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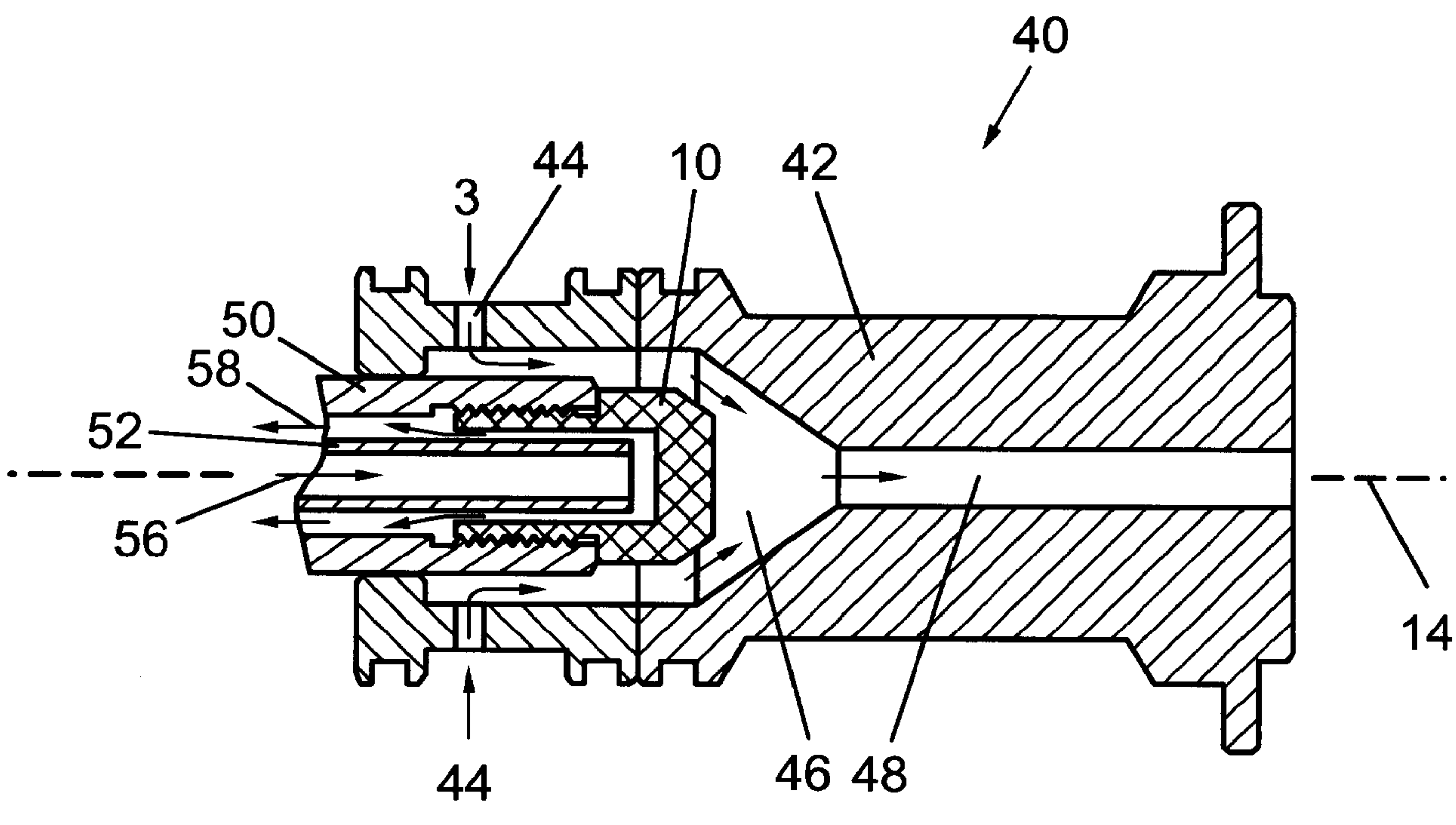
(54) Titre : CATHODES COMPOSITES DE GRAPHITE PYROLYTIQUE OU DE CARBONE-CARBONE A STRUCTURE HAUTEMENT ORDONNEE PERMETTANT DE GENERER DU PLASMA DANS DES GAZ CONTENANT DU CARBONE

(54) Title: HIGHLY ORDERED STRUCTURE PYROLITIC GRAPHITE OR CARBON-CARBON COMPOSITE CATHODES FOR PLASMA GENERATION IN CARBON CONTAINING GASES



(57) Abrégé/Abstract:
A DC plasma torch which includes a long lasting thermionic cathode and has a high thermal efficiency. The DC plasma torch employs a solid cathode made of graphite with highly ordered structure such as Pyrolitic Graphite or Carbon-Carbon composites. Furthermore, carbon containing gases will be used as plasma gas. The cathode will allow for theoretically an unlimited lifetime of the cathode.

