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(84) **Designated States** *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

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(54) **Title**: SYSTEMS AND METHODS FOR PREVENTING LASER BACK-WALL DAMAGE

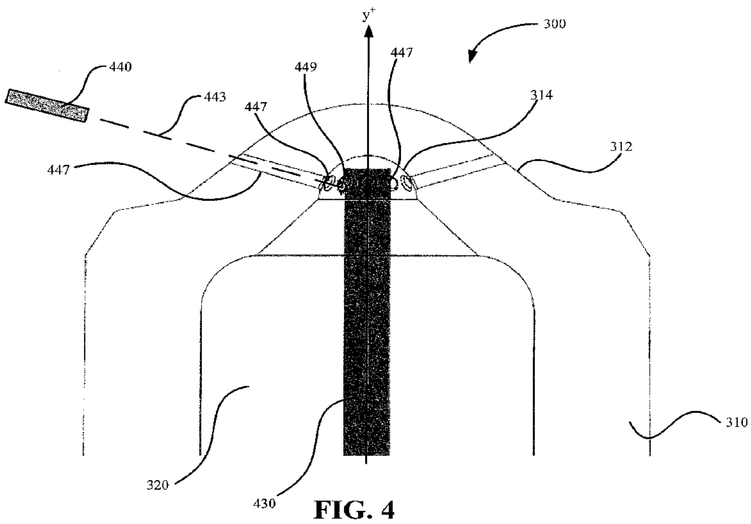

FIG. 4

(57) **Abstract**: Methods comprising providing an article comprising a first wall between an inner diameter and an outer diameter, wherein the article is structured to receive a mandrel within the inner diameter, inserting the mandrel into the article, and cutting a hole in the first wall with a laser until the laser passes through the first wall are disclosed. Systems comprising a laser structured drill a hole in an article having a cavity and a mandrel structured to be inserted into the cavity of the article are also disclosed.

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SYSTEMS AND METHODS FOR PREVENTING LASER BACK-WALL DAMAGE

FIELD OF THE DISCLOSURE

[0001] This disclosure relates to methods and systems of laser-drilling articles. More specifically, this disclosure relates to methods and systems of laser-drilling small articles, such as a hole in a fuel injector, while preventing back-wall damage to the article.

BACKGROUND

[0002] Injector nozzles, such as those in diesel engines, are often placed under high amounts of pressure to atomize the gas to be injected into a cylinder of an engine. Due to performance and emission requirements, especially on diesel engines, the fuel pressure has increased steadily over the last several decades.

[0003] Some diesel emission and performance requirements require small fuel injection holes or orifices from about 100 μm to about 400 μm to create the high pressure levels. However, at such pressures, many engine manufacturers use electrical discharge machining (EDM) methods.

[0004] Conventional EDM methods for nozzle holes often can leave a rough surface finish which requires a follow up step of abrasive flow machining to smooth the interior hole surface. Other laser drilling methods, such as methods with high power and long pulse lasers can produce poor quality holes, which makes conventional long pulse laser drilling methods unattractive for drilling holes in nozzles.

[0005] Short pulse lasers however, have been found to have the ability to make sufficiently smooth nozzle holes. Although short laser technology is sufficient to create the desired smooth hole, back-wall damage can often occur. As used herein, the term "back-wall damage" can be understood to include damage that occurs when the laser passes through one wall of an article, passes through an internal cavity, and strikes the internal wall opposite the hole. Thus, even though short pulses, such as pulses lasting only a femtosecond, are used, back-wall damage can occur.

[0006] In many instances, back-wall damage can adversely affect the article, such as a fuel injection nozzle. For example, damage to the internal cavity of a fuel injector can adversely affect the fuel injector performance and, thus, engine performance.

[0007] Accordingly, improved laser-drilling techniques are needed to permit cost efficient production of articles of manufacture, such as fuel injector nozzles, with minimal back-wall damage.

SUMMARY

[0008] In some embodiments, methods may include providing an article comprising a first wall between an inner diameter and an outer diameter, wherein the article is structured to receive a mandrel within the inner diameter, inserting the mandrel into the article, and cutting a hole in the first wall with a laser until the laser passes through the first wall, wherein energy from the laser that passes through the hole is absorbed by the mandrel.

[0009] In some embodiments, laser cutting systems may including a laser structured to drill a hole in an article having a cavity, and a mandrel structured to be inserted into the cavity of the article and absorb energy from the laser that passes through the hole.

[0010] Also provided are laser cutting systems including means for laser-drilling a hole in a fuel injector nozzle having a cavity, a mandrel configured to absorb energy from the means for laser-drilling that passes through the hole and means for inserting the mandrel into the cavity of the fuel injector nozzle.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] The above mentioned and other features and objects of this disclosure, and the manner of attaining them, will become more apparent and the disclosure itself will be better understood by reference to the following description of exemplary embodiments of the disclosure taken in conjunction with the accompanying drawings, wherein:

[0012] FIG. 1 illustrates a method of laser-drilling with a mandrel according to various embodiments;

[0013] FIG. 2 illustrates exemplary back-wall damage that occurs with conventional laser-drilling techniques;

[0014] FIG. 3 is a cross-sectional view of a fuel injection nozzle prior to drilling;

[0015] FIG. 4 is a cross-sectional view of a system for laser-drilling a fuel injection nozzle according to various embodiments;

[0016] FIG. 5 is a cross-sectional x-ray scan of a fuel injection nozzle with orifices laser-drilled according to various methods disclosed herein;

[0017] FIG. 6A and 6B illustrate damage to a mandrel after performing a laser-drilling according to an exemplary embodiment; and

[0018] FIG. 7 is a box-plot comparison of the roughness of orifices drilled with a conventional electrostatic discharge machining (EDM) and a laser method according to an exemplary embodiment.

