

METHOD FOR OPERATING A PULSED ARC SOURCE

Technical field

5 The invention relates to a method for operating an arc source, as claimed in the precharacterizing clauses of claims 1, 8 and 9, and to an arc source as claimed in the precharacterizing clauses of claims 34, 43 and 45.

10 Prior Art

The pulsing of arc sources has already been known for a relatively long time from the prior art, for example WO 02/070776 describes in a very general form the
15 pulsing of spark sources in order to deposit various super-hard layers including TiSiN.

WO 03/057939 describes a spark source in which the spark is ignited via a pulsed high-voltage supply, and
20 the spark is fed via a pulsed high-current supply. In this case, the spark is operated discontinuously. Initial materials are metallically conductive cathodes, conductive alloys and, in addition, carbon, and/or semiconductors which can be vaporized. The arc source
25 described here is, however, difficult to manufacture and expensive to operate, particularly for cathode materials which are difficult to process, because of the highly complex geometry of the target body.

30 US 6, 361, 663 describes an arc source with a cathode composed of electrically conductive material, which is operated in a pulsed or modulated-pulsed form with peak currents of up to 5 kA and with a base current of, for example, 100 A. This source as well is difficult to
35 manufacture and expensive to operate as a result of its design with a magnetic tunnel and an anode which is completely surrounded by the cathode.

The deposition of electrically insulated layers by means of cathodic spark vapor deposition is already known, for example US 5,518, 597, describes the production of such layers using a reactive process. In
5 this case, the surfaces to be coated are arranged outside an optical link to the active target surface, which in this case is used synonymously with the vapor-deposition surface of the cathode. After pumping out, the process pressure is set using inert gas. During the
10 coating process, the oxygen is introduced in the immediate vicinity of the surface to be coated, to be precise only at a rate such that it is consumed during the operation, and a stable pressure can be maintained. This coincides with the known view from other documents
15 from the prior art as well, that the introduction of the reactive gas in the vicinity of the substrate is important to reduce the oxidation of the target and to stabilize the spark discharge. As an additional measure in order to avoid process interruptions resulting from
20 an undesirable build-up of insulating layers on the anode, the anode is preferably kept at a temperature of approximately 1200°C in US 5,518 597, and must be manufactured from expensive, that is to say costly, refractory metal.

25 All of these methods have the common feature that special measures must be taken when using reactive gases which react quickly with the material or materials being vaporized forming an insulating layer,
30 in order on the one hand not to contaminate the active surface of the target or of the anode, while on the other hand avoiding the formation of undesirable droplets. In addition to the heating of the anode and the supply and precise metering of the reactive gas in
35 the immediate vicinity of the surface to be coated that have been mentioned, measures such as these include dilution of the reactive gas with a high proportion of inert gas.

In this case, particular care must be taken to ensure that the surface of the target is metallically bare, or that its conductivity corresponds at least to that of a semiconductor. The positive temperature gradients of
5 semiconductors in the area of the arc spot admittedly results in sufficiently good conductivity in order to allow the spark to burn, but the increased tendency associated with this of the spark to burn continuously normally leads to greater splatter formation than in
10 the case of metallically conductive target surfaces. A range of options relating to this are also known from the prior art. For example as mentioned above, the sources can be arranged outside the optical connecting line to the target surface, although this drastically
15 restricts the yield of target material and the coating rate. Magnetic fields can be applied additionally or on their own, guiding only the ionized vapor component to the surfaces to be coated, while electrically neutral droplets are trapped on impingement surfaces. Examples
20 of this are curved magnetic filters, magnetic lenses and the like.

A further way to reduce splatter is to briefly interrupt the current supply, with the sparks being
25 restruck, for example controlled by means of a laser beam, at a different point in each case on the active target surface. This method is used in particular in the field of cathodic spark deposition of carbon, although it is also used for alloys composed of metal.

30 All of these measures, as well as the combinations of these measures that are likewise known, have the common feature of considerable additional technical complexity and/or a major reduction in the coating rate. However,
35 if an insulating coating is formed on the target surface, then it has not yet been possible to achieve a stable process, even with the measures mentioned above.

