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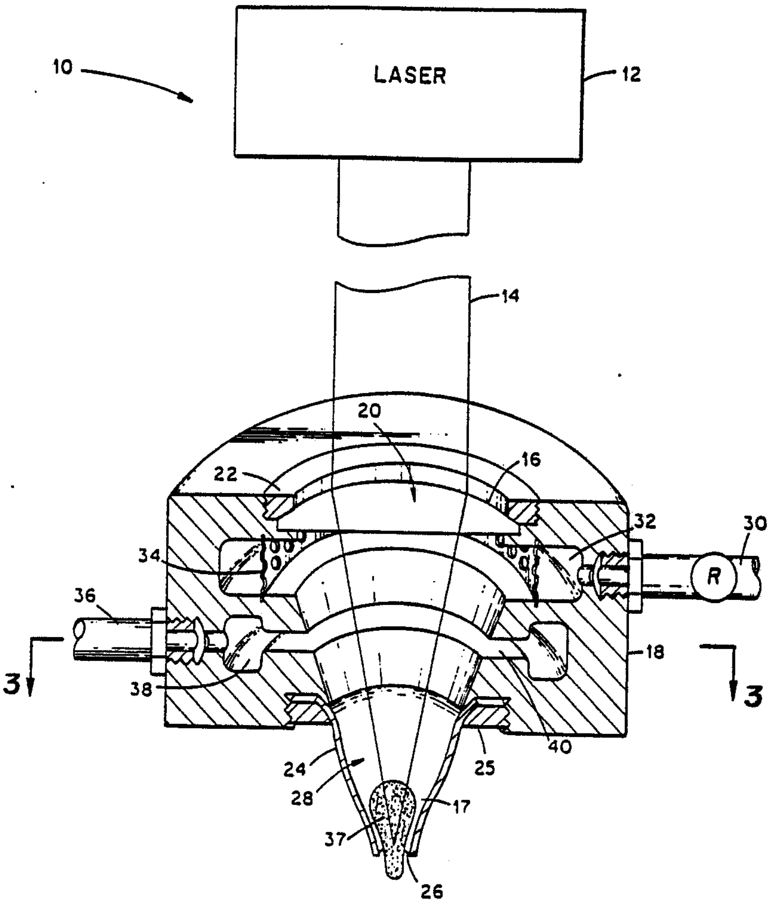
(54) Title: LASER SUSTAINED PLASMA TORCH AND METHOD FOR USING SAME

(57) Abstract

Apparatus (10) generating a laser sustained plasma torch includes a laser (12), producing laser radiation (14) which is focused to a focal region (17) at least partially within a plasma torch nozzle means (24). The plasma torch nozzle means (24) is supplied with pressurized gas and includes an outlet (26) so that a plasma (37) sustained by the focused laser radiation is at least partially confined within the plasma torch nozzle means (24). The plasma (37) produced by the torch is employed as a working medium in materials processing applications such as welding, drilling, cutting, flame spraying, heat treating, and surface alloying.



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LASER SUSTAINED PLASMA TORCH AND METHOD FOR USING SAME

Technical Field

The present invention relates to the use of high power lasers in industrial operations and more particularly relates to a laser sustained plasma torch and a method for employing the torch.

Background Art and Industrial Applicability

Lasers have attained a substantial commercial market for industrial material processing applications, particularly in the areas of cutting and drilling of metals and nonmetallic materials, welding of metals, heat treatment of metals, and for surface alloying of metals. For many of these applications, the carbon dioxide laser is the laser of choice because of its high power, high efficiency, and good reliability in the industrial environment. This laser operates at a wavelength of 10.6 micrometers in the far-infrared portion of the portion of the spectrum. At these long wavelengths, many materials of interest are highly reflective which results in poor energy coupling efficiency. This necessitates the use of lasers of larger size and power output, increasing considerably the cost of the laser systems and virtually precludes the use of these lasers for processing some commercially important materials such as copper and brass.

Additional problems arise in the use of lasers in the cutting, drilling and welding of metals due to the formation of plasma at the work point of the laser. Plasma in the path of the laser, being an efficient absorber of laser energy, blocks a substantial portion of the laser energy from directly impinging at the work point and energy absorbed by the plasma can be transferred to a larger area of the workpiece in an undesirable manner. It is generally necessary to employ complicated control systems tailored to a particular operation to control plasma formation so that the laser energy is properly applied to the workpiece.