[0019] Corresponding reference characters indicate corresponding parts throughout the several views. Although the drawings represent embodiments of the present disclosure, the drawings are not necessarily to scale and certain features may be exaggerated in order to better illustrate and explain the present disclosure. The exemplification set out herein illustrates exemplary embodiments of the disclosure, in various forms, and such exemplifications are not to be construed as limiting the scope of the disclosure in any manner.

DETAILED DESCRIPTION

[0020] The embodiments disclosed below are not intended to be exhaustive or limit the disclosure to the precise form disclosed in the following detailed description. Rather, the embodiments are chosen and described so that others skilled in the art may utilize their teachings.

[0021] As used herein, the modifier "about" used in connection with a quantity is inclusive of the stated value and has the meaning dictated by the context (for example, it includes at least the degree of error associated with the measurement of the particular quantity). When used in the context of a range, the modifier "about" should also be considered as disclosing the range defined by the absolute values of the two endpoints. For example, the range "from about 2 to about 4" also discloses the range "from 2 to 4."

[0022] FIG. 1 illustrates a method for laser-drilling an article according to various embodiments. Method 100 may comprise providing an article comprising a first wall between an inner diameter and an outer diameter (step 110). In various embodiments, the article may be structured to receive a mandrel within the inner diameter. Method 100 may also comprise inserting a mandrel into the article (step 120) and cutting a hole in the first wall with a laser until the laser passes through the first wall (step 130).

[0023] Step 120 may include inserting the mandrel into the article to form an eccentricity between the article and the mandrel. Exemplary eccentricity ranges include ranges between about 1 μm and about 500 μm, between about 10 μm and about 400 μm, and between about 50 μm and 200 μm.

[0024] In some embodiments, the mandrel may be kept stationary during the cutting process (step 130). In other embodiments, the mandrel may be spun before, during, and/or after the laser cutting process (step 130). Without being limited to any theory, it is believed that spinning the mandrel may improve the life of the mandrel and, thus reduce costs. Exemplary rotational speeds include speed greater than 5 revolutions per minute (rpm), speeds greater than 5,000 rpm, or greater than 20,000 rpm, or about 32,000 rpm.

[0025] In various embodiments, the mandrel may comprise at least one of tungsten, rhenium, tantalum, molybdenum, niobium, tantalum, alloys thereof, and mixtures thereof. For example, in some embodiments, the mandrel may include tungsten or a tungsten alloy. Alternatively, in other embodiments, the mandrel may comprise tantalum hafnium carbide.

[0026] In various embodiments, method 100 may comprise adding a flushing fluid to the article. The flushing fluid is not particularly limited and may either be a gas, vapor, or liquid. For example, in some embodiments, the flushing fluid may be a gas that comprises helium, argon, neon, xenon, krypton, radon, or mixtures thereof. Similarly, in various embodiments, the flushing gas may comprise nitrogen, oxygen, or air. Exemplary flushing liquids include various liquids, such as water.

[0027] Without being limited to any theory, it is believed that the addition of a flushing fluid may help to remove debris during the laser-drilling process and/or may help control the temperature of the article and/or mandrel.

[0028] FIG. 2 illustrates an x-ray image of a laser drilled fuel injector nozzle 200 using conventional methods. As can be seen in Fig. 2, fuel injector nozzle 200 suffered back-wall damage 220 opposite laser-drilled orifice 210.

[0029] FIG. 3 illustrates an exemplary fuel injector 30 prior to drilling. Fuel injector 30 may comprise fuel injector nozzle 300. In various embodiments fuel injector nozzle 300 may comprise nozzle wall 310, which may surround a cavity of the nozzle (nozzle needle bore 320).

[0030] FIG. 4 illustrates a cross-sectional view of a system for laser-drilling a fuel injection nozzle according to various embodiments. As shown in FIG. 4, the laser cutting system may comprise laser 440 structured to drill a hole in an article (exemplified with fuel injector nozzle 300) having a cavity (nozzle needle bore 320). In various embodiments, the laser cutting system may comprise mandrel 430 structured to be inserted into the cavity of the article (nozzle needle bore 320).

[0031] As exemplified in FIG. 4, the creation of injection bores 447 with laser 440 may be accomplished by radiating laser beam 443 from laser 440. Laser 440 is not particularly limited and may include any known laser capable of drilling an orifice in the article. Exemplary lasers, include fast-pulse lasers, such as Monaco and Rapid FX, produced by Coherent®. The radiating of laser beam 443 may continue until the laser cuts or drills an orifice or hole through nozzle wall 310 (through outer nozzle wall surface 312 and inner nozzle wall surface 314) until the laser beam 443 strikes mandrel 430 at 449.

[0032] Exemplary articles may include, for example, fuel injectors, such as fuel injectors for diesel engines. The fuel injectors are not particularly limited and may include hemispherical sac fuel injectors, spherical sac fuel injectors, conical sac fuel injectors, or a valve covered orifice (VCO) fuel injectors.

[0033] As described above, the mandrel is not particularly limited and may form eccentricity with the article. Exemplary eccentricity ranges include ranges between about 1 μm and about 500 μm, between about 10 μm and about 400 μm, and between about 50 μm and 200 μm.

[0034] Also, the mandrel may comprise any suitable material, such as various metals or alloys. Exemplary materials include tungsten, rhenium, tantalum, molybdenum, niobium, tantalum, alloys thereof, and mixtures thereof.

[0035] In some embodiments, the mandrel may be configured to spin before, during, and/or after the laser cutting process, for example around the y-axis. Exemplary rotational speeds include speed greater than 5 revolutions per minute (rpm), speeds greater than 5,000 rpm, or greater than 20,000 rpm, or about 32,000 rpm.

[0036] In some embodiments, the system may comprise a fluid sprayer (not shown) configured to impart a flushing fluid into the cavity of the article. The flushing fluid is not particularly limited and may either be a gas, vapor, or liquid. For example, in some embodiments, the flushing fluid may be a gas that comprises helium, argon, neon, xenon, krypton, radon, or mixtures thereof. Similarly, in various embodiments, the flushing gas comprises nitrogen, oxygen, or air. Exemplary flushing liquids include liquids such as water.

