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COIL development in Kawasaki Heavy Industries, Ltd.

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ABSTRACT

The Chemical Oxygen-Iodine Laser (COIL) has been studied for military use because it has many excellent features. These features count with not only the military but also the industry. The wavelength of COIL 1.315 μm , is a significant features of the industrial laser because it is located in a minimum loss transmission region for optical silica fibers. Therefore, we started the COIL development for industrial use in 1986. In the first stage, we developed a subsonic type. In 1992, the first 1 kW class commercial COIL was delivered. This system was successfully operated for several hours, and its output beam was delivered through the optical silica fiber of 0.3 mm core diameter. But the subsonic COIL has the disadvantage that the device size is relatively large. To solve this problem, the supersonic COIL has been introduced and developed. In 1994, 1 kW supersonic output power was attained. On the basis of this technology, we constructed a 10 kW class in 1996. This system achieved over 12 kW output power and chemical efficiency of 26 %.

Keywords: COIL, iodine laser, chemical laser, gas laser, chemical efficiency

1. INTRODUCTION

The first COIL lasing was demonstrated at the U.S. Air Force Weapons Laboratory in 1977¹. The attractive characteristics of the COIL, the short wavelength, narrow emission line, etc., motivated many researchers to develop the military COIL. On the other hand, in Japan, the COIL drew a great deal of interest to the industrial application because of its following excellent features. The wavelength of COIL is 1.315 μm and its absorption on the surfaces of material is higher than that of CO₂ laser. The optical silica fiber transmission loss of COIL is very low as same as that of Nd:YAG laser. The beam quality of COIL is very good as same as that of CO₂ laser because the laser medium is low pressure gas. The COIL can be called the laser having merits of CO₂ and Nd:YAG lasers. The COIL research in Japan was started in 1982 on basic experiment and theoretical studies at Keio Univ. The extensive studies of Keio Univ.² accelerated the study of industrial COIL and led to the joint research program of Industrial Research Institute (IRI) and us.

We have started the development of the industrial COIL in 1986. In the first stage of our COIL research, a subsonic type was studied and developed. After the joint research with IRI for several years, we have completed a 1 kW class proto-type subsonic COIL³. On the basis of this technology, the first 1kW class commercial COIL for material processing was delivered to the Applied Laser Engineering Center in Japan^{4,5}. It was successfully operated for several hours and proved the possibility of the industrial COIL. But the subsonic COIL has the disadvantage that the device size is relatively large compared with the laser power. The gain length of the 1 kW commercial COIL was about 1 m. In the early 1990's, our study of COIL has shifted to the supersonic type. And the target laser power has been pulled up to compete against the other industrial laser, especially Nd:YAG laser. In 1994, 1 kW supersonic output power was attained^{6,7}. We have constructed the 5 kW class supersonic COIL in 1995⁸ and the 10 kW class supersonic COIL in 1996^{9,10} by use of this base supersonic COIL technology. We could get gratifying COIL performance and conducted a lot of laser processing tests by use of them. A historical overview of our researches for these past 16 years about the COIL devices and its applications are discussed.

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2. DEVELOPMENT OF SUBSONIC COIL DEVICE

The early study of the subsonic COIL from 1986 was conducted with IRI for several years. In this joint study, we constructed a couple of small-scale systems to study efficient operation¹¹, and long term continuous operation¹². In Ref. 11, we demonstrated a maximum chemical efficiency of 40 %. In Ref. 12, we succeeded in operating a 100 W class system for over 3 hrs by continuously replenishing the Basic Hydrogen Peroxide (BHP). In addition to those small-scale devices, we constructed a high-power version prototype and succeeded in achieving an output power of 1 kW. The 2nd version prototype, equipped with a fuel replenishing system, was constructed on the basis of these results in succession. The maximum output power of 1.1 kW, and a continuous operation time of more than 2 hr with a power of over 500 W were achieved by this system³. Based on this long-standing effort, we brought the first 1kW class commercial COIL for material processing to completion^{4,5}.