Accordingly, a need has arisen for apparatus and a method for the more effective and versatile utilization of laser energy for industrial applications.

Disclosure of the Invention

In accordance with one form of the present invention, there is provided an apparatus for generating a laser sustained plasma torch. The apparatus includes a laser for producing laser radiation and a source of pressurized gas. A plasma torch nozzle includes an outlet and structure is provided to direct a flow of the gas received from the source toward the outlet. A lens focuses the laser radiation into the nozzle in a focal region at least partially within the nozzle and a plasma is sustained and at least partially confined within the nozzle by the flow of gas toward the outlet.

In accordance with one form of the method of the present invention, focused laser radiation is directed into a nozzle having an outlet with the focal region of the laser radiation being at least partially within the nozzle. Pressured gas is introduced into the nozzle to cause the gas to flow towards the outlet. Plasma is initiated within the nozzle and is sustained in the focal region of the laser radiation, and at least a portion of the plasma is confined with the nozzle by the flow of gas being caused to flow toward the outlet. The method further includes employing the plasma as a working medium in performing an operation.

Brief Description of the Drawings

The present invention may best be understood by reference to the following detailed description of a preferred embodiment when read in conjunction with the accompanying drawings in which:

FIGURE 1 is a somewhat diagrammatical perspective view partially in cross section of apparatus providing a laser sustained plasma torch embodying one form of the present invention;

FIGURE 2 is a partial cross-sectional view of the torch of FIGURE 1 shown cutting a steel plate; and

FIGURE 3 is a partial cross section of the torch taken through lines 3-3.

Best Mode of Carrying Out the Invention

Referring now to the drawings in which like reference characters designate like or corresponding parts, apparatus embodying one form of the present invention is illustrated in FIGURE 1. Apparatus 10 for producing a laser sustained plasma torch includes a laser 12 for transmitting a beam 14 of laser radiation to a focusing lens 16 which is preferably a plano-convex lens as illustrated although other focusing systems can also be employed. The laser 12 is any one of a wide variety of continuous wave lasers providing sufficient power when focused to sustain a plasma by inverse bremsstrahlung absorption of the laser beam. A suitable laser 12, for example, is a 1.5 KW carbon dioxide laser operating at a wavelength of 10.6 micrometers.

As shown in FIGURE 1, laser radiation is focused by the focusing lens 16 to a focal region 17, and the lens 16 is mounted in support housing 18 having a frustro-conical throat 20 which preferably tapers slightly from top to bottom as depicted. The lens 16 is sealingly secured by a recessed externally threaded ring 22 adjacent the upper end of the throat 20 and thus closes off the upper opening into the throat 20. The lower end of the throat 20 opens into a nozzle 24 which is preferably secured to the housing similarly to the focusing lens 16 by externally threaded ring 25. The nozzle 24 tapers from top to bottom in the orientation depicted and is provided with an outlet 26 at its lower end. It is necessary for the nozzle 24 to be resistant to the extremely high heat produced by a plasma. Preferably, the nozzle is fabricated from ceramic materials such as those produced by chemical vapor deposition or refractory metals such as tungsten or rhenium, but it will be understood that numerous nozzles of different materials and shapes are suitable for use in the torch depending on the particular application.

The focusing lens 16, housing 18, and nozzle 24 collectively define an enclosed area 28 into which the focused laser radiation is directed. The focusing lens 16, housing 18 and nozzle 24 are appropriately dimensioned and configured so that the focal region 17 of the laser radiation is at least partially within the enclosed area and preferably entirely within the volume defined by the nozzle 24.

