

(19) **DANMARK**

(10) **DK/EP 2809468 T3**



(12) **Oversættelse af  
europæisk patentskrift**

Patent- og  
Varemærkestyrelsen

- 
- (51) Int.Cl.: **B 22 F 9/14 (2006.01)**                      **B 22 F 1/00 (2006.01)**                      **C 23 C 14/00 (2006.01)**  
**H 01 J 37/32 (2006.01)**
- (45) Oversættelsen bekendtgjort den: **2020-08-17**
- (80) Dato for Den Europæiske Patentmyndigheds bekendtgørelse om meddelelse af patentet: **2020-06-17**
- (86) Europæisk ansøgning nr.: **13705026.6**
- (86) Europæisk indleveringsdag: **2013-01-29**
- (87) Den europæiske ansøgnings publiceringsdag: **2014-12-10**
- (86) International ansøgning nr.: **NL2013050049**
- (87) Internationalt publikationsnr.: **WO2013115644**
- (30) Prioritet: **2012-01-31 NL 2008208**
- (84) Designerede stater: **AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR**
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- (54) Benævnelse: **GNISTABLATIONSANORDNING OG FREMGANGSMÅDE TIL GENERERING AF NANOPARTIKLER**
- (56) Fremdragne publikationer:  
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## DESCRIPTION

**[0001]** The invention relates to a spark ablation device and to a method for generating nanoparticles.

**[0002]** Ablation devices based on electrode vaporisation by spark discharge are known in the prior art; see e.g. S. Schwyn et al., J. Aerosol Sci, 1988, 19(5), 639. The spark generator of such devices typically comprises a power source, an RLC circuit (i.e. a circuit comprising a resistor, an inductor and a capacitor) and a pair of electrodes. The capacitor is continually charged by the power source; when the breakdown voltage is reached, discharge occurs between the electrodes. The spark discharge is repetitive, and between sparks there is no discharge. Components and conditions are chosen such that the energy of the discharge is sufficient to cause electrode ablation. Electrode ablation is the evaporation/vaporisation of the electrode through the presence of plasma i.e. as a result of heating and ion bombardment. The power of the discharge is the product of voltage and current.

**[0003]** Disadvantages of state of the art devices and methods for spark ablation are: (a) their limited nanoparticle production rates: typical maximum production rates are in the range of milligrams per hour. This is due to the low spark repetition frequencies of conventional spark generator circuits; (b) as the frequency is increased local heating of the electrodes occurs as subsequent sparks hit the same point on the electrode surface; this leads to emission of (relative to nanoparticles) large particles formed from dispersions of melted material; (c) above a certain frequency, discharge becomes continuous and particle generation stops or desired particle characteristics are lost.

**[0004]** Each of US2005/034668 and US2008/166500 disclose a spark ablation device for generating nanoparticles comprising a spark generator; the spark generator comprising first and second electrodes and at least one power source which is arranged to be operative for maintaining a discharge between the first and second electrodes. A spark generator is an electrical circuit arranged for generating sparks between electrodes of the spark generator. In the device of US2005/034668 the electrodes are hollow and connected to a gas supply. Further in this device a ring shaped electromagnet is applied providing a magnetic field in the discharge area between the first and second electrodes. Since in such a ring shaped electromagnet the magnetic field lines pass through in parallel with the core axis of the magnet, the magnetic field lines in US2005/034668 are predominantly parallel with the electrical field lines that entertain the discharge.

**[0005]** US 2003/0230554 discloses an apparatus for synthesizing nanopowders, which comprises an anode electrode and a cathode electrode which are comprised of precursor material, and which are substantially axially aligned but spaced apart within a gaseous atmosphere; and a power supply which is in electrical communication with the anode electrode and the cathode electrode, and which effects a high-power pulsed electrical discharge to ablate said anode electrode and said cathode electrode to produce said nanopowders.

**[0006]** US 2005/0061785 relates to a method and system for synthesizing nanopowders with reduced nanoparticles agglomeration, which comprises at least one member of a nanopowder precursor material immersed in a gaseous atmosphere; means for applying a magnetic field to said at least one member in near proximity of an area of interaction of said at least one member with a plasma; power means in an electrical connection with said at least one member and said means for applying a high magnetic field for creating said plasma in the presence of said high magnetic field to produce said nanopowder; and means for applying a coating precursor material to said nanopowder to reduce nanoparticle agglomeration.