[0037] As shown in FIG. 5, systems and methods using a mandrel when drilling with a laser may help prevent laser back-wall damage to the articles being processes. FIG. 5 illustrates a cross-sectional view of an x-ray scan of fuel injector nozzle 300 with injection bores 447 according to various embodiments. As can be seen in FIG. 5, inner nozzle wall surface 314 was not damaged during the laser cutting of injection bores 447.

[0038] Accordingly, it has been found that mandrel 430 may be able to absorb energy from laser beam 443 that passes through nozzle wall 310. FIGs. 6A and 6B are photos showing the effects of laser beam 443 on mandrel 430. FIG. 6A a shows an axial perspective view, while FIG. 6B shows another axial perspective view of mandrel 430 that is perpendicular to the view shown in FIG. 6A. As can be seen in photos 6A and 6B, the laser beam 443 did not pass through mandrel 430 and, thus, did not create any laser back-wall damage.

[0039] FIG. 7 illustrates a box plot showing the roughness of the injection bores created by EDM and laser-drilling. As can be seen in FIG. 7, the roughness parameter (R_a) is significantly less for laser-drilling techniques than for EDM.

[0040] Also disclosed herein are laser cutting systems comprising means for laser-drilling a hole in an article having a cavity, a mandrel, and means for inserting the mandrel into the cavity of the article. The laser cutting system may also comprise means for rotating the mandrel, such as a lathe, drill, or article capable of holding and rotating the mandrel.

[0041] While this disclosure has been described as having an exemplary design, the present disclosure may be further modified within the spirit and scope of this disclosure. This application is therefore intended to cover any variations, uses, or adaptations of the disclosure using its general principles. Further, this application is intended to cover such departures from the present disclosure as come within known or customary practice in the art to which this disclosure pertains.

[0042] Furthermore, the connecting lines shown in the various figures contained herein are intended to represent exemplary functional relationships and/or physical couplings between the various elements. It should be noted that many alternative or additional functional relationships or physical connections may be present in a practical system. However, the benefits, advantages, solutions to problems, and any elements that may cause any benefit, advantage, or solution to occur or become more pronounced are not to be construed as critical, required, or essential features or elements. The scope is accordingly to be limited by nothing other than the appended claims, in which reference to an element in the singular is not intended to mean “one and only one” unless explicitly so stated, but rather “one or more.” Moreover, where a phrase similar to “at least one of A, B, or C” is used in the claims, it is intended that the phrase be interpreted to mean that A alone may be present in an embodiment, B alone may be present in an embodiment, C alone may be present in an embodiment, or that any combination of the elements A, B or C may be present in a single embodiment; for example, A and B, A and C, B and C, or A and B and C.

[0043] In the detailed description herein, references to “one embodiment,” “an embodiment,” “an example embodiment,” etc., indicate that the embodiment described may include a particular feature, structure, or characteristic, but every embodiment may not necessarily include the particular feature, structure, or characteristic. Moreover, such phrases are not necessarily referring to the same embodiment. Further, when a particular feature, structure, or characteristic is described in connection with an embodiment, it is submitted that it is within the knowledge of one skilled in the art with the benefit of the present disclosure to affect such feature, structure, or characteristic in connection with other embodiments whether or not explicitly described. After reading the description, it will be apparent to one skilled in the relevant art(s) how to implement the disclosure in alternative embodiments.

[0044] Furthermore, no element, component, or method step in the present disclosure is intended to be dedicated to the public regardless of whether the element, component, or method step is explicitly recited in the claims. No claim element herein is to be construed under the provisions of 35 U.S.C. § 112(f), unless the element is expressly recited using the phrase "means for." As used herein, the terms "comprises," "comprising," or any other variation thereof, are intended to cover a non-exclusive inclusion, such that a process, method, article, or apparatus that comprises a list of elements does not include only those elements but may include other elements not expressly listed or inherent to such process, method, article, or apparatus.

WHAT IS CLAIMED IS:

1. A method comprising:

providing an article comprising a first wall between an inner diameter and an outer diameter, wherein the article is structured to receive a mandrel within the inner diameter;

inserting the mandrel into the article; and

cutting a hole in the first wall with a laser until the laser passes through the first wall, wherein energy from the laser that passes through the hole is absorbed by the mandrel.

2. The method of claim 1, wherein the mandrel is inserted into the article forming an eccentricity between 1 μm and 500 μm.

3. The method of claim 1, further comprising spinning the mandrel.

4. The method of claim 1, wherein the mandrel comprises at least one of tungsten, rhenium, tantalum, molybdenum, niobium, tantalum, alloys thereof, and mixtures thereof.

5. The method of claim 4, wherein the mandrel comprises tungsten or a tungsten alloy.

6. The method of claim 4, wherein the mandrel comprises tantalum hafnium carbide.

7. The method of claim 2, wherein the mandrel is spun at a speed greater than 5 revolutions per minute.

8. The method of claim 1, further comprising adding a flushing fluid to the article.

9. The method of claim 8, wherein the flushing fluid is a gas that comprises helium, argon, neon, xenon, krypton, radon, or mixtures thereof.

10. The method of claim 8, wherein the flushing fluid is a gas that comprises nitrogen, oxygen, or air.

11. The method of claim 8, wherein the flushing fluid is a liquid.

12. The method of claim 1, wherein the article is a fuel injector nozzle.

13. The method of claim 12, wherein the fuel injector is selected from the group consisting of a hemispherical sac fuel injector, a spherical sac fuel injector, a conical sac fuel injector, or a valve covered orifice (VCO) fuel injector.

14. The method of claim 12, wherein the fuel injector nozzle is a diesel engine fuel injector nozzle.

15. A laser cutting system comprising:

a laser structured to drill a hole in an article having a cavity; and

a mandrel structured to be inserted into the cavity of the article and absorb energy from the laser that passes through the hole.