Figure 1 shows the photograph of the 1 kW commercial COIL system. The major specifications of this system are summarized in Table 1. The laser beam of the COIL can be delivered by mirror optics or an optical silica fiber. By using this system, the use of 0.3 mm core diameter optical silica fiber of 200 m length was succeeded to transmit the 1 kW output power COIL beam with low transmission loss of about 4.6 dB/km in 200 m distance⁸.

Figure 2 shows the schematic diagram of the main construction. This COIL system has some specific facilities for long time stable oscillation, such as the fuel recirculation system, pressure control system at the laser cavity, the iodine evaporator with the halogen lamp heater for coping with quickly to the laser power variation, and the water vapor trap of rotating disk type. In the fuel recirculation system, the composition and temperature of BHP are controlled automatically for stabilizing the excited oxygen generation. And the waste solution of after reaction is utilized to melt the ice which scraped off from the disk surfaces of the water vapor trap. This molten water is continuously discharged to outside the vacuum line by means of the ice discharge pump. Thus the operation could be continued stably for long time. The performance of this COIL system is over 1 kW

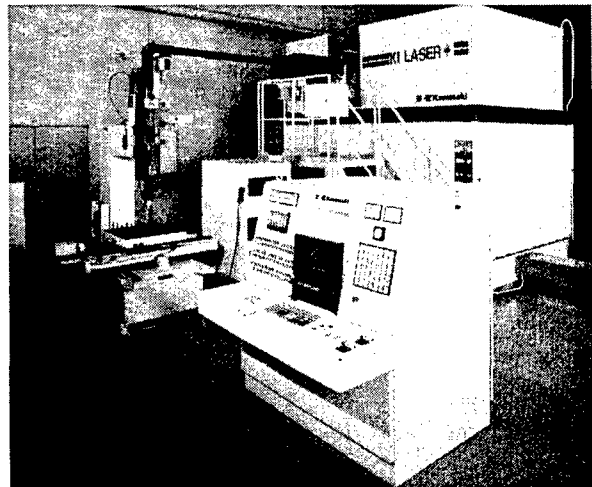


Fig. 1: 1 kW commercial COIL

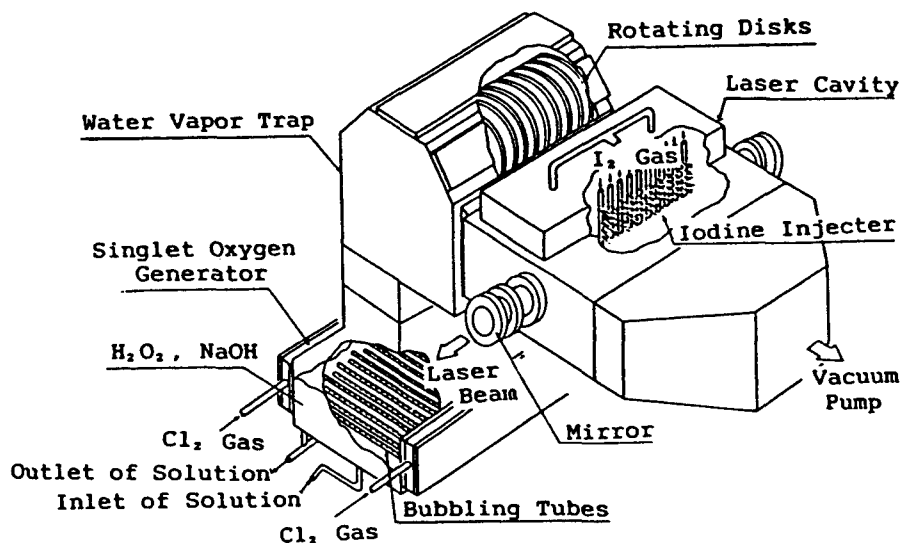


Fig. 2: The main construction of 1 kW commercial COIL

output power within ± 2 % power fluctuation with 30 % chemical efficiency. This system is in good running order to date.