Description of the invention

One object of the present invention is therefore to provide a method by means of which it is also possible
5 to produce insulating layers using conventional arc sources, without any complex additional measures, and in stable process conditions.

This object is achieved by a method as claimed in
10 claims 1, 8 and 9 with an arc source as claimed in claims 34, 43 and 45. Further inventive embodiments are described in the dependent claims, which can be used individually or can be combined together, where this is technically worthwhile.

15 Surprisingly, it has been possible to show that a stable arc process can be achieved by a simultaneous application of a direct current on which a pulsed current or alternating current is superimposed, even if
20 the target surface is at least partially covered by an insulating coating.

By way of example, it has been possible to operate an aluminum target for several hours in a pure oxygen
25 atmosphere without any further additional measures. During this process, a rise was observed in the voltage on the target, but this rise stabilized within minutes and did not lead to interruption or to instability of the arc process. The aluminum oxide layer which is
30 deposited during this process on a substrate positioned directly in front of the target exhibited a completely unexpected considerable reduction in the surface flaws caused by adhering droplets, in comparison to a metallic aluminum layer deposited in the same
35 conditions. Similar results were also achieved by operating chromium or titanium targets, and metallic targets composed of these materials with a high silicon content, even above 50%, in a pure oxygen or pure nitrogen atmosphere. In all cases, the target could be

restruck without any problems in a reactive-gas atmosphere, after a complete insulating coating had been formed on the surface, even following process interruptions and could be operated with reduced droplet formation. In this pulsed mode, operation in a pure reactive-gas atmosphere and with the coating of the target surface by the reactive gas or its reaction with the target surface, led to improved layer quality with reduced droplet formation.

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In comparison to operation of the targets without an insulating coating, it was found that the proportion of the reactive gas should be chosen to be at least sufficiently high that the source voltage increases by at least 10%, but preferably by at least 20% in comparison to operation without an insulating coating. The rise in the source voltage is fundamentally dependent on the reactive gas and the target material used. The higher the insulation characteristics of the compound or compounds produced from the target material and the reactive gas on the target surface, the greater the difference in the source voltage normally becomes, even if it is not directly possible to produce a direct mathematical relationship in this case owing to numerous surface-specific and material-specific reaction patterns and constraints.

In this case, the following gases are suitable, by way of example, as reactive gases: oxygen, nitrogen acetylene, methane, silanes such as tetramethylsilane, trimethylaluminum, diborane or, in principle, all gases containing oxygen, nitrogen, silicon, boron or carbon. This method is particularly suitable for processes with high reactive gas flows, in which the proportion of the reactive gas is chosen to be greater than that of the inert gas, for example to be more than 70% and in particular more than 90%. However, as mentioned above, processes can also advantageously be carried out in a

pure atmosphere, that is to say an atmosphere containing 100% reactive gas.

In principle, in this case, the target material may be any material which forms corresponding insulating coatings, for example composed of oxide, nitride, boride, silicide, carbide or a mixture of the compounds mentioned, with above mentioned gases on the surface of a target operated as described above. However, the following materials are particularly suitable for producing hard layers, barrier layers and decorative layers: transition metals from the IVth, Vth, VIth group in the periodic table or aluminum, boron, carbon or silicon, or an alloy or compound of the abovementioned materials, such as TiAl, CrAl, TiAlCr, TiSi, TaSi, NbSi, CrSi, WC. However, this method can also be used for simpler vapor deposition of pure materials with high melting points such as tungsten, tantalum, niobium and molybdenum

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In order to reduce splatter further, particularly when a target is operated in an atmosphere containing oxygen, it may be advantageous as disclosed in US 6,602,390 for the target material to be composed of a single crystallographic phase.