16. The laser cutting system of claim 15, wherein the mandrel is configured to form an eccentricity of 1 μm to 500 μm with the article.

17. The laser cutting system of claim 15, wherein the mandrel comprises at least one of tungsten, rhenium, tantalum, molybdenum, niobium, tantalum, alloys thereof, and mixtures thereof.

18. The laser cutting system of claim 15, wherein the mandrel is configured to spin.

19. The laser cutting system of claim 15, further comprising a fluid sprayer configured to impart a flushing fluid into the cavity of the article.

20. The laser cutting system of claim 19, wherein the flushing fluid is a gas that comprises helium, argon, neon, xenon, krypton, radon, or mixtures thereof.

21. A laser cutting system comprising:

means for laser-drilling a hole in a fuel injector nozzle having a cavity;

a mandrel configured to absorb energy from the means for laser-drilling that passes through the hole; and means for inserting the mandrel into the cavity of the fuel injector nozzle.

22. The laser cutting system of claim 21, further comprising means for rotating the mandrel.

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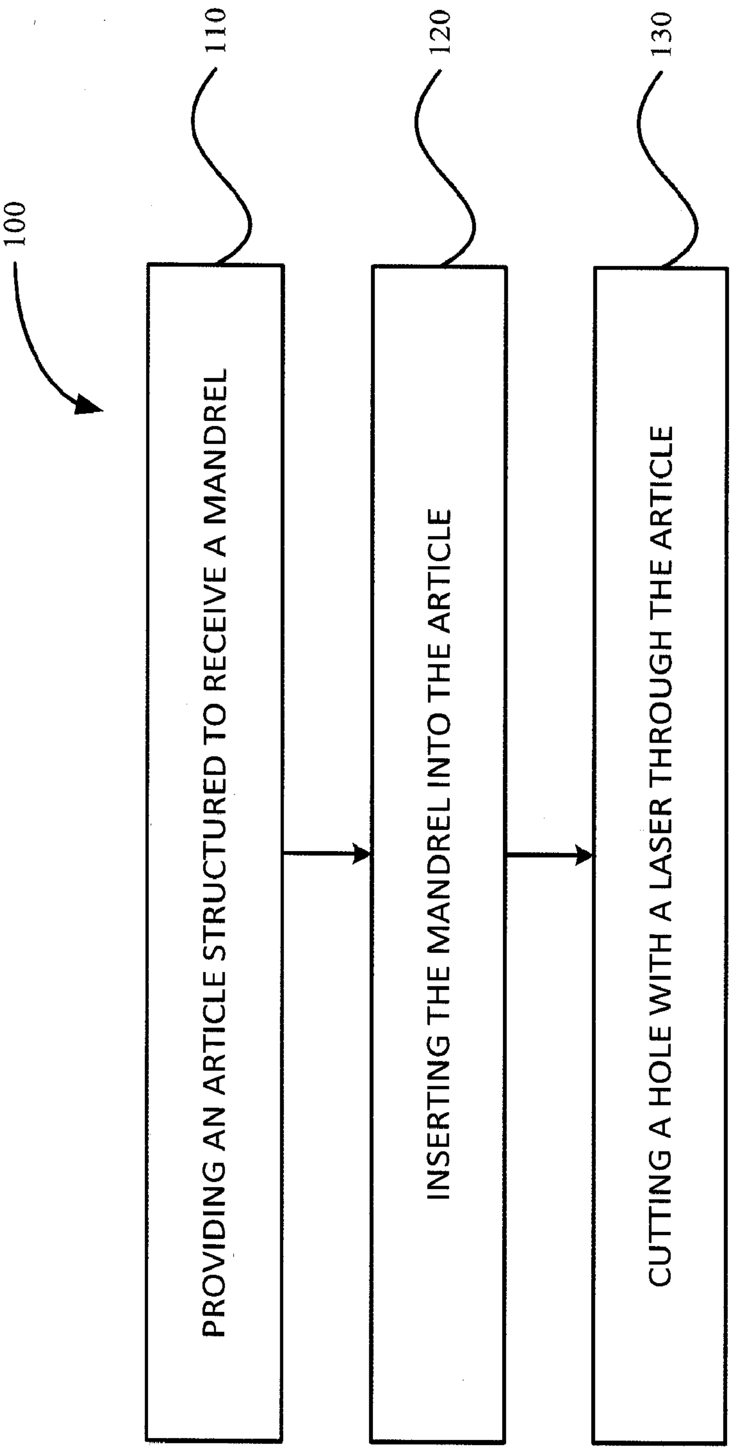
100
110
120
130
PROVIDING AN ARTICLE STRUCTURED TO RECEIVE A MANDREL
INSERTING THE MANDREL INTO THE ARTICLE
CUTTING A HOLE WITH A LASER THROUGH THE ARTICLE