Referring still to the FIGURE 1, it is shown that provision is made in the housing 18 for the introduction of pressurized gas into the enclosed area 28 to provide a flow towards the outlet 26 of the nozzle 24. The pressurized gas is introduced to provide a flow field and pressure coordinated with the configuration of the interior area and the size of the outlet 26 to at least partially confine and sustain a plasma in focal region 17 of the laser radiation within the nozzle 24. For the embodiment illustrated in FIGURE 1, pressurized gas is supplied from a source (not shown) to supply line and regulator 30 which supplies gas at a selected pressure to the housing 18. The housing 18 is provided with passageways for introducing the gas into the enclosed area 28. Preferably an annular discharge opening 32 is employed to discharge the gas with the annular discharge opening 32 being located coaxially with the axis of the beam 14 of laser radiation. Annular restriction structure 34 is advantageously employed to create a uniform higher pressure in the annular opening 32 upstream from the restriction structure 34 to assure uniform flow of gas into the enclosed area 28. Most preferably, the flow of gas is sufficient to create a sonic flow at the outlet 26 from the nozzle 24 when the apparatus 10 is in operation to isolate the plasma within the nozzle 24 from pressure disturbances generated by the proximity of a workpiece to the apparatus 10.

The gas introduced into the enclosed area 28 functions in cooperation with the laser beam 14 to sustain a plasma 37 in the focal region 17. When the plasma 37 is created within the nozzle 24 it will migrate away from the focal point of the laser beam 14 toward the laser 12 if it is not controlled. The flow of gas in cooperation with the configuration of the nozzle 24 stops the migration of the plasma and forces some of the plasma through the outlet 26 to form a torch or jet. Preferably, an inert gas such as argon or helium is employed which does not react chemically with the workpiece and from which a plasma is generated without extremely high laser energies.

As shown in the embodiment of FIGURE 1, a second supply line 36 is provided to introduce additional gas to further tailor the flow field within the enclosed area 28 and for providing secondary materials to be introduced into the enclosed area 28 with the additional gas if desired. Secondary materials to be introduced into the apparatus 10 are particulate or gaseous materials to be processed within the laser sustained plasma to produce a chemical or physical change in the material and may be collected from the torch after processing or deposited on a workpiece. As illustrated the supply line 36 connects to an annular opening 38 generally coaxial with the beam 14 of laser radiation and in a plane generally perpendicular to the beam 14. The annular opening 38 is provided with an annular restriction 40 which provides for even flow into the enclosed area 28. When secondary materials are to be introduced the configuration of the enclosed area 28 and the openings 32 and 38 are provided so that sufficient residence time within the plasma 37 for the secondary materials is achieved.

For some applications, it is desirable to impart a vortex or helical characteristic to the flow to achieve the desired residence time. As shown in the cross section of FIGURE 3 to achieve a helical gas flow, vanes 46 or similar structure may be employed in the annular restriction 40 to direct the gas in a helical flow path. Similarly, vanes, such as vanes 46, may be employed in the annular opening 32 to achieve desired gas flow characteristics.

In operation, a flow of gas is created through the enclosed area 28 to outlet 26 by supplying pressurized gas through supply line and regulator 30 and into the enclosed area 28 through discharge opening 32. A beam of laser radiation 14 is transmitted by laser 12 to the focusing lens 16 where it is focused into the focal region 17. To initiate plasma 37, it is necessary to create conditions within the nozzle which will begin plasma formation such as by placing a solid material in the focusing region 17 which is heated by the laser sufficiently to liberate electrons through thermionic emission. A suitable material is a tungsten rod inserted through nozzle 26. A plasma is sustained by inverse bremsstrahlung absorption of the laser beam and the pressure and gas flow field within the enclosed area 28 are operable to confine the plasma in the nozzle 24 adjacent the outlet 26.

If desired, gas flow is begun through the second supply line 36 and annular opening 38 to achieve the desired plasma characteristics or to introduce secondary materials to be processed into the enclosed area 28.

Since the plasma produced by apparatus 10 is confined and sustained within the enclosed area 28 by the gas flow, the plasma is not dependent on the proximity to a work surface and can be moved to any position or orientation without affecting the operation of the apparatus 10 or the characteristics of the plasma. In addition, in embodiments where sonic flow through the nozzle 24 is created, the confined plasma is essentially isolated from any pressure disturbances generated by the proximity of the outlet 26 of the nozzle 24 to a workpiece.

