig. 1 Schematics of the 20-kW CO laser.

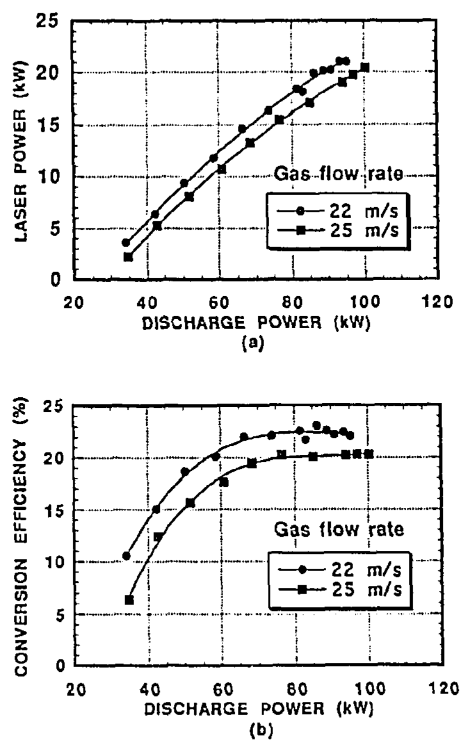


Fig. 2 Output performance of the 20-kW CO laser.

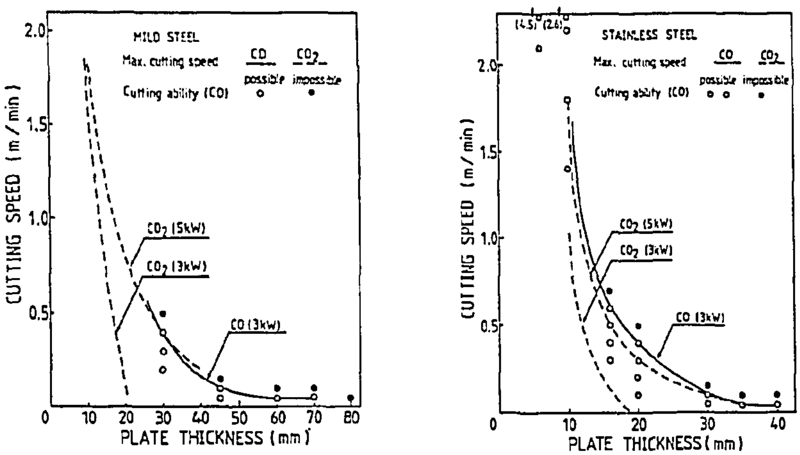


Fig. 3 Comparison of cutting capability between CO and CO_2 laser [6].

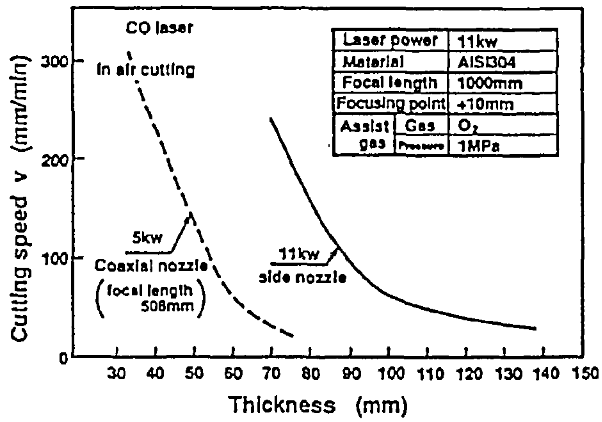
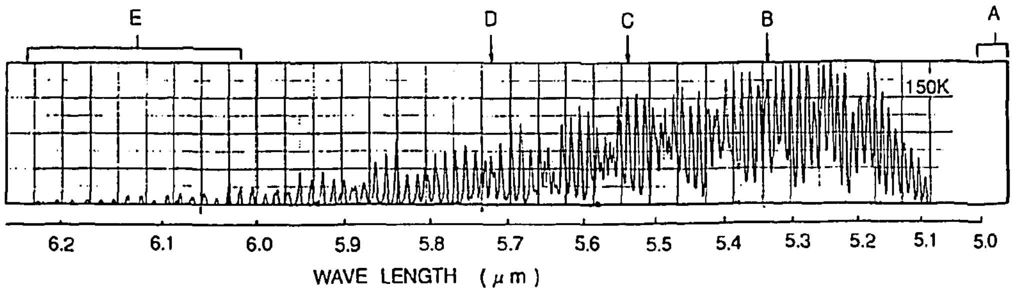


Fig. 4 Cutting of stainless steel over 100-mm thickness with the CO laser beam [10].



A CO V-V pumping applications (diamond growth, ^{13}C, ^{18}O enrichment)

B ^{235}U *enrichment (CRISLA)*

C ^{13}C, ^{18}O enrichment (multiphoton dissociation of $COCl_2$)

D deutrium, tritium enrichment (multiphoton dissociation of CHF_3)

E remote sensing of NO

Fig. 5 Output spectrum of the tunable CO laser and its potential applications.