3. DEVELOPMENT OF SUPERSONIC COIL DEVICE

In the early 1990's, kW class Nd:YAG laser had been brought to the market. The target range of COIL output power was gradually shifted to high-power to maintain its competitive edge by using the easy output power scalability of COIL's as leverage. In order to realize the high-power and compact industrial COIL, our study of COIL has shifted to the supersonic type. In 1994, 1 kW supersonic output power was attained as a result of several years research^{6,7}.

On the basis of this research, we have constructed the 5 kW class supersonic COIL, shown in Fig. 3, in 1995⁸. The major specifications of this 5 kW class COIL are summarized in Table 1. This system mainly consists of a jet-type singlet oxygen generator (J-SOG), a water vapor trap and others. The design specification was cleared, successfully, and it was used for quite a number of material processing tests. However, this system has a serious issue which is the short run length, because it is difficult to operate the water vapor trap continuously for a long stretch of time in the supersonic operation mode owing to the high gas pressure.

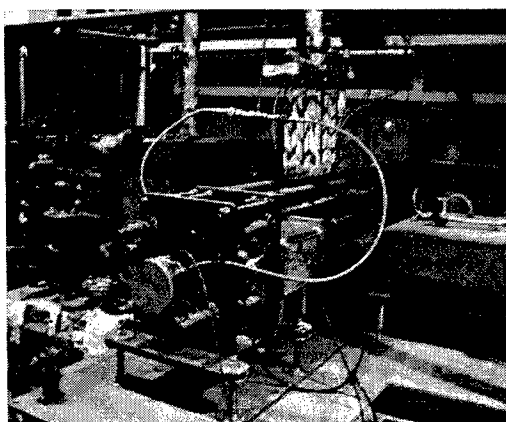


Fig. 3: 5 kW class supersonic COIL

The important factor in the industrialization of COIL is long term operation, not to mention cost. The long term operation is difficult for the former supersonic COIL, since there are two factors which are the water vapor trap and maintaining the BHP composition. We had solved these problems by further studies, and so the 10 kW class supersonic COIL had been completed in 1996^{9,10}. The main construction and the outside view of this 10 kW system are shown in Fig. 4 and 5, respectively. The major specifications of this system are summarized in Table 1.

This COIL mainly consists of a J-SOG, a supersonic cavity and a BHP circulation system. The schematic diagram of the main construction is shown in Fig. 6. In the J-SOG, singlet oxygen is generated by the chemical reaction between gaseous chlorine and BHP which is produced by mixing KOH with H_2O_2 . A mixture chlorine is introduced transversely to the BHP jet flow. The supersonic cavity is divided into three parts: iodine injectors, supersonic nozzles and a resonator. To obtain good mixing of the iodine with the primary flow of the mixture gas, the iodine is injected transversely and diagonally by the iodine injectors in the subsonic region just up stream of the supersonic nozzle throat.