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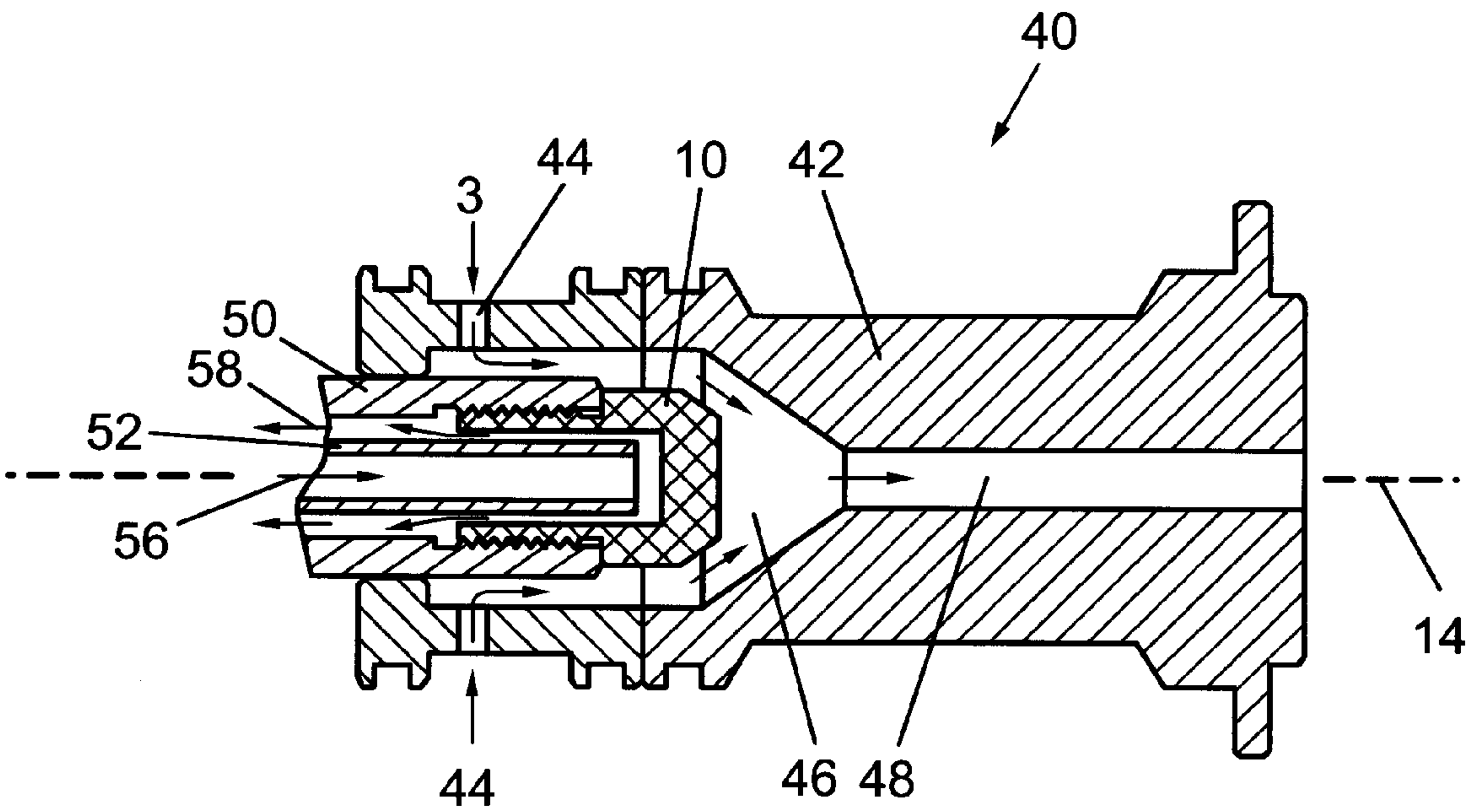
(54) **Title:** HIGHLY ORDERED STRUCTURE PYROLITIC GRAPHITE OR CARBON-CARBON COMPOSITE CATHODES FOR PLASMA GENERATION IN CARBON CONTAINING GASES