**[0007]** US2008/0143260 relates to a vacuum plasma generator for providing a plasma discharge for treating workpieces by way of a pulsed plasma process in a vacuum chamber. In such plasma processes it is often desirable to superimpose a pulse voltage onto a DC operated plasma discharge. Although the apparatus is used under vacuum and does not have an outlet to gather any evaporated matter, it is considered to be suitable for generating nanoparticles when used under appropriate conditions.

**[0008]** It is an object of the invention to provide a spark ablation device and method which overcome one or more problems of the devices and methods of the prior art. The object of the invention is achieved by providing a device according to claim 1 and a method according to claim 6. Spark ablation involves applying electrical energy to create sparks between pairs of electrodes. Electrode material is vaporised at the electrode or electrodes from which each high-energy spark originates. Under suitable conditions, nanoparticles are formed from the vaporized material. Nanoparticles as understood in this application are particles having a diameter up to a maximum of about 1  $\mu\text{m}$ .

**[0009]** In a first aspect, the invention relates to a spark ablation device for generating nanoparticles provided with an inlet/outlet for gas and comprising a spark generator; the spark generator comprising first and second electrodes and at least one power source which is arranged to be operative for maintaining a discharge between the first and second electrodes, wherein the power source comprises a continuous DC or AC power source, supplemented with a source for pulsed power, and wherein the device is provided with an outlet for the generated nanoparticles, and said power source is configured for repetitively and intermittently varying its power output between a first energy level wherein a continuous discharge is maintained between the electrodes of the spark ablation device and a second energy level higher than the first energy level for ablating at least a portion of the electrodes, and wherein the first energy level is selected at a level insufficient to generate nanoparticles, and the second energy level is selected at a level to unavoidably generate nanoparticles.

**[0010]** Providing an at least substantially continuous discharge or simmer discharge between the electrodes and superimposing a pulsed discharge thereover results in a number of advantages: (i) lower voltages can be applied as the break-down voltage between the electrodes does not have to be reached; (ii) each spark has the same "starting" conditions, thus constant particle characteristics and a narrow distribution of particle sizes can be

achieved; (iii) very short, high power discharge pulses are possible, but with the average power being low enough to avoid cooling problems; (iv) sufficiently high pulse energies can be used to allow simultaneous evaporation of materials of different boiling points wherein the electrodes are sintered electrodes; (v) the RLC circuits commonly applied allow repetition frequencies up to only 1000 Hz, whereas for the method and device of the present invention this limit is not applicable and thus much higher nanoparticle production rates are possible, such as at least a factor of 10 greater; (vi) for most electrode arrangements, the position where the simmer discharge meets the electrodes fluctuates; subsequent sparks do not strike repetitively at the same point on the electrodes which would otherwise lead to non-even evaporation and formation of liquid pools and therewith large particles, and; (vii) the average electric field in the spark generator is smaller than with conventional circuits, because the otherwise required break-down voltage between the electrodes does not need to be reached. This reduces particle loss by electrostatic precipitation.

**[0011]** It is possible to implement the functionality of the spark ablation device such that only a single power source is needed. According to the invention, the at least one power source comprises a pulse generator for repetitively increasing the energy of the discharge. Various examples of suitable pulse generators are known to a person of skill in the art.

**[0012]** As mentioned above the at least one power source comprises a continuous DC power source or a continuous AC power source, supplemented with pulsed power from the same or another power source. The continuous power source may comprise one or more elements that can store electrical energy, such as a capacitor or a coil. The pulsed power source has the function of periodically supplying energy for the production of nanoparticles as well as periodically providing recharging energy for the said elements that can store electrical energy. Preferably the at least one power source is selected to be (a) a current source, or (b) a voltage source.

**[0013]** In a further preferred embodiment, the spark ablation device further comprises an ignition circuit for initial ignition of the continuous discharge.

**[0014]** According to the invention, the first and/or second electrodes are hollow and connected or connectable to a gas supply.

**[0015]** Hollow electrodes that are connected or are connectable to a gas supply, are advantageous since they allow the addition or removal of reactants or products e.g. nanoparticles once formed are removed via one or both of the electrodes. The gas flow can be held at a temperature providing effective cooling of the electrodes to avoid heating problems. The tube shape of the electrodes provides an additional advantage when combined with a magnetic field, as described below, because the resulting toroidal gap allows spinning of the discharge within this torus.