As illustrated in FIGURE 2, a small jet of plasma is ejected from the nozzle 24 and is impinging upon a steel plate 42 and forming a cut 44. The plasma 37, which is the working medium in the cutting operation, is formed in the focusing region by laser radiation and directed out of the nozzle 24. In the embodiment illustrated employing a carbon dioxide laser, the infrared laser radiation is converted to shorter wavelength thermal radiation in the plasma which couples much more effectively with most metals. Energy transfer is increased due to the ionized components at the plasma recombining on the surface of the workpiece. Furthermore, the apparatus 10 produces a high velocity, high temperature jet which can greatly aid in dross removal in laser cutting operations.

For other operations such as those involving the processing of secondary materials, the plasma within the enclosed area 28 is employed as the working medium and the nozzle 24 is appropriately configured to eject the materials as desired as the materials are processed within the apparatus or are applied to a workpiece.

While a preferred embodiment of the invention has been shown and described in the foregoing detailed description, there is no intent to limit the invention to this embodiment and it will be understood that the invention is capable of numerous modifications without departing from the spirit of the invention as set forth in the appended claims.

THE CLAIMS:

1. A laser sustained plasma torch comprising:

a laser for producing laser radiation;

a source of pressurized gas;

plasma torch nozzle means receiving gas from said source and directing a flow of said gas into an interior area of said nozzle means;

an outlet formed in said nozzle means adjacent to said interior area said flow of gas being directed toward said outlet;

focusing means for focusing laser radiation into said nozzle means to a focal region at least partially within said nozzle means; and

said laser radiation and gas flow in said focal region being operable to sustain a plasma at least partially confined within said interior area of said nozzle means by said flow of gas being directed toward said outlet.

2. The apparatus of Claim 1 wherein said focusing means focuses said radiation to a focal region entirely within said plasma torch nozzle means.

3. The apparatus of Claim 1 wherein said plasma torch nozzle means comprises a nozzle providing said outlet and having tapering interior walls generally coaxial with the focused laser radiation for directing a flow of gas toward the outlet to at least partially confine plasma within said nozzle.

4. The apparatus of Claim 3 wherein said nozzle is fabricated from a refractory material.

5. The apparatus of Claim 1 wherein said outlet is operable to direct a jet of plasma outwardly from said interior area.

6. The apparatus of Claim 1 further comprising means for introducing secondary materials into said interior area.

7. The apparatus of Claim 6 further comprising means for imparting a helical or vortex flow to said flow of

gas within said interior area to increase the residence time for said secondary materials within said interior area.

8. The apparatus of Claim 1 when said laser is a carbon dioxide laser.

9. In a process employing high power laser radiation and focusing means for focusing laser radiation to a focal region to perform an operation, the improvement comprising:

directing the laser radiation into an interior area of plasma torch nozzle means, said interior area having an outlet;

focusing the laser radiation in a focal region at least partially within said plasma torch nozzle means;

introducing pressurized gas into said interior area of said plasma torch nozzle means and causing said gas to flow toward said outlet;

initiating a plasma within said confinement means;

sustaining said plasma at the focal region of said laser radiation and at least partially confining said plasma within said plasma torch nozzle means by said flow of gas being caused to flow toward said outlet; and

employing said plasma as a working medium in performing the operation.

10. The method of Claim 9 further comprising:

directing a jet of said plasma out of said outlet toward a workpiece and employing said jet in performing the operation on the workpiece.

11. The method of Claim 9 further comprising introducing secondary materials into said flow of said gas and employing said plasma to process said materials.

12. The method of Claim 11 further comprising, after processing in said plasma, directing said secondary materials toward a workpiece.

13. The method of Claim 11 further comprising directing said gas to flow in a helical or vortex flow to increase the residence time of the secondary materials within said plasma.