(57) **Abstract:** A DC plasma torch which includes a long lasting thermionic cathode and has a high thermal efficiency. The DC plasma torch employs a solid cathode made of graphite with highly ordered structure such as Pyrolitic Graphite or Carbon-Carbon composites. Furthermore, carbon containing gases will be used as plasma gas. The cathode will allow for theoretically an unlimited lifetime of the cathode.

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HIGHLY ORDERED STRUCTURE PYROLITIC GRAPHITE OR CARBON-CARBON COMPOSITE CATHODES FOR PLASMA GENERATION IN CARBON CONTAINING GASES

FIELD OF THE INVENTION

The present invention relates generally to carbon based cathodes for DC plasma torches which includes a long lasting thermionic cathode and a high thermal efficiency.

BACKGROUND OF THE INVENTION

Industrial types of direct current (DC) thermal spray plasma torches are built with a water-cooled tungsten cathode and a copper anode. Main plasma gas is argon. The use of argon is dictated by its inertness at high temperatures to the thermionic tungsten cathode. Thermionic cathodes emit electrons from their surface since their temperature is high enough for easy emission of electrons. Tungsten is the preferred cathode material since it is a refractory metal with high melting point temperature. It is however, highly reactive to oxygen at high temperatures. During the operation of the torch, cathode tip is melted and tungsten evaporates. The cathode erosion rate is directly dependent on its temperature. Cathode lifetime and consistency of its performance is an important issue in this technology.

One disadvantage of argon is its low thermal conductivity and its low enthalpy which results in reduced thermal efficiency of the DC plasma torches. The low thermal efficiency limits powder feed rate, deposition efficiency and coating quality. To enhance thermal conductivity and thermal efficiency, small amounts of hydrogen or helium are normally mixed with argon.

It is known that to reduce the erosion of the graphite cathodes, they must be cooled either by encasing them in a water-cooled metal jacket (see for example U.S. Patent Nos. 4,490,825 and 4,304,980) or by external water spraying directly onto the electrode (U.S. Patent No. 5,795,539). Direct internal water cooling of graphite electrodes is not practical since the cathode is normally made of polycrystalline graphite which has open porosity and, compared to metals, lower thermal conductivity. This leads to the infiltration of the cooling water through the electrode as well as a less effective heat removal. The latter imposes limits on power generated by the plasma torch.

It would be very advantageous to provide a DC plasma torch which has a long lasting thermionic cathode having a high thermal efficiency.

SUMMARY OF THE INVENTION

Accordingly, the present invention provides a DC plasma torch embodiments of which employ a carbon cathode made of graphite with highly ordered structure such as pyrolitic graphite or carbon-carbon composites.

Furthermore, carbon containing gases are used as the plasma gas to give a long lifetime of the cathode since by using carbon the cathode is regenerated.

The present invention provides a cathode electrode for plasma generation, comprising:

a carbon electrode **10** having a chamber **20** and a substantially planar outer electrode surface region **18**, said chamber **20** having an interior surface region **16** spaced from said planar outer electrode surface region **18** and a liquid inlet **22** for admitting liquid coolant to said chamber **20** to cool said interior surface region **16**, and wherein a region **24** of said carbon electrode **10** between said planar outer electrode surface region **18** and said interior surface **16** has a molecular orientation such that maximum thermal conductivity occurs between said interior surface **16** and said planar outer electrode surface region **18** for dissipation of heat at said planar outer electrode surface region **18** such that when in operation as a cathode in a plasma torch, a plasma arc is formed adjacent to said planar outer electrode surface region **18**.