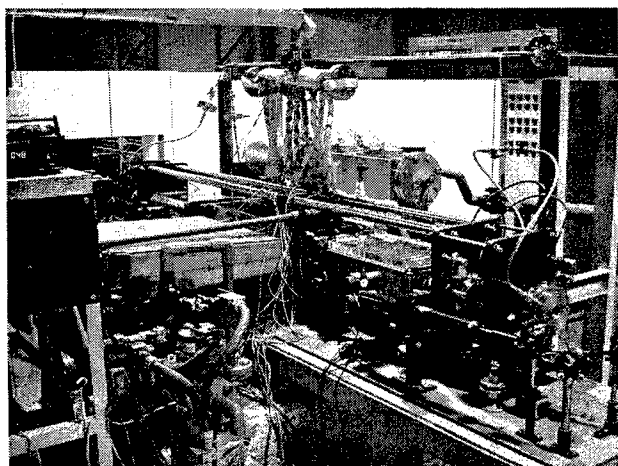


Fig. 4: The main construction of 10 kW COIL

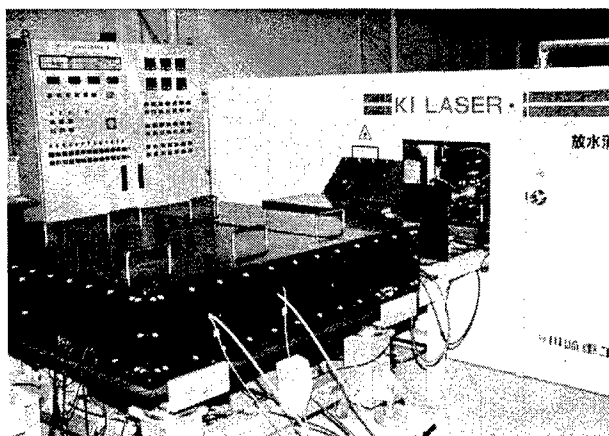


Fig. 5: The outside view of 10 kW COIL

Then the laser gas, which is composed of the mixture gas and the iodine, is expanded and accelerated to a laser gas velocity of about Mach 2 through the supersonic nozzle. The supersonic nozzle is made up of many small nozzles with vertical nozzle blades, and the area ratio of the nozzle throat to the nozzle exit plain is 1 to 2.3. To attain high efficiency and good beam quality, a Z-folded resonator configuration was adopted to this system, which makes maximum 3 paths through the gain region and the total cavity length was 5.2 m at that setting. The maximum gain length was 3.2 m per a round trip. The BHP circulation system is made up of a BHP circulation pump, a heat exchanger and a chiller. The heat generated by the chemical reaction between gaseous chlorine and BHP is continuously removed from the BHP solution and the BHP inlet temperature is maintained at 255 K to minimize the generation of water vapor, which promises long-term operation over 30 minutes.