FIG. 1

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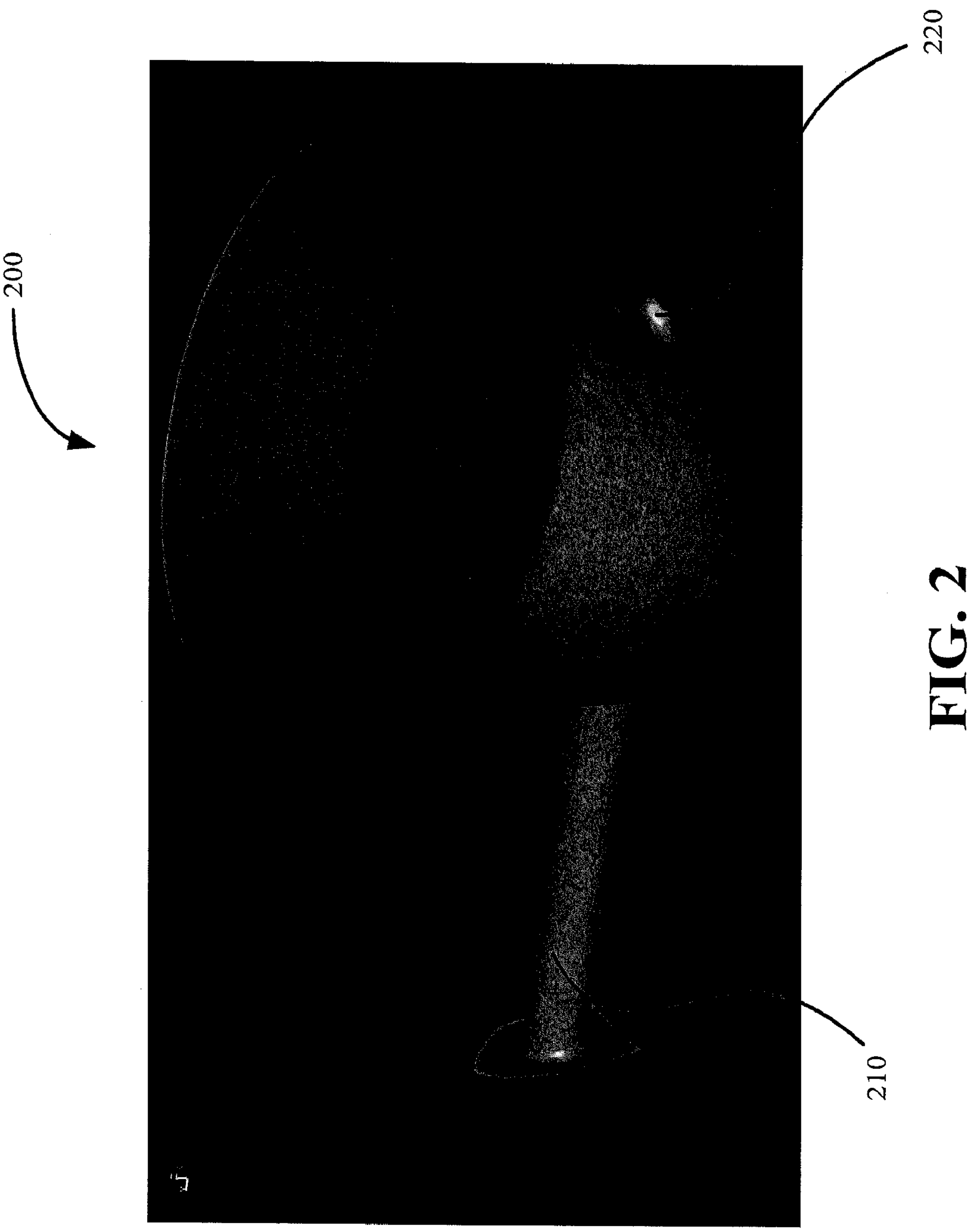

FIG. 2
(PRIOR ART)

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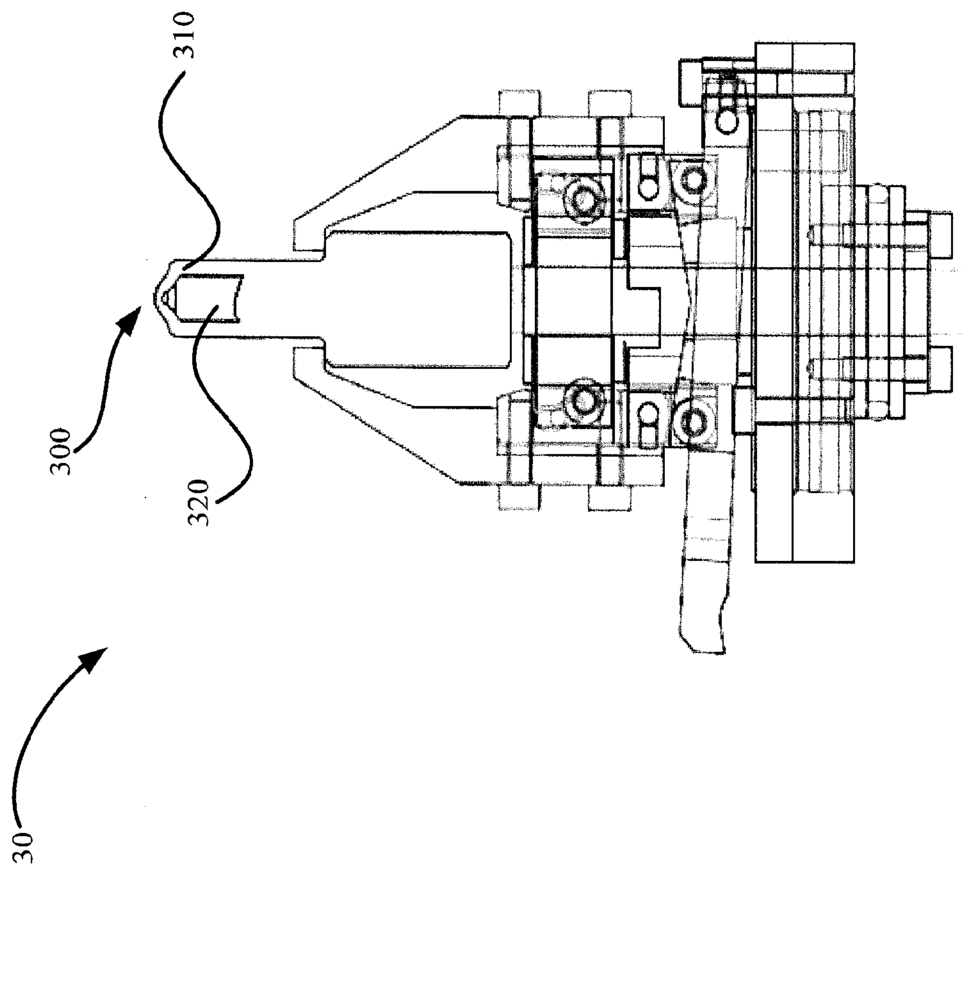