The present invention also provides embodiments of a plasma torch, comprising:

a) a carbon electrode **10** having a chamber **20** and a substantially planar outer electrode surface region **18**, said chamber **20** having an interior surface region **16** spaced from said planar outer electrode surface region **18**, and wherein a region **24** of said carbon electrode **10** between said planar outer electrode surface region **18** and said interior surface **16** has a molecular orientation such that maximum thermal conductivity occurs between said interior surface **16** and said planar outer electrode surface region **18** for dissipation of heat at said planar outer electrode surface region **18**;

b) an anode **42** including an interior chamber **46** in communication with an exit channel **48**;

c) an outer mounting tube **50** having a first end portion to which cathode **10** is attached, said outer mounting tube **50** being inserted into said interior chamber **46** of said anode **42** with said planar outer electrode surface region **18** being spaced from and symmetrically aligned with said exit passageway **48**;

d) an inner tube **52** inserted into said chamber **20** of the electrode **10** with one open end of the inner tube **52** being adjacent to a space from the interior surface **16** and having a diameter smaller than diameter of the chamber **20** so that an annular passageway **58** is formed between an interior side wall of the chamber **20** and an outer surface of the inner tube **52**, a second open end of the inner tube **52** being a fluid inlet for cooling fluid to flow down through the inner tube **52** to contact interior surface **16** after which the fluid flows back through the annular passageway **58** and out of the plasma torch, said anode including ports **44** for introducing plasma gas into said interior chamber **46**; and

e) wherein in operation a gas mixture comprised of one or more carbon containing gases is flowed into said interior chamber **46** through said ports **44** and a plasma arc is formed in said interior chamber **46** and discharged through said exit passageway **48**.

A further understanding of the functional and advantageous aspects of the invention can be realized by reference to the following detailed description and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the present invention are described in greater detail with reference to the accompanying drawings.

Figure 1shows a cross sectional view of a plasma torch cathode electrode constructed in accordance with the present invention; and

Figure 2 shows a plasma torch containing the cathode electrode of Figure 1.

DETAILED DESCRIPTION OF THE INVENTION

Generally speaking, the systems described herein are directed to cathodes for DC plasma torches and plasma torches containing same. As required, embodiments of the present invention are disclosed herein. However, the disclosed embodiments are merely exemplary, and it should be understood that the invention may be embodied in many various and alternative forms. The Figures are not to scale and some features may be exaggerated or minimized to show details of particular elements while related elements may have been eliminated to prevent obscuring novel aspects. Therefore, specific structural and functional details disclosed herein are not to be interpreted as limiting but merely as a basis for the claims and as a representative basis for teaching one skilled in the art to variously employ the present invention. For purposes of teaching and not limitation, the illustrated embodiments are directed cathodes for DC plasma torches and DC plasma torches containing same.

As used herein, the term "about", when used in conjunction with ranges of dimensions of particles or other physical properties or characteristics, is meant to cover slight variations that may exist in the upper and lower limits of the ranges of dimensions so as to not exclude embodiments where on average most of the dimensions are satisfied but where statistically dimensions may exist outside this region. It is not the intention to exclude embodiments such as these from the present invention.

Embodiments of the present invention relate to cathodes for DC plasma torches which includes a long lasting thermionic cathode and has a high thermal efficiency. Specifically, the new design employs a solid cathode made of graphite with highly ordered structure such as pyrolitic graphite or Carbon-Carbon composites. Furthermore, carbon containing gases will be used as plasma gas. As it will be shown in the following paragraphs description, the above combination will allow for theoretically an unlimited lifetime of the cathode.

In order to improve the graphite electrode cooling and increase torch power, a graphite electrode made of high thermal conductivity pyrolitic graphite or of a carbon fiber–carbon matrix composite is used as the cathode electrode. Pyrolitic graphite structure has low crystal lattice defects and carbon atoms planes are placed parallel to each other, therefore the structure and its properties closely match those of the ideal graphite crystal. This specific crystal structure results in significant electrical and thermal properties anisotropy. Particularly, thermal conductivity varies considerably from 1100-1500 W/mK when measured within the plane compared to only 2 W/mK when measured perpendicular to the plane. Graphite fibers also have high thermal conductivity of up to 1200 w/mK which is four times higher than copper.