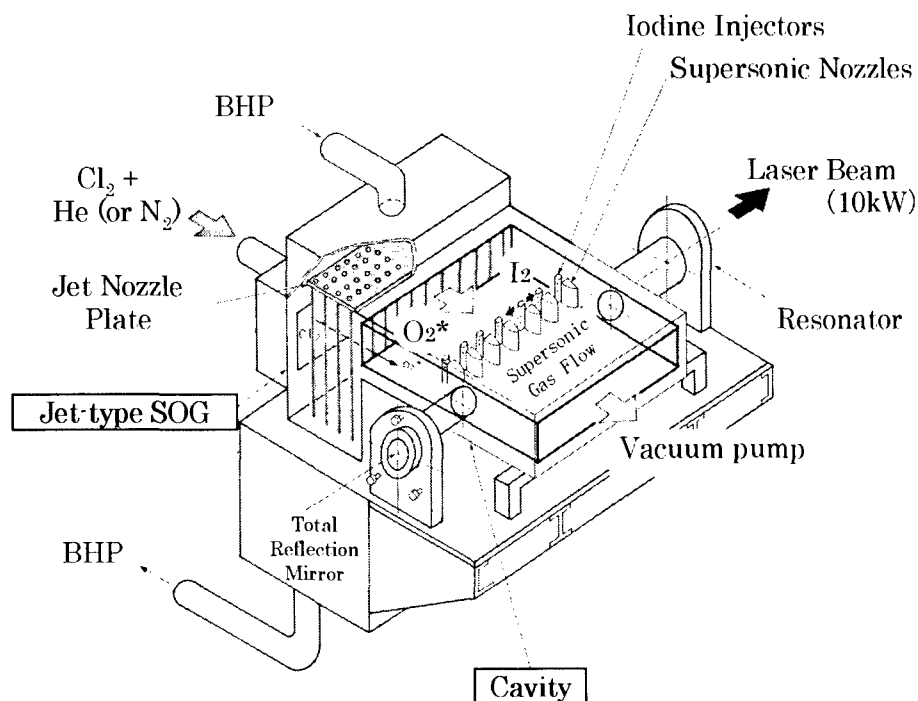


Fig. 6: Schematic diagram of the 10 kW COIL main construction

The experimental results with helium diluent gas about the dependence of the laser power on the mirror transmission are shown in Fig. 7. In the folded resonator configuration (2 paths), about 11 kW output was attained, and its beam shapes was 25 mm by 17 mm. The operation was conducted over a chlorine flow rate of 0.67 mol/s, a primary helium flow rate of 1.5 mol/s and a secondary helium flow rate of 0.75 mol/s. The upstream beam path in the gain medium was set in the distance of 30 mm from the supersonic nozzle outlet. The downstream beam path was set in the distance of 120 mm from the nozzle outlet. The typical measured values of the 10 kW COIL small signal gain are shown in Fig. 8. We made certain of the enough gain, 60 % of the upstream one, at the downstream side. This 10 kW COIL system can be also operated with nitrogen diluent gas instead of helium gas to curb the running cost because helium gas is very expensive, more than 5 times as expensive as nitrogen, in Japan. The output power of 5.3 kW was attained at a chlorine flow rate of 0.37 mol/s, a primary nitrogen flow rate of 0.97 mol/s and a secondary nitrogen flow rate of 0.57 mol/s. But the output

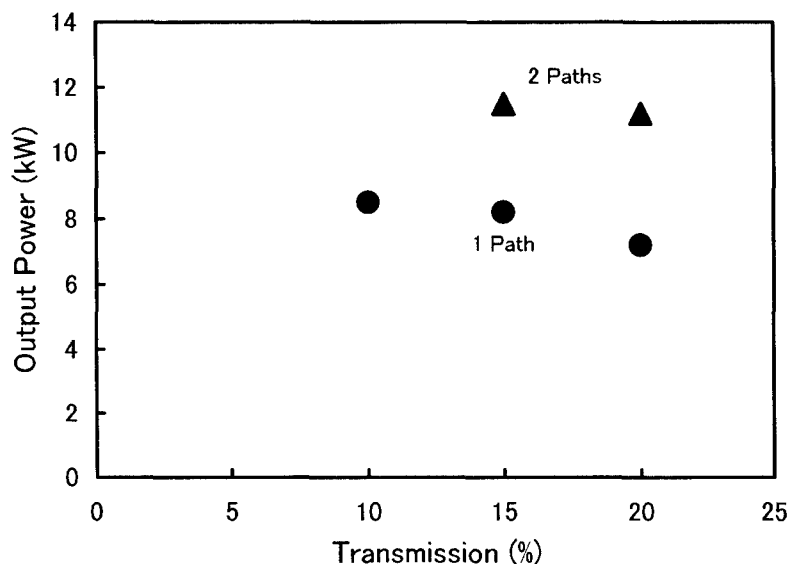


Fig. 7: Dependence of output power on mirror transmission

laser power with nitrogen diluent gas is limited to about a half of that with helium diluent to maintain the same total pressure with helium diluent gas in the J-SOG. By further studies, iodine injection technique etc., we obtained a maximum output power of 12 kW and a maximum chemical efficiency of 26 % at 3 paths configuration with helium diluent gas in 1999. This 10 kW system is operated 1-2 days a week for the laser processing at the present day.