**[0016]** According to US2005/034668 the spark generator may comprise means to provide a magnetic field in a discharge area between the first and second electrodes. In this known

device the magnetic field lines are predominantly parallel to the electrical field lines.

**[0017]** In a third aspect of the invention the means to provide a magnetic field provide a magnetic field with field lines that are substantially perpendicular to the electrical field lines that cause the discharge between the electrodes, so as to influence the location on the first and second electrodes at which discharge occurs. It is possible that the magnetic field lines of the magnetic field are oriented oblique with respect to the electrical field lines between the electrodes, provided that there is a notable component of these field lines that are substantially perpendicular to the electrical field lines causing the discharge between the electrodes.

**[0018]** Through providing a magnetic field with magnetic field lines that are at least in part predominantly perpendicular to the electrical field lines, the position at which the continuous discharge meets the electrodes is constantly varied. This results in the pulsed discharges occurring at different positions and ensures a more even electrode evaporation. Wherein the electrodes are hollow (tube-shaped) and the spark generator comprises means to provide said magnetic field relative to the first and/or second electrodes, this advantageously permits spinning of the discharge.

**[0019]** The means to provide a magnetic field may be either a permanent magnet or magnets, an electric magnet or magnets, or a combination thereof.

**[0020]** Wherein the means for providing a magnetic field are embodied as electric magnets, this allows the magnetic field to be switched on only during certain periods in each cycle. The magnetic field can then for example be switched off during the pulse discharges so as to prevent them from being disturbed thereby. Permanent magnets constitute a mechanically simpler solution.

**[0021]** In a fourth aspect, the invention relates to a method for generating nanoparticles with a spark ablation device comprising electrodes for providing sparks by repetitively providing pulsed energy to the electrodes, wherein a substantially continuous discharge is maintained between the electrodes of the spark ablation device, the energy level of which discharge is intermittently increased from a first energy level to a second energy level higher than the first energy level for ablating a portion of the electrodes.

**[0022]** The invention will hereafter be further elucidated with reference to the drawing of Figure 1 showing schematically an example of a spark ablation device according to the invention. It should be appreciated that this example is provided for illustrative purposes only and is not to be considered limiting of the invention.

**[0023]** With reference to the drawing:

Figure 1 shows a spark ablation device 1 for generating nanoparticles comprising a spark generator 2; nanoparticles are generated in the region A. It is remarked that although not specifically shown, the device also includes an outlet for the generated nanoparticles.

**[0024]** The spark generator comprising first and second electrodes 3a, 3b, and the spark generator 2 further comprises at least one power source 4 which is arranged to be operative at a first energy level for maintaining a discharge between the first and second electrodes 3a, 3b. The power source 4 is configured for repetitively varying its power output between a first energy level and a second energy level to arrange that a substantially continuous discharge is maintained between the electrodes 3a, 3b of the spark ablation device 1 at the first energy level. The energy level of the discharge is intermittently increased from said first energy level to a second energy level higher than the first energy level for ablating at least a portion of the electrodes 3a, 3b.

**[0025]** For repetitively increasing the energy of the discharge the at least one power source 4 comprises a pulse generator 5. The at least one power source 4 comprises for instance a continuous DC power source and/or a continuous AC power source, supplemented with a source for pulsed power, wherein preferably the at least one power source is selected to be either (a) a current source, or (b) a voltage source.

**[0026]** According to the invention, the first and second electrodes 3a, 3b are hollow i.e. they are provided with conduits 6a, 6b running the length of each electrode 3a, 3b, and connected to a gas supply G. Also an (additional) inlet/outlet for the gas will be present. Such an arrangement allows the addition or removal of reactants or products e.g. nanoparticles once formed are removed via one or both of the electrodes 3a, 3b. One or more additional gas flows into and/or out of zone A may further be provided for the same purpose.

**[0027]** According to one of the aspects of the invention, the spark ablation device 1 comprises means to provide a magnetic field (not shown) arranged relative to the first and second electrodes 3a, 3b to influence the location on the electrodes 3a, 3b at which the discharge occurs. The means to provide a magnetic field provide a magnetic field with field lines preferably substantially perpendicular to the discharge.

**[0028]** The magnets could be embodied as rings around the electrodes. Permanent ring-shaped or tube-shaped magnets magnetized in the direction of the axis of the electrodes are suitable. Alternatively, electrical coils providing a magnetic field could be used and positioned accordingly.