Referring to **Figure 1**, the cathode disclosed herein is shown generally at **10** and is made in the shape of a cylindrical cup **12** from graphite with a highly ordered, low defect crystal structure such as obtained using for example pyrolitic graphite or carbon fibers. The graphite structure has an orientation in such a way that the maximum thermal conductivity plane coincides with the axis **14** of the electrode from inner surface **16** to the outer surface **18**. For the electrode made of a carbon fiber -carbon composite, the fibers must be aligned longitudinally along the electrode axis **14** as well. In other words the carbon fibers are parallel to axis **14** to give the optimum thermal conductivity from inner surface **16** to outer surface **18**. This ensures the highest heat removal from area of the arc attachment. The density of pyrolitic graphite is high; it is close to the theoretical density of carbon (2.25 g/cm^3) which makes it essentially non-porous (**Table 1**). This allows for direct water cooling of the electrode **12** by flowing water into chamber **20** through the chamber opening **22** without infiltration of water through the cathode **10**.

Although graphite is evaporated during the torch operation, its erosion will be compensated by the precipitation of carbon ions on the graphite cathode. This reconstruction of the cathode **10** is only possible if the arc is operated in carbon containing gases. **Figure 2** shows a plasma torch **40** with graphite cathode **10**, an anode **42** including an interior chamber **46** in communication with an exit passageway **48** and ports **44** for introducing plasma gas into chamber **46**. Cathode **10** is preferably cylindrically shaped having an inner threaded portion and is threaded onto the end of an outer threaded mounting tube **50**. An inner tube **52** is inserted into chamber **20** with one open end of the inner tube **52** being adjacent to and spaced from the interior surface **16** of cathode **10** and having a diameter smaller than diameter of the chamber **20** so that an annular passageway **58** is formed between an interior side wall of the chamber **20** and an outer surface of the inner tube **52**. The second open end of the inner tube **52** is a fluid inlet for cooling fluid to flow down through inner tube **52** to contact interior surface **16** after which the fluid flows back through annular passageway **58** and out of the plasma torch. The anode includes ports **44** for introducing plasma gas into the interior chamber **46**.

Cooling water to cool cathode **10** flows through the outer end of inner tube **52** and down central channel **56** around the end of inner tube **52** over the inner surface **16** (**Figure 1**) of cathode **10** thereby cooling it, and out through annular channel **58** between inner tube **52** and outer tube **50**. Because the molecular orientation of the constituent components of electrode **10** (whether graphite planes or longitudinal fibers) which run parallel to axis **14**, so that the region **24** between inner surface **16** and the outer surface **18** of electrode **10** form planes of maximum thermal conductivity parallel to axis **14** so that surface **18** is cooled. In operation a sufficiently high DC voltage is applied between the cathode and anode electrodes and a gas mixture comprised of one or more carbon containing gases is flowed into the interior chamber **46** through the ports **44** and a plasma arc is formed in the chamber **46** and discharged through the passageway **48**.

The gas mixture will be composed from hydrocarbons (methane, ethylene, propane, etc.) and carbon dioxide. Because of the high plasma temperature, hydrocarbons dissociate into free carbon and hydrogen. They are then ionized. Subsequently positive carbon ions move from the gas phase to the cathode emissive surface, where dynamic equilibrium between carbon evaporation and precipitation takes place. This process compensates cathode erosion and ensures long operation life.

As used herein, the terms “comprises”, “comprising”, “including” and “includes” are to be construed as being inclusive and open ended, and not exclusive. Specifically, when used in this specification including claims, the terms “comprises”, “comprising”, “including” and “includes” and variations thereof mean the specified features, steps or components are included. These terms are not to be interpreted to exclude the presence of other features, steps or components.

The foregoing description of the preferred embodiments of the invention has been presented to illustrate the principles of the invention and not to limit the invention to the particular embodiment illustrated. It is intended that the scope of the invention be defined by all of the embodiments encompassed within the following claims and their equivalents.

Table 1:GRAPHITE MATERIALS

TYPE OR BRAND NAME	DENSITY [g/c^3]	THERMAL CONDUCTIVITY [W/mK]	REFER-ENCE
APG Pyrolitic Graphite	2.3	1700	1
Annealed Pyrolitic Graphite	2.22	1100-1300	2
Carbon Fiber	1.8-2.2	1100	1,5
Graphite electrodes for steelmaking	1.6-1.75	2.20-300	3,4

References

1. Website of k-Technology Corporation (www.k-technology.com)
2. Website of Pyrogenics Group (www.pyrographite.com)
3. Website of SGL Carbon AG (www.sglcarbon.com)
4. Pierson, H.O. “Handbook of Carbon, Graphite, Diamond and Fullerenes-Properties, Processing and Applications”, William Andrew Publishing, 2001, pp 399.
5. Dresselhaus, M.S. “Graphite fibers and filaments”, Springer-Verlag, 1988, 382 p.