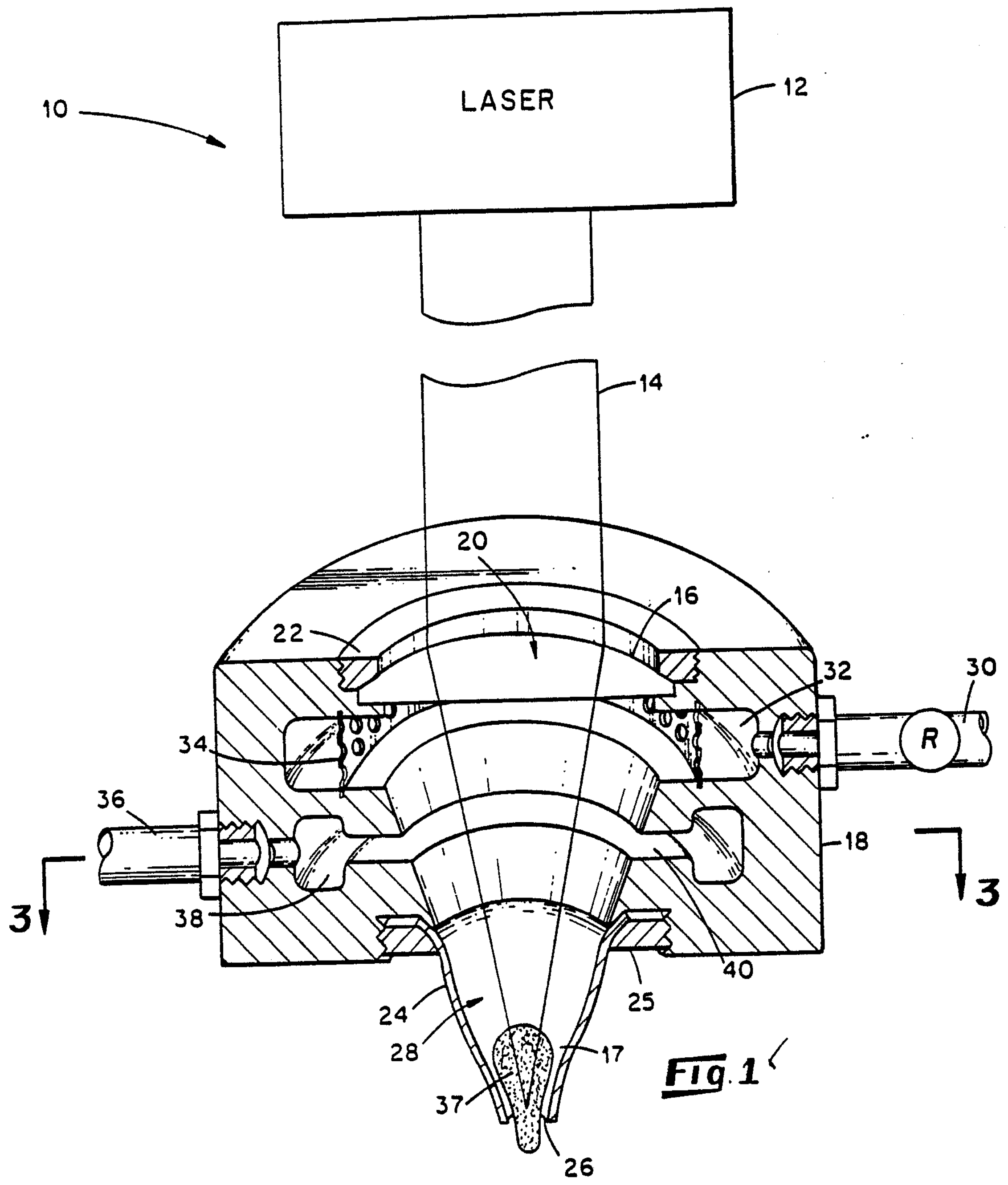
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Fig. 1

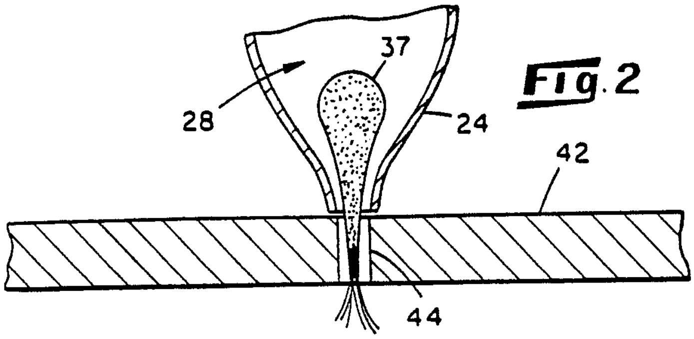
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Fig. 2