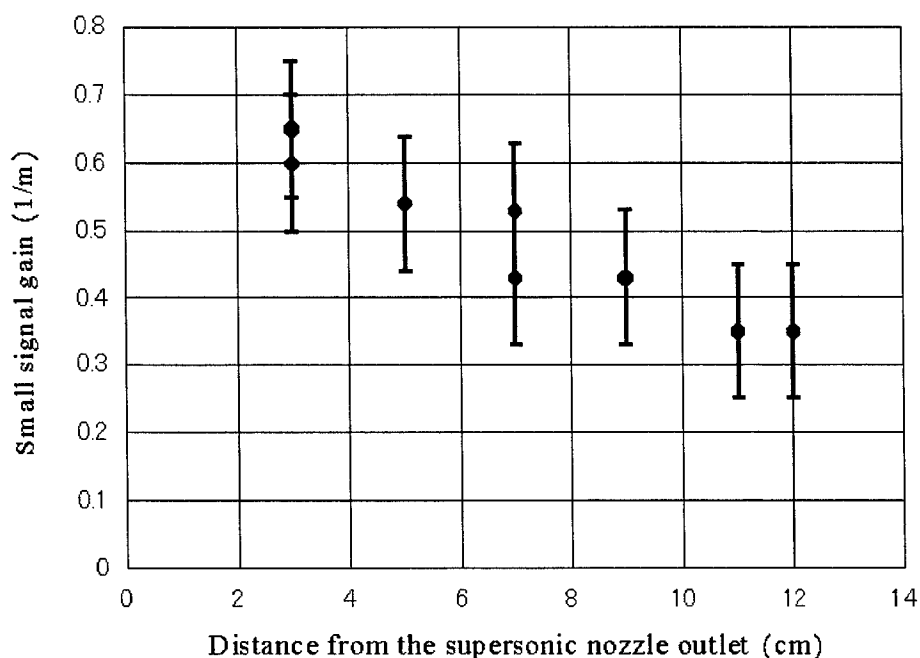


Fig. 8: Measured results of the 10 kW COIL small signal gain

Table 1: The major specifications of KHI's COILs

	1 kW (ALEC)	5 kW class	10 kW class
Operation mode	Subsonic	Supersonic	Supersonic
SOG type	Bubbler	Jet	Jet
Output power (kW)	1-2	-5	-12
Water vapor trap type	Rotating disk	Fin	Non
Chemical efficiency (%)	30	15	20-26
Cavity length (m)	2.2 (1 path)	5.1 (3 paths)	5.2 (3 paths)
Beam quality (mm*mrad)	86	60-80	60-80
Focused beam spot diameter at $1/e^2$ (μm)	280	300	220
Focal length of the focusing lens (mm)	77	84	82
Delivered fiber core diameter (mm)	0.3	0.6-0.8	0.6-0.8

4. STUDY OF COIL APPLICATIONS

The above-mentioned excellent COIL characteristics enable us to apply the laser processing to wide application fields. To examine the feasibility of the promising COIL application, we conducted various laser welding and cutting tests by using a fiber-transmitted high-power COIL beam. Especially, we conducted the study bent upon the laser remote dismantling system and the laser welding system for thick plates.

The COIL is of great advantage to application to the dismantling of the nuclear facilities, considering low transmission loss in radiation-proof optical silica fibers, high beam quality, high-power, and large energy absorption on the material surface. Figure 9 shows the concept of this COIL dismantling system. In dismantling of nuclear facilities, components of many different materials, shapes, dimensions or places need to be cut in the high radiation field so as to minimize secondary rad-wastes produced by cutting. Therefore, the cutting system for it is desired to be multipurpose, flexible, radiation-proof and easy in treatment. The laser cutting method can minimize the secondary rad-wastes because of a small beam size compared with other thermal cutting ones, and the treatment of the laser cutting devices is easy since the laser cutting head is smaller than the mechanical ones. The remote cutting system with a laser, especially COIL, transmitted through an optical silica fiber is promising for dismantling of activated in-vessel components and pressure vessels. Therefore, we conducted the empirical study of the remote laser dismantling system from 1994 to 2000^{13,14}. The laser cutting tests were conducted under the water because the operation has the matter of preventing radioactive contamination. This series of tests was carried out by use of the 1 kW subsonic commercial COIL, the 5 kW and 10 kW class supersonic COILs.