THEREFORE WHAT IS CLAIMED IS:

1. A cathode electrode for plasma generation, comprising:

a carbon electrode **10** having a chamber **20** and a substantially planar outer electrode surface region **18**, said chamber **20** having an interior surface region **16** spaced from said planar outer electrode surface region **18** and a liquid inlet **22** for admitting liquid coolant to said chamber **20** to cool said interior surface region **16**, and wherein a region **24** of said carbon electrode **10** between said planar outer electrode surface region **18** and said interior surface **16** has a molecular orientation such that maximum thermal conductivity occurs between said interior surface **16** and said planar outer electrode surface region **18** for dissipation of heat at said planar outer electrode surface region **18** such that when in operation as a cathode in a plasma torch, a plasma arc is formed adjacent to said planar outer electrode surface region **18**.

2. The cathode electrode according to claim 1 wherein said carbon electrode **10** has a generally cylindrical shape having a planar end coinciding with said planar outer electrode surface region **18**, said carbon electrode **10** including a cylindrical axis **14** which extends symmetrically through said planar outer electrode surface region **18** and said interior surface **16**, and wherein said maximum thermal conductivity occurs parallel to said cylindrical axis **14**.

3. The cathode electrode according to claim 2 wherein said carbon electrode **10** is made of pyrolitic graphite having highly ordered, low defect crystal structure, and an orientation such that a maximum thermal conductivity plane of the pyrolitic graphite is parallel with the cylindrical axis **14** of the carbon electrode **10** from said interior surface **16** to the planar outer electrode surface **18**.

4. The cathode electrode according to claim 2 wherein said carbon electrode **10** is made of carbon fibers, wherein the carbon fibres are aligned longitudinally along the cylindrical axis **14** of the carbon electrode **10** parallel thereto.

5. The cathode electrode according to claim 1, 2, 3 or 4 wherein said carbon electrode **10** is for use for plasma generation in carbon containing gases.

6. A plasma torch, comprising:

a) a carbon electrode **10** having a chamber **20** and a substantially planar outer electrode surface region **18**, said chamber **20** having an interior surface region **16** spaced from said planar outer electrode surface region **18**, and wherein a region **24** of said carbon electrode **10** between said planar outer electrode surface region **18** and said interior surface **16** has a molecular orientation such that maximum thermal conductivity occurs between said interior surface **16** and said planar outer electrode surface region **18** for dissipation of heat at said planar outer electrode surface region **18**;

b) an anode **42** including an interior chamber **46** in communication with an exit channel **48**;

c) an outer mounting tube **50** having a first end portion to which cathode **10** is attached, said outer mounting tube **50** being inserted into said interior chamber **46** of said anode **42** with said planar outer electrode surface region **18** being spaced from and symmetrically aligned with said exit passageway **48**;

d) an inner tube **52** inserted into said chamber **20** of the electrode **10** with one open end of the inner tube **52** being adjacent to a space from the interior surface **16** and having a diameter smaller than diameter of the chamber **20** so that an annular passageway **58** is formed between an interior side wall of the chamber **20** and an outer surface of the inner tube **52**, a second open end of the inner tube **52** being a fluid inlet for cooling fluid to flow down through the inner tube **52** to contact interior surface **16** after which the fluid flows back through the annular passageway **58** and out of the plasma torch, said anode including ports **44** for introducing plasma gas into said interior chamber **46**; and

e) wherein in operation a gas mixture comprised of one or more carbon containing gases is flowed into said interior chamber **46** through said ports **44** and a plasma arc is formed in said interior chamber **46** and discharged through said exit passageway **48**.

7. The plasma torch according to claim 6 wherein said carbon electrode **10** has a generally cylindrical shape having an outer part of which is threaded and being threaded onto the end of the outer mounting tube **50**, said cathode

10 having a planar end coinciding with said planar outer electrode surface region **18**, said carbon electrode **10** including a cylindrical axis **14** which extends symmetrically through said planar outer electrode surface region **18** and said interior surface **16**, and wherein said maximum thermal conductivity occurs parallel to said cylindrical axis **14**.