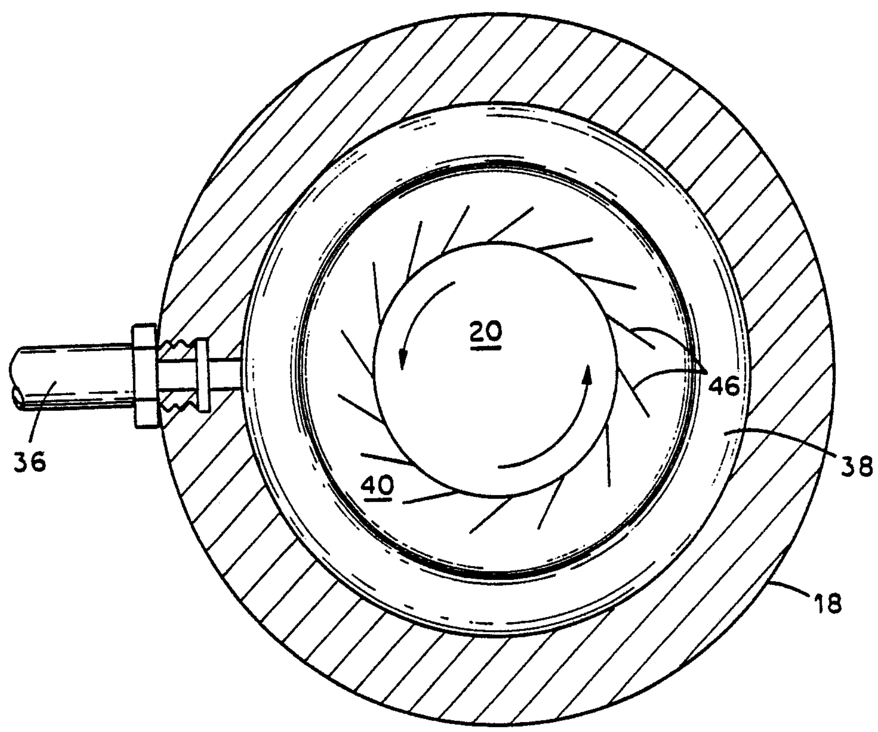

Fig. 3

INTERNATIONAL SEARCH REPORT

International Application No PCT/US87/01504

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [3]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC: 4 B23K 9/00

U.S. CL. 148/9R; 266/48

II. FIELDS SEARCHED

Minimum Documentation Searched [4]

Classification System	Classification Symbols
U.S.	266/48 219/121L, 121LM; 148/9R

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [5]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [14]

Category *	Citation of Document, [16] with indication, where appropriate, of the relevant passages [17]	Relevant to Claim No. [18]
X	U.S. A, 4,036,012, (Monsler), 19 July 1977 See the entire document	1-3,5,6,8-12
X	AIAA-85-1552 D.Keefer, R.Welle, C. Peters, "Power Absorbtion Processes In Laser-Sustained Argon Plasmas" AIAA 18th Fluid Dynamics & Plasmadynamics & Laser Conference 16-18 July 1985 See pages 1-3	1-6,8-12
X	AIAA-85-1077 R.Welle, D.Keefer, C. Peters "Energy Conversion Efficiency In High Flow Laser-Sustained Argon Plasmas" AIAA/ASME 4th Fluid Mechanics, Plasma Dynamics And Lasers Conference 12-14 May 1986 See pages 1 and 2 and figure 1	1-6,8-12
Y	U.S. A, 4,179,599, (Conrad), 18 December 1979, See columns 2 and 3 and the figure	7,13

* Special categories of cited documents: [15]

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search [2]	Date of Mailing of this International Search Report [2]
20 August 1987	01 SEP 1987
International Searching Authority [1]	**Signature of Authorized Officer [20]**
ISA/US	Scott Kastler

International Application No. PCT/US87/01504

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)

Category *	Citation of Document, [16] with indication, where appropriate, of the relevant passages [17]	Relevant to Claim No [18]
Y	U.S. A, 3,463,601, (Childree), 26 August 1969 See figures 1, 3 and column 3, lines 1-11	7,13

Form PCT/ISA/210 (extra sheet) (October 1981)