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A further advantage from the simultaneous operation of an arc source with a direct current and with a pulsed current or alternating current is obtained when coating temperature-sensitive workpieces, such as hardened steel, precipitation alloys on a bronze and a brass base, aluminum-magnesium alloys, plastics and others. When one or more arc sources are operated with direct current in the vicinity of the holding current, which is the smallest current at which stable operation of an electrically conductive arc source is still possible with a simple DC power supply, the temperature load on the workpieces to be coated is admittedly low, but the coating rate is at the same time unsatisfactory for

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industrial applications. The value of the holding current or the holding power is in this case dependent on the target material, on the nature of the arc source and the operation of the discharge, for example whether
5 this is operated in a vacuum with or without the addition of inert or reactive gases. Adequate conductivity to ensure stable operation at low currents is provided, for example, by metallically bare surfaces and by compounds such as WC, TiN or CrN. Graphite or
10 silicon targets in this case form a limit case, since on the one hand their conductivity is admittedly still adequate for them to be vapor-deposited by means of a DC arc, but on the other hand they exhibit a severe tendency for a spark to be burnt locally, thus leading
15 to plasma fluctuations and severe droplet formation for which reason, for example, graphite targets are nowadays preferably operated in a pulsed form.

If, in contrast, a source is operated in the vicinity
20 of a DC holding current and a pulsed current is superimposed on it at the same time, it has surprisingly been found to be possible not only to considerably increase the rate but also to keep the temperature load low in comparison to DC coating at a
25 comparable rate. The DC component is in this case advantageously set to between 100 and 300%, preferably between 100 and 200%, of the holding current, or of the holding power.

30 In the case of the sources as described in more detail below, a percentage of the holding current such as this corresponds to a DC component of the current flow in a range between 30 and 90 A, preferably between 30 and 60 A. In this case, in principle, the arc source may be
35 operated without process gas, but preferably with a process gas which contains only reactive gas, only inert gas or a mixture of reactive gas and inert gas.

In this case, in principle, all conductive and semiconductive materials may be used as the target material, but preferably those as mentioned above.

5 In this case, the various current components can be applied and produced in a known manner. For example, the direct-current component can be produced by a direct-current generator, and the pulsed- or alternating-current component can be produced by a
10 pulsed- or alternating-current generator, with the two generators being connected either in parallel or in series between the arc source and at least one anode or ground.

15 Another option is to produce the direct-current and pulsed-current components by means of pulsed- or alternating-current generators which are likewise switched and are operated in a superimposed and synchronized form. Furthermore and finally, it is also
20 possible to produce the direct-current and pulsed-current components by means of a single current generator, which is clocked on the secondary or primary.

25 A procedure such as this is of particular interest for industrial applications when, for example, workpieces which are subject to particular requirements with regard to wear resistance and workpieces whose surfaces are intended to have insulating or decorative
30 characteristics, need to be coated. Layer examples for which methods such as these are particularly suitable are aluminumoxide, aluminumnitride, aluminumoxynitride, chromiumoxide, chromiumnitride, chromiumoxynitride, aluminumchromiumoxide,
35 aluminumchromiumnitride, aluminumchromium-oxynitride, aluminumchromiumoxycarbonitride, siliconoxide, siliconnitride siliconoxynitride, siliconaluminumoxide, siliconaluminumnitride, siliconaluminumoxynitride, titaniumsiliconnitride, titaniumsiliconoxynitride,

tantalumsiliconnitride, tantalumoxide,
tantalumoxynitride, tungstensiliconnitride,
niobiumsiliconnitride, titaniumcarbide,
tungstencarbide, tungstensiliconcarbide or an alloy or
5 compound of the abovementioned materials.

The materials mentioned may be deposited as a single
layer or as a sequence of two or more layers with
varying elementary composition, stoichiometry and
10 crystallographic alignment, in which case the layer
thickness of the individual layer element can be
adjusted as required between a few nanometers and
several micrometers. In addition, as those skilled in
the art may be aware, metallic or nitridic adhesion
15 layers or matching layers composed of different
compounds which, for example, allow a graded transition
from the substrate material of the workpiece to the
layer material can, for example, also be deposited
before the layers mentioned above. Known adhesion
20 layers are, for example, Cr, Ti, CrN or TiN. Matching
layers are listed in example 1.

In addition, in methods such as these, a DC, a pulsed
or an alternating-current bias can advantageously be
25 applied, and, if required, is synchronized to the
pulsed or alternating-current generator of the source.