**[0029]** It is expressly pointed out that the inventive merit that is embodied in the invention is exclusively determined by the appended claims. In connection therewith the claims should not be deemed limited to merely the provided schematic example of an embodiment of the invention. On the contrary, the discussed embodiment merely serves to elucidate possible ambiguities in the claims without intention to restrict the scope of protection of the claims to this embodiment only.

## **REFERENCES CITED IN THE DESCRIPTION**

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**Patent documents cited in the description**

- US2005034668A [0004] [0004] [0004] [0016]
- US2008166500A [0004]
- US20030230554A [0005]
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**Non-patent literature cited in the description**

- **S. SCHWYN et al.**J. Aerosol Sci, 1988, vol. 19, 5639- [0002]

## Patentkrav

1. En gnistablationsanordning (1) til generering af nanopartikler, som er forsynet med et indløb/udløb til gas, og som omfatter en gnistgenerator (2); gnistgeneratoren omfatter første og anden elektrode (3a, 3b), hvori den første og/eller anden elektrode er hul og forbundet med eller kan forbindes med en gasforsyning, og mindst én strømkilde (4), der er arrangeret til at være funktionsdygtig til opretholdelse af en afladning mellem den første og anden elektrode (3a, 3b), hvori strømkilden (4) omfatter en kontinuerlig jævnstrøms- eller vekselstrømskilde, suppleret med en kilde til impulseffekt, **kendetegnet ved, at** anordningen er forsynet med et udløb til de genererede nanopartikler, hvori de genererede nanopartikler fjernes via én eller begge af elektroderne (3a, 3b), og nævnte strømkilde er konfigureret til repetitivt og intermitterende at variere dens effektafgivelse mellem et første energiniveau, hvori en kontinuerlig afladning opretholdes mellem elektroderne (3a, 3b) på gnistablationsanordningen (1) og et andet energiniveau, der er højere end det første energiniveau, til ablation af mindst en del af elektroderne (3a, 3b), og hvori det første energiniveau er valgt ved et niveau, der er tilstrækkeligt til at generere nanopartikler, og det andet energiniveau er valgt ved et niveau, hvorved der uundgåeligt genereres nanopartikler, hvori mindst den ene strømkilde (4) omfatter en impulsgenerator (2) til repetitiv forøgelse af afladningsenergien.
2. Gnistablationsanordningen i henhold til krav 1, **kendetegnet ved, at** den mindst ene strømkilde (4) omfatter (a) en strømkilde, eller (b) en spændingskilde.
3. Gnistablationsanordningen i henhold til ét eller flere af de forrige krav, **kendetegnet ved, at** gnistablationsanordningen omfatter et tændingskredsløb til indledende antænding af den kontinuerlige afladning.
4. Gnistablationsanordningen i henhold til ét eller flere af de forrige krav, hvori gnistgeneratoren (2) desuden omfatter midler til at tilvejebringe et magnetfelt i et afladningsområde mellem den første og den anden elektrode (3a, 3b), **kendetegnet ved, at** midlerne til at tilvejebringe et magnetfelt tilvejebringer et magnetfelt med feltlinjerne

vinkelret på de elektriske feltlinjer, som forårsager afladningen mellem elektroderne (3a, 3b) for dermed at påvirke placeringen af den første og den anden elektrode (3a, 3b), hvorved afladningen sker.

5 **5.** Gnistablationsanordningen i henhold til krav 4, **kendetegnet ved, at** elektroderne er forsynet med magneter eller elektriske spoler til at tilvejebringe de magnetiske feltlinjer.

6. En fremgangsmåde til generering af nanopartikler med en gnistablationsanordning (1), der omfatter en første og en anden elektrode (3a, 3b) til tilvejebringelse af gnister  
10 gennem repetitivt at forsyne elektroderne (3a, 3b) med impulsenergi til elektroderne, og ved at tilføre gas til et indløb/udløb på gnistablationsanordningen (1), hvori den første og/eller den anden elektrode er hul og forbundet med en gasforsyning, **kendetegnet ved, at** der opretholdes en kontinuerlig afladning eller langsom afladning mellem elektroderne (3a, 3b) på gnistablationsanordningen (1) ved et første energiniveau, der er  
15 afledt fra en kontinuerlig jævnstrøms- eller vekselstrømskilde, og suppleret af impulsenergi fra samme eller anden strømkilde for repetitivt at variere effektafgivelsen mellem et første energiniveau og et andet energiniveau for at arrangere, at der opretholdes en kontinuerlig afladning mellem elektroderne (3a, 3b) på gnistablationsanordningen ved det første energiniveau, og hvori energiniveauet af  
20 afladningen intermitterende øges fra nævnte første energiniveau til et andet energiniveau, der er højere end det første energiniveau, til ablation af mindst en del af elektroderne (3a, 3b), hvori det første energiniveau er valgt på et niveau, der er utilstrækkeligt til at generere nanopartikler, og det andet energiniveau er valgt på et niveau for uundgåeligt at generere nanopartikler, og tilvejebringelse af de genererede  
25 nanopartikler til et udløb på gnistablationsanordningen (1), hvori de genererede nanopartikler fjernes via én eller begge af elektroderne (3a, 3b), og hvori energien af afladningen øges intermitterende ved at tilføre elektroderne (3a, 3b) elektriske impulser.