8. The plasma torch according to claim 7 wherein said carbon electrode **10** is made of pyrolitic graphite having highly ordered, low defect crystal structure, and an orientation such that a maximum thermal conductivity plane of the pyrolitic graphite is parallel with the cylindrical axis **14** of the carbon electrode **10** from said interior surface **16** to the planar outer electrode surface **18**.

9. The plasma torch according to claim 7 wherein said carbon electrode **10** is made of carbon fibers, wherein the carbon fibres are aligned longitudinally along the cylindrical axis **14** of the carbon electrode **10** parallel thereto.

10. The plasma torch according to claim 6, 7, 8 or 9 wherein including a DC power supply connected between said anode electrode and said cathode electrode.

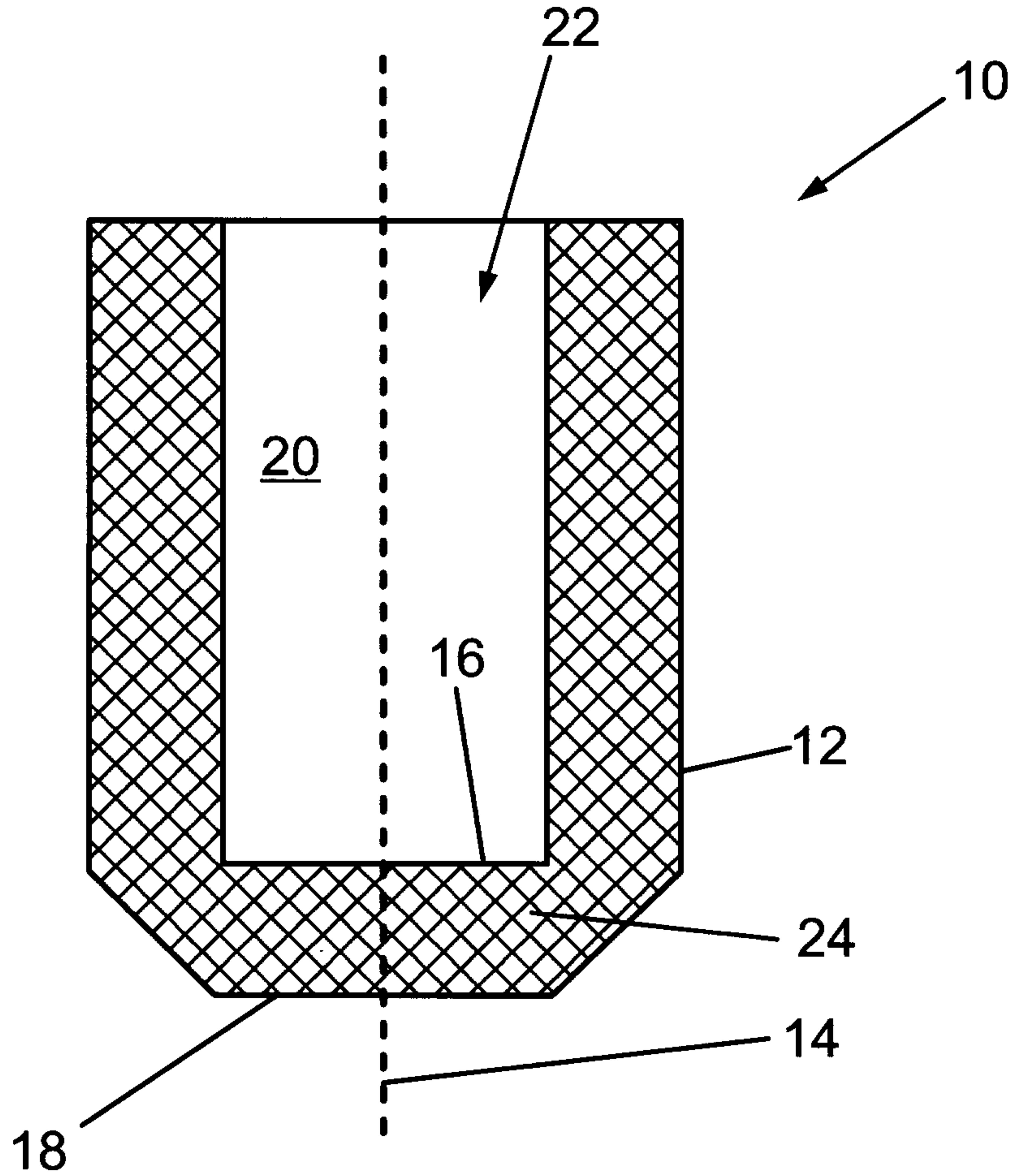

FIG. 1

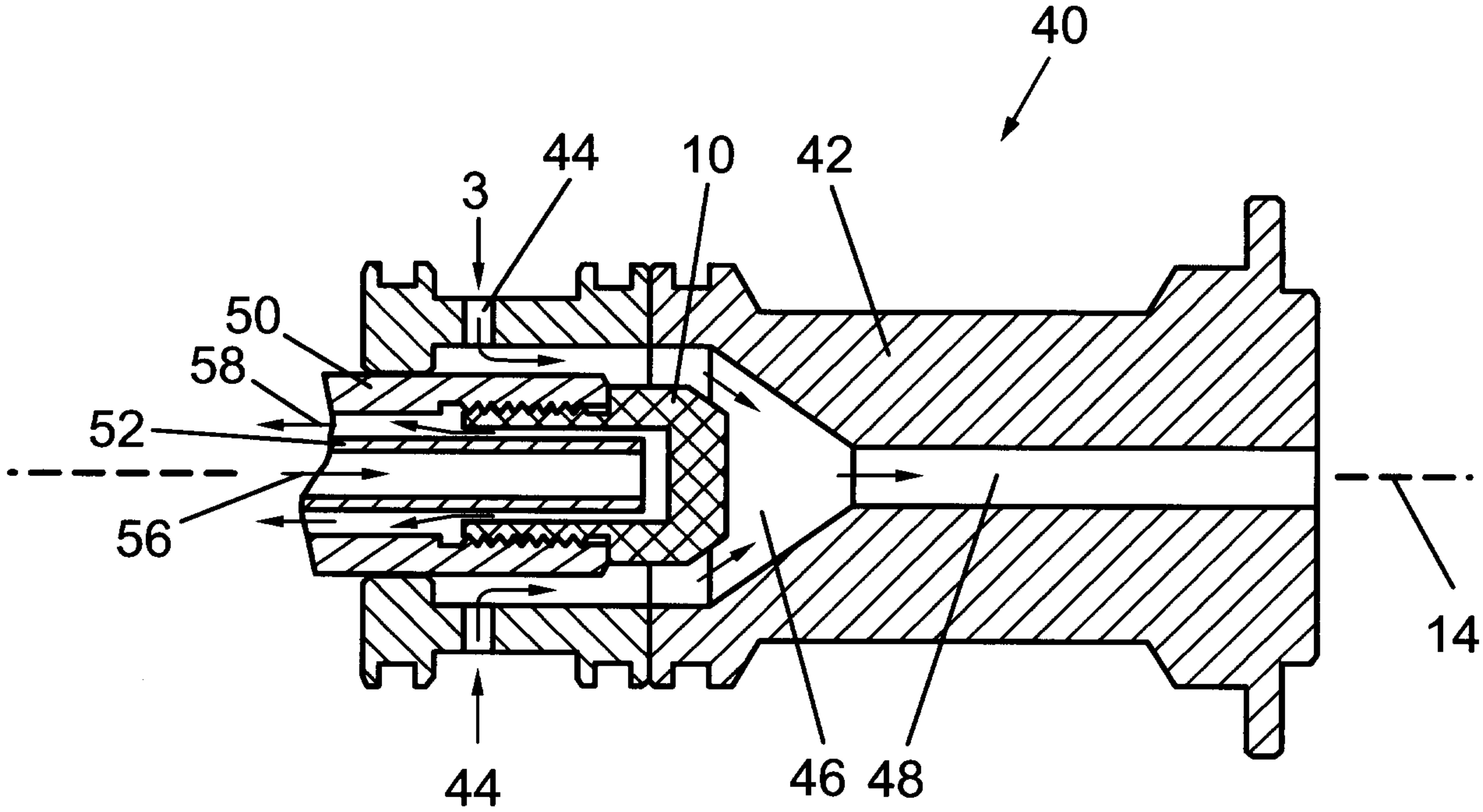

FIG. 2


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