In this case, changes in the layer composition, and
therefore two-layer or multiple-layer systems with a
30 graded or stepped profile, as required, of the layer
composition can be deposited in a known manner by an
alternating addition of at least one inert gas and at
least one reactive gas, or by an alternating addition
of at least two reactive gases, at right angles to the
35 workpiece surface. A plurality of sources with an
identical or different target material can be used for
this purpose.

A method as described above can be used in a similarly advantageous manner for operating an arc source when a source is used to etch workpiece surfaces since, in this case, the surface is coated to a considerably lesser extent with droplets than is the case with metallic target surfaces. In this case a DC, a pulsed or an alternating-current bias is also applied to the workpieces, although this is generally considerably higher than the bias applied during coating. For example, substrate voltages between -50 and -2000 V, preferably between -200 and -1500 V can be set in this case. In order to increase the etching erosion, an etching gas can additionally be introduced, containing the following components by way of example, helium, argon, krypton, oxygen, nitrogen, hydrogen, halogen, (for example chlorine, fluorine, bromine, iodine), or a compound containing halogen.

In all of the methods mentioned above, the coating rate and the energy introduced into the workpiece can be adapted or regulated by setting the pulse width, the current pulse, the magnitude of the current pulse or by the duty ratio, or by a combination of these parameters. A further option is to increase the DC source current, although, for example, this is not very suitable for low-temperature processes.

Workpieces that are suitable for a coating or etching method such as this include, in particular tool and components composed of steels and construction metals such as copper and lead bronzes, brass and special alloys such as aluminum-magnesium alloys, hard metals, ceramic materials such as boronitride, in particular CBN, cermet compounds and corresponding workpieces which have been at least partially provided with diamond or ceramic surfaces.

A further field of application for methods such as these is coating of workpieces composed of silicon or other semiconductive materials.

- 5 It has been found that coating in the described pulse mode is also suitable for insulating substrates for which no DC substrate bias or DC-pulsed substrate bias at relatively low or medium frequencies is worthwhile.
- 10 Summarized in the form of key words, a method as described above can be used to achieve the following further advantageous effects:
1. A stable process for producing insulating layers
15 by means of spark vapor deposition without any splatter being formed preventing through-oxidation/reaction of the layer.
 2. For the first time, it is possible to work with a completely contaminated spark target. Reactivity,
20 that is to say the reactive component available for example oxygen when depositing aluminumoxide, can be increased by working in the completely contaminated mode or in a pure reactive gas atmosphere, thus achieving greater layer growth.
 - 25 3. Neither local or pressure-stage in separation of the target and reaction area nor complex separation of splatter and ionizing vapor is required.
 4. Spark guidance can be carried out without any
30 additional magnetic field assistance.
 5. The amount and size of the splatter is reduced even with a contaminated target.
 6. Modulated pulsed operation makes it possible to work with higher currents, thus leading to greater
35 ionization while the thermal load on the target remains the same, or is even reduced.
 7. Carbon and semiconductor materials can be vapor-deposited, effectively without any splatter, without restriking and complex spark guidance.

8. More uniform removal of conductive, semiconductive and non-conductive target surfaces.
9. Finer splitting of the spark, that is to say a large number of small arc spots running quickly over the surface.
10. Greater ionization is achieved by using high-current pulses and by the increase in the substrate current associated with this.
11. The process control for reactive spark vapor deposition is independent of the target coating by insulating or semiconductive layers. This allows reactive gases to be mixed, and allows the use of ramps for reactive processes, with this being advantageous not only for the intermediate layer but also for the functional layer.
12. An increase in the process stability and a broader process window.
13. The use of known electrical power supplies which permit a wide range of specifications for the current and voltage (versatile economic combinations possible, for example a low-cost DC power supply for the basic load).
14. The invention ensures that the plasma is not interrupted and thus that there is no longer any need for repeated or periodic restriking by means of the complex technique required for this purpose.
15. The method can be combined with additional plasma sources; in this context, reference should be made in particular to additional excitation by means of a low-voltage arc operated at the same time, thus resulting in an additional increase in the reactivity in the case of layer deposition on the substrate.