FIG. 3

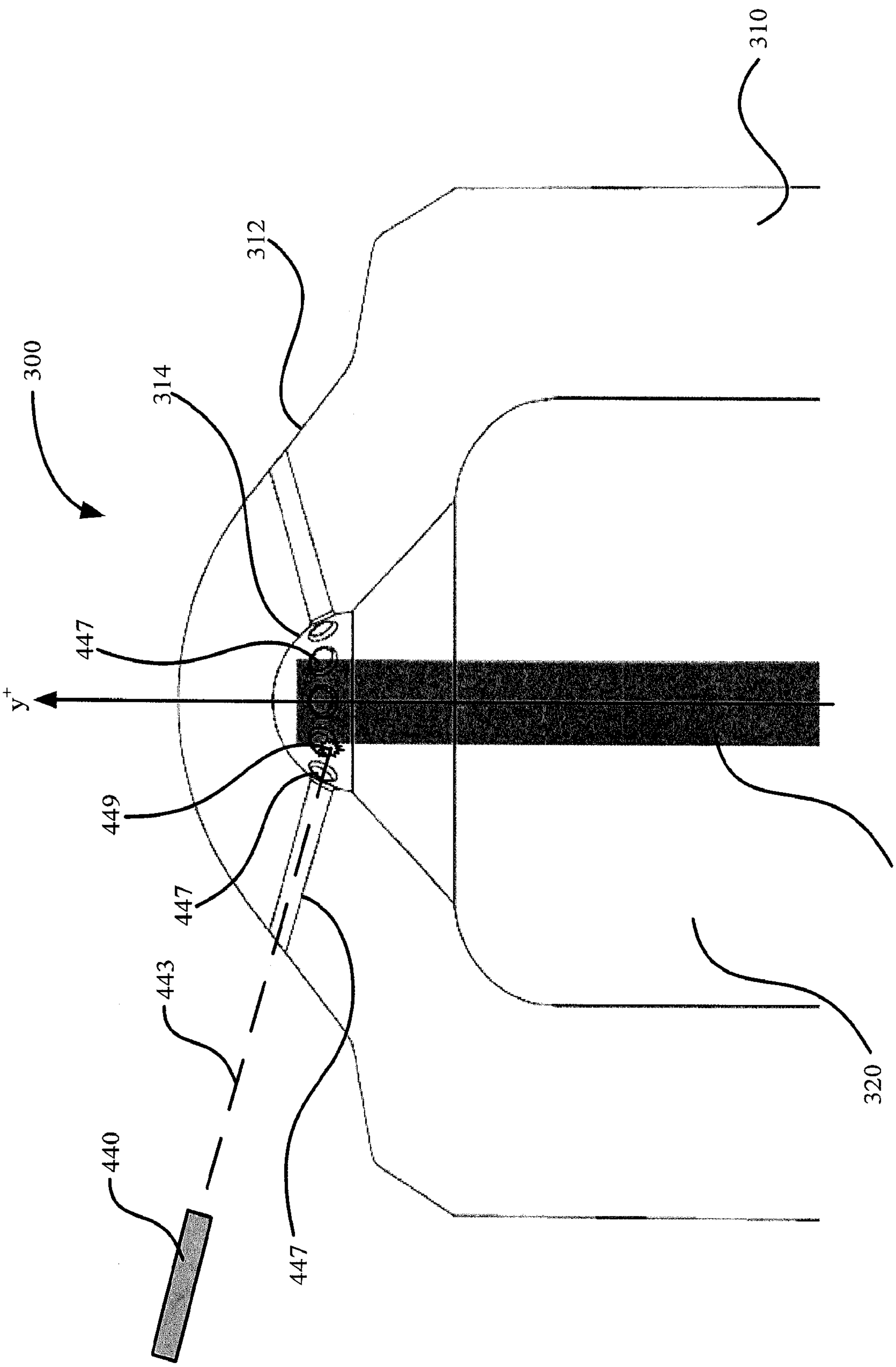

FIG. 4

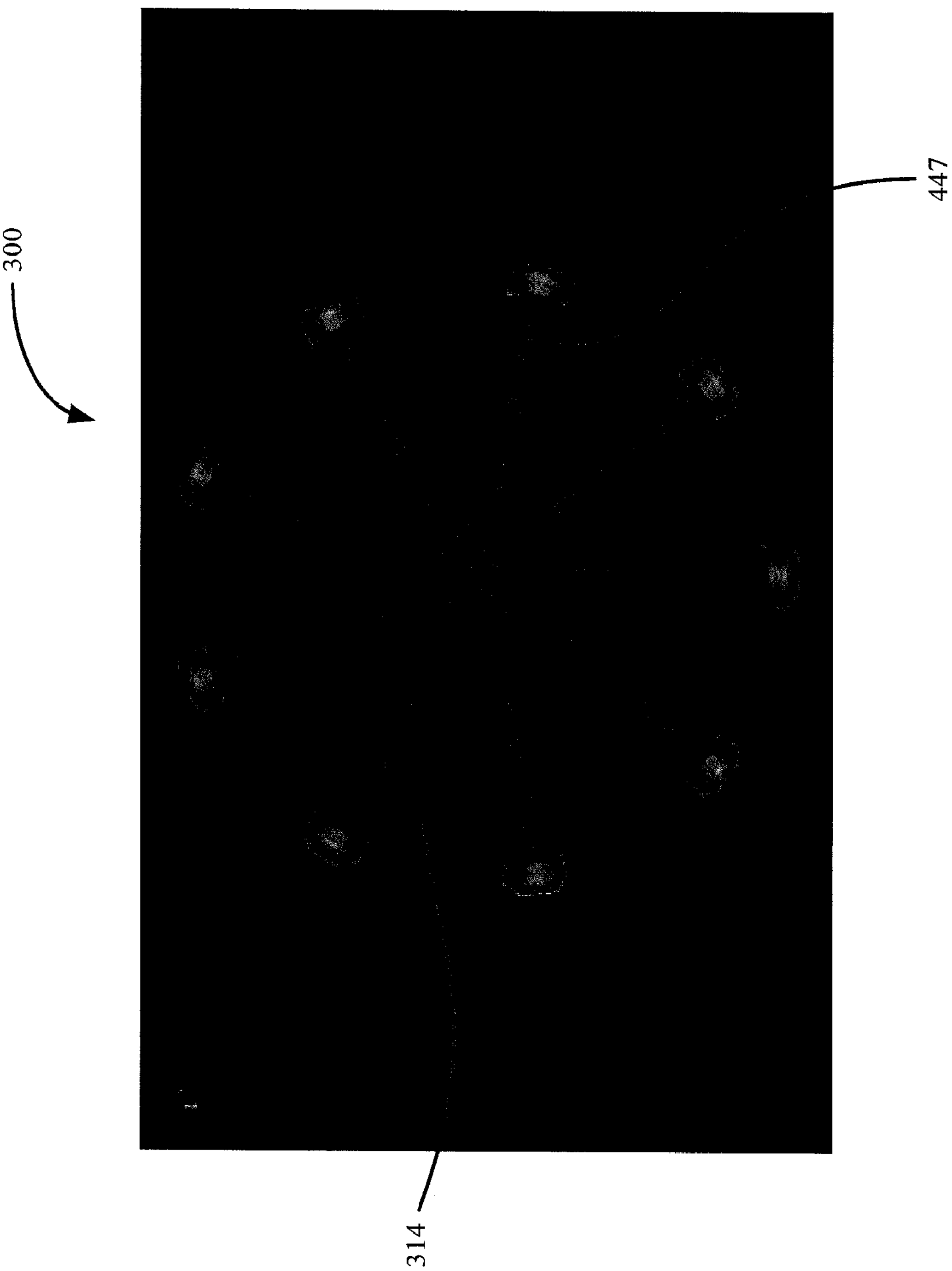

FIG. 5

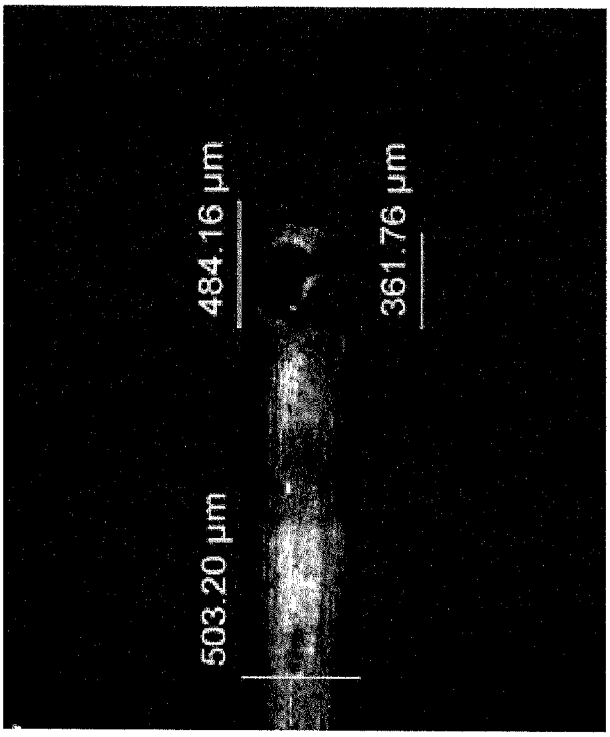

FIG. 6B

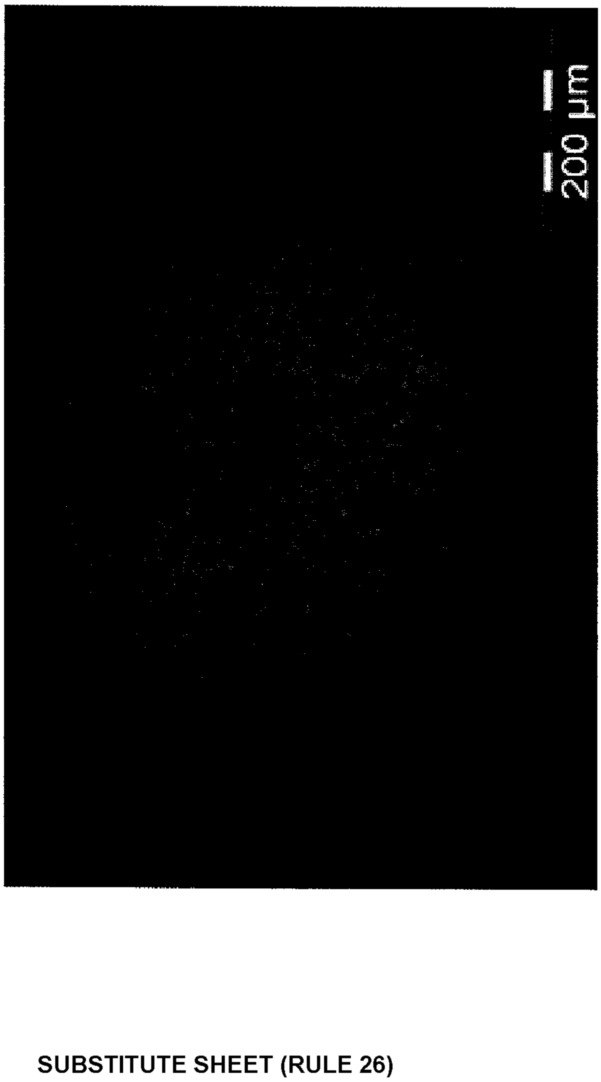

FIG. 6A

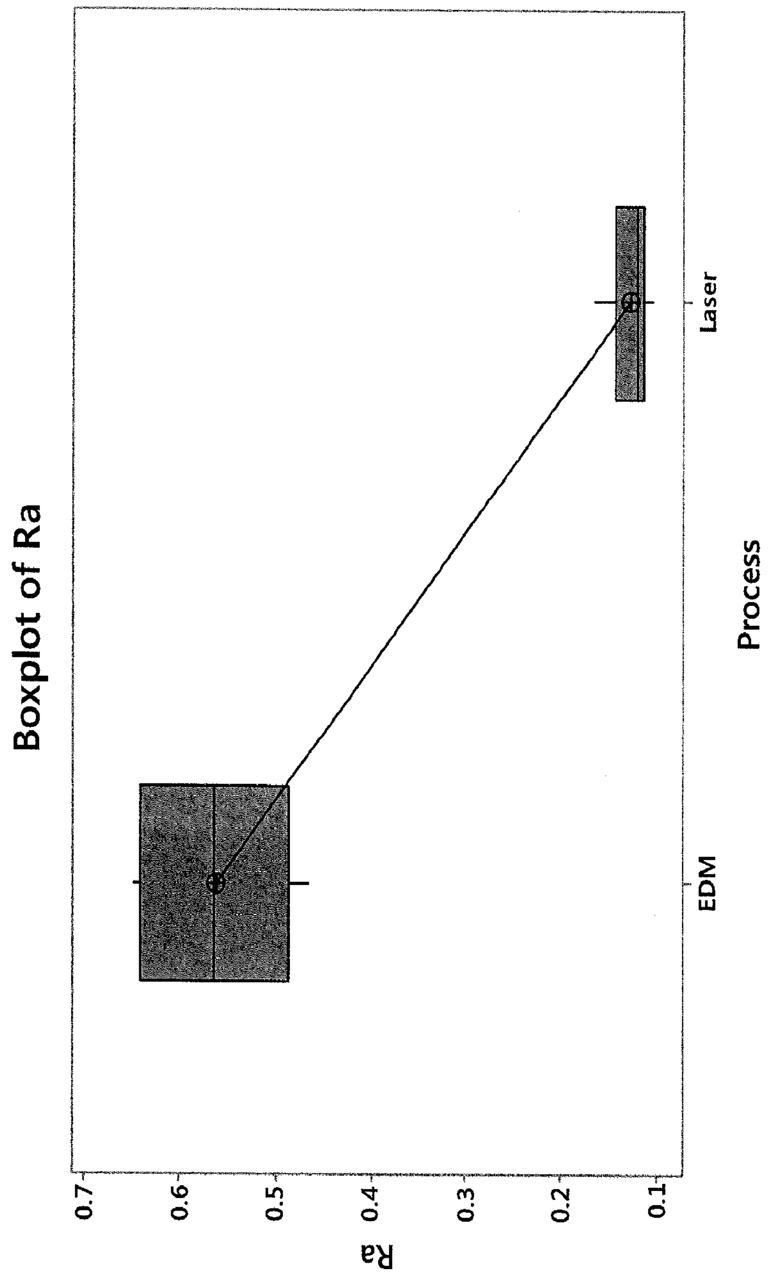

FIG. 7

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US16/20365

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - B23K 26/18; B23K 26/38; B23K 26/142 (2016.01)
CPC - B23K 26/389; B23K 26/18; B23K 26/142
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC: B23K26/18, B23K26/38, B23K26/55, F02M61/16 (2016.01)
CPC: B23K26/142, B23K26/18, B23K26/382, B23K26/389, B23K26/55, F02M61/168, F02M2200/8069

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
USPC: 219/121.7, 219/121.71

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