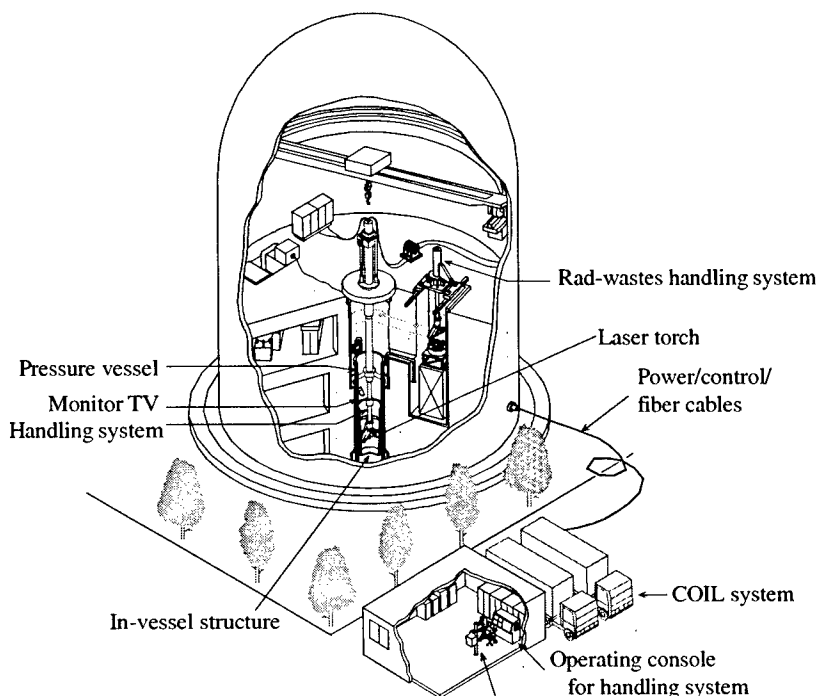


Fig. 9: Concept of remote dismantling system of nuclear reactor with COIL

We also conducted the laser welding study with COIL, energetically. Especially, the study of high-power laser welding has been accelerated under the Japanese national R&D project "Advanced Photon Processing and Measurement Technologies" since 1997. The aims of this project are to develop the technologies for generating high-power, high-quality lasers of high efficiency and low cost and also the advanced processing and measurement technologies which will use them. We secured a contract for the development of the advanced laser processing, namely, "Macroscopic processing technology", and had

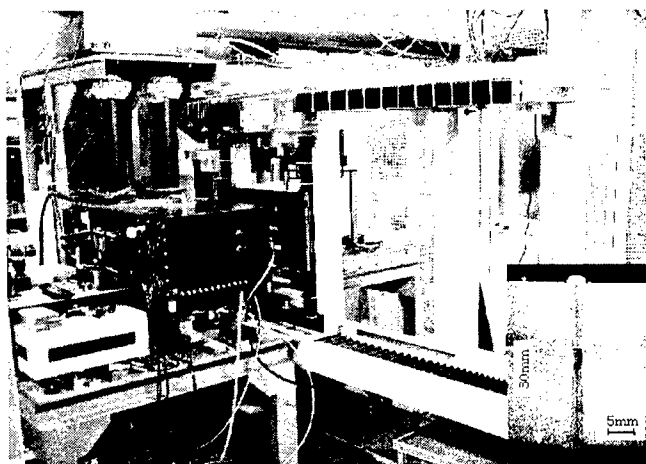


Fig. 10: Laser processing machine and welded sample of stainless steel

started the development of highly reliable laser welding technology. The goal of this contract is to establish the technology for laser welding of 30 mm thick steel plates and 20 mm thick aluminum alloy plates at a welding speed of higher than 1 m/min, providing high aspect ratio and equivalent or better strength than the base material. The laser processing machine and a cross section of the welded stainless steel are shown in Fig. 10. This study is carrying out with high-power lasers, 4 kW and 6 kW Nd:YAG lasers and the 10 kW class COIL, and many beneficial findings are obtained^{15,16,17}. The detail discussion of this study is yielded to another paper of ours¹⁸.

CONCLUSION

In this paper, we have reviewed our study of the industrial COIL from 1986 to date. As a result of long-standing study of the industrial COIL for the last 16 years, we have successfully completed the 10 kW COIL system. This system is used for the investigation of the various laser processing fields which are difficult to study by use of the conventional industrial lasers, and produces a lot of exciting results.

In the United States, the practical application of COIL is coming out true as the airborne laser (ABL). To realize a practical application in Japan, too, we will step up efforts toward the development of COIL. We hope that the brilliant features of COIL and the strenuous efforts of its researchers throughout the world will work out the broad application fields of it in the early 21st century.

ACKNOWLEDGMENTS

The development of highly reliable laser welding technology was partially conducted in the program "Advanced Photon Processing and Measurement Technologies" of the national Institute of Advanced Industrial Science and Technology, the Ministry of Economy, Trade and Industry, consigned to the R&D Institute for Photonics Engineering from the New Energy and Industrial Technology Development Organization (NEDO).