7. Fremgangsmåden i henhold til krav 6, **kendetegnet ved, at** elektroderne (3a, 3b) på  
30 gnistablationsanordningen (1) er udsat for et magnetfelt til opretholdelse af ensartet ablation af elektroderne (3a, 3b) på gnistablationsanordningen (1).

DRAWINGS

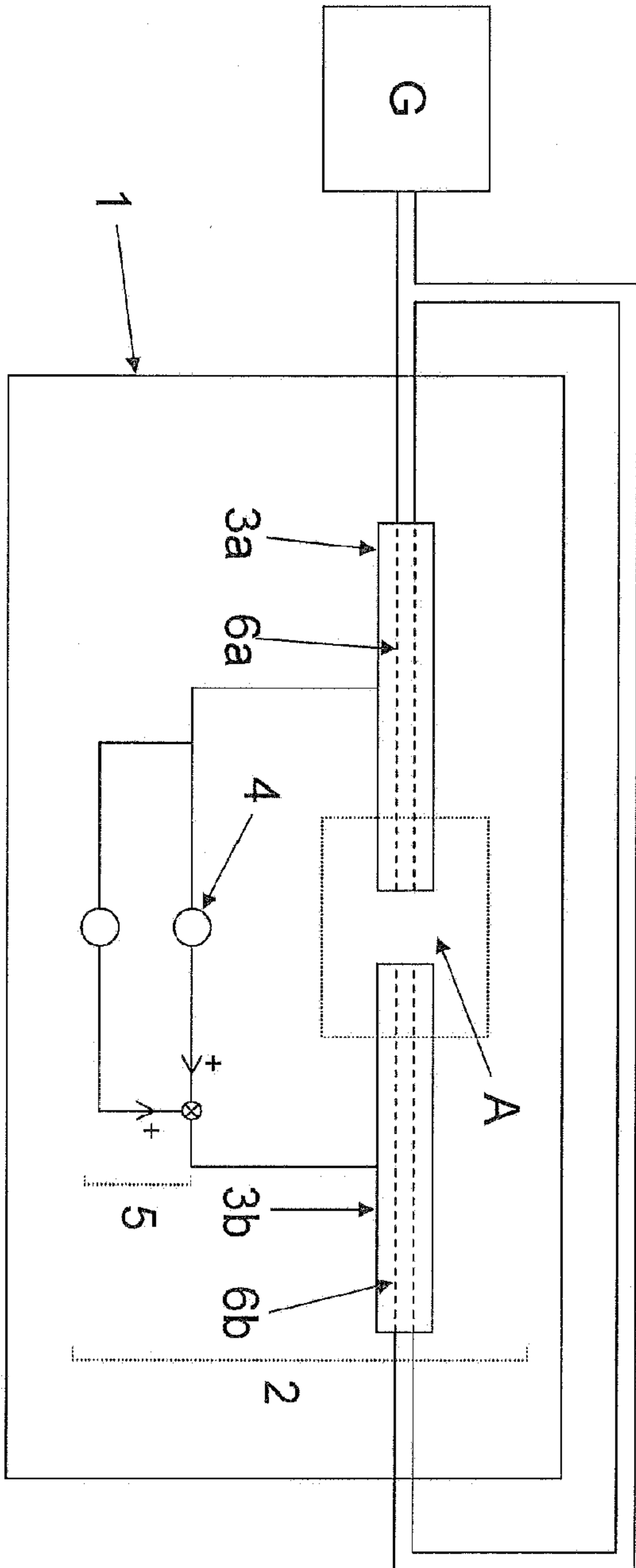


FIG. 1