PatSeer (US, EP, WO, JP, DE, GB, CN, FR, KR, ES, AU, IN, CA, INPADOC Data); Google; Google Scholar; EBSCO; Search Terms: protect, shield, prevent, obstruct, block, limit, absorb, damage, overpenetrate, overdrill, energy, laser, back, inner, inside, internal, wall, side, surface, metal, mandrel, pin, rod, cylinder, shaft, spindle, diesel, fuel, injector, tantalum hafnium carbide, eccentric, μm, micrometer

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X -- Y	EP 1,661,658 A1 (DELPHI TECHNOLOGIES, INC.) 31 May 2006 (31.05.2006) figure 1; paragraphs [0034]-[0038], [0042], [0043], [0059], [0060], [0062], [0065], [0117]	1, 3-5, 7, 12, 15, 17, 18, 21, 22 --------- 2, 6, 16
X	US 2013/0146570 A1 (FORSMAN, A. et al) 13 June 2013 (13.06.2013) figure 1, 3, 15; [0035], [0059], [0060], [0062], [0065], [0117]	1, 8-11, 15, 19, 20
X	US 6,365,871 B1 (KNOWLES, M. et al) 02 April 2002 (02.04.2002) figure 6; column 3, lines 15-20, 30-35; column 8, lines 1-5; column 9, lines 15-20	1, 12-14
Y	US 5,156,341 A (TERAKADO, K. et al) 20 October 1992 (20.10.1992) figures 1, 2B; column 5, lines 10-15	2, 16
Y	US 2011/0127450 A1 (HOLBER, W. et al) 02 June 2011 (02.06.2011) figure 1; paragraph [0026], [0044]	6
A	US 6,407,362 B1 (SCHMID, G. et al) 18 June 2002 (18.06.2002); entire document	1-22
A	US 2011/0163078 A1 (FUKUSHIMA, T. et al) 07 July 2011 (07.07.2011); entire document	1-22
A	US 8,173,932 B2 (KOBAYASHI, T. et al) 08 May 2012 (08.05.2012); entire document	1-22
A	US 8,779,328 B2 (ANUKHIN, B. et al) 15 July 2014 (15.07.2014); entire document	1-22

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
15 April 2016 (15.04.2016)	05 MAY 2016

Name and mailing address of the ISA/
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