REFERENCES

1. W. E. McDermott, N. R. Pchelkin, D. J. Benard, and R. R. Bousek, "An electric transition chemical laser", *Appl. Phys. Lett.* **32**, pp. 469-470, 1978.
2. H. Yoshimoto, H. Yamakoshi, Y. Shibukawa, and T. Uchiyama, "A highly efficient, compact chemical oxygen-iodine laser", *J. Appl. Phys.* **59**, pp. 3965-3967, 1986.
3. H. Fujii, S. Yoshida, M. Iizuka, and T. Atsuta, "Development of high-power chemical oxygen-iodine laser for industrial application", *J. Appl. Phys.* **67**, pp. 3948-3953, 1990.
4. F. Wani, N. Naito, T. Nagai, M. Iizuka, H. Tsuji, and H. Fujii, "Development of 1 kW CW Iodine Laser for Industrial Use", *Proc. Laser Advanced Material Processing (LAMP'92)*, pp. 127-132, 1992.
5. H. Fujii, "COIL Development in Japan", *Proc. AIAA* **94-2419**, 1994.
6. N. Naito, F. Wani, T. Nagai, T. Nakabayashi, and H. Fujii, "High power COIL development", *Proc. CLEO/Pacific Rim'95*, pp. 160, 1995.
7. F. Wani, T. Nakabayashi, and H. Fujii, "High-pressure singlet oxygen production using a jet-type generator", *Proc. CLEO/Pacific Rim'95*, pp. 160, 1995.
8. T. Sakurai, K. Yasuda, T. Osaki, E. Tada, K. Koizumi, and M. Nakahira, "Study on material processing and fiber transmittance of COIL", *Proc. ICALEO 1996, Section E*, pp. 28-37, 1996.
9. F. Wani, N. Naito, T. Nagai, and H. Fujii, "Achievement of 10 kW oscillation of the industrial chemical oxygen iodine laser", *Proc. CLEO/Pacific Rim'97*, pp. 99, 1997.
10. N. Naito, F. Wani, T. Nagai, and H. Fujii, "Industrial COIL in Japan", *Proc. AIAA* **97-2392**, 1997.

11. S. Yoshida, M. Endo, T. Sawano, S. Amano, H. Fujii, and T. Fujioka, "Chemical oxygen iodine laser of extremely high efficiency", *J. Appl. Phys.* **65**, pp. 870-872, 1989.
12. H. Fujii, S. Yoshida, M. Iizuka, and T. Atsuta, "Long-term stability in the operation of chemical oxygen-iodine laser for industrial use", *J. Appl. Phys.* **66**, pp. 1033-1037, 1989.
13. K. Tsurumaki, H. Miyao, H. Tomioka, J. Adachi, K. Yasuda, H. Okado, A. Hayakawa, and S. Yoshizawa, "Development of remote dismantling of components in nuclear reactor with laser transmitted through optical fiber", *Proc. ICONE 5-2074*, 1997.
14. H. Okado, T. Sakurai, J. Adachi, H. Miyao, and K. Hara, "Underwater cutting of stainless steel with the laser transmitted through optical fiber", *Proc. SPIE 3887*, pp. 152-160, 2000.
15. T. Nakabayashi and M. Muro, "High power chemical oxygen-iodine laser welding", *Proc. SPIE 3887*, pp. 359-366, 2000.
16. T. Nakabayashi, F. Wani, H. Okado, A. Hayakawa, S. Suzuki, and K. Yasuda, "Laser welding characteristics with high power combining beam", *Proc. ICALEO 2001, Section A-302*, 2001.
17. H. Okado, T. Nakabayashi, F. Wani, A. Hayakawa, S. Suzuki, and K. Yasuda, "Beam operation for thick plate laser welding", *Proc. the 7th Int. Symp.*, pp. 491-496, 2001.
18. F. Wani, T. Nakabayashi, A. Hayakawa, S. Suzuki, and K. Kozo, "High-power COIL and YAG laser welding", *Proc. SPIE 4631*, 2002, to be published.