Approaches to implementation of the invention

The following text describes a typical procedure for a coating method according to the invention with a

reactive spark coating process. Aluminumoxide has been deposited on various workpieces in this way using an industrial coating installation of the RCS type from the Balzers Company, for example as described in EP 1 186 681 in figures 3 to 6 and column 7, line 18 to column 9, line 25 of the description, on the basis of the example described in detail in the following text.

In addition to the actual coating process, further process steps which relate to the prior and subsequent treatment of the substrates will also be described briefly, when necessary. Many of these steps, such as the cleaning of the substrates, which is carried out differently depending on the material and the prior treatment, as known to those skilled in the art, can vary widely, while some can also be omitted, shortened, lengthened or combined in some other way in certain circumstances.

Example 1

Once the workpieces have been inserted into holders which can be rotated two or three times and are provided for this purpose, and the holders have been introduced into the vacuum treatment installation, the treatment chamber is pumped out to a pressure of approximately 10^{-4} mbar.

In order to set the process temperature, a low-voltage arc (NVB) plasma, assisted by radiation heating, was struck between a cathode chamber, separated by a shutter and having a hot cathode, and the anodically connected workpieces in an argon/hydrogen atmosphere.

The following heating parameters were set in this case:

Discharge: LVA	150 A
Argon flow	50 sccm
Hydrogen flow	300 sccm

Process pressure	1.4×10^{-2} mbar
Substrate temperature	approx. 500°C
Process time	45 min

5 Those skilled in the art will be familiar to the alternatives to this. The substrates were in this case preferably connected as an anode for the low-voltage arc, and were preferably additionally pulsed on a unipolar or bipolar basis.

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The etching is started as the next process step. For this purpose, the low-voltage arc is struck between the filament and the auxiliary anode. In this case as well, DC supply, a pulsed DC supply or an MF or RF supply
15 operating with alternating current can be connected between workpieces and ground. However, the workpieces preferably had a negative bias voltage applied to them.

The following etching parameters were set in this case:

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Argon flow	60 sccm
Process pressure	2.4×10^{-3} mbar
Discharge: LVA	150 A
Substrate temperature	approx. 500°C
25 Process time	30 min

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In order to ensure the stability of the low-voltage arc discharge during the production of insulating layers, either a hot conductive auxiliary anode is used, or a
30 pulsed high-current supply is connected between the auxiliary anode and earth, for all of the LVA-assisted process steps.

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In order to increase the adhesion strength, CrN layer with the thickness of approximately 300 nanometers is applied by spark vapor deposition, and can be assisted, if required, by additional ionization by the plasma of the low-voltage arc as well.

In this case, the following intermediate-layer parameters were set:

	Argon flow	80 sccm
5	Nitrogen flow	200 sccm
	Process pressure	8×10^{-3} mbar
	DC source current Cr	140 A
	Substrate bias	from -100V to -40V bipolar
10		36 μ s negative and 4 μ s
		positive bias
	Substrate temperature	approx. 500°C
	Process time	10 min

15 For the transfer to the actual functional layer, lasting for approximately 5 minutes, the aluminum arc sources have DC source current of 60 A applied to them, with the positive pole of the DC source being connected to the anode ring and ground. In addition, unipolar DC
20 pulses are superimposed from a second, parallel-connected electrical power supply, which is operated at 50 kHz. In the present example, a symmetrical duty ratio comprising 10 μ s pulses and 10 μ s pauses was used, with currents of up to 150 A being generated in the
25 pulses. This was followed by introduction of the oxygen at 300 sccm, to be precise using the parameters listed in the table.

Once aluminum targets have been started up and the
30 oxygen flow has been set, the source current at the Cr target is reduced to zero in approximately 10 minutes by means of a ramp, and the nitrogen flow is reduced at the same time. The argon flow is then reduced to zero.

35 The substrates are coated with the actual functional layer in pure reactive gas (in this case oxygen). Since aluminumoxide results in insulating layers, either a pulsed or an AC bias supply is used.

The major functional layer parameters were in this case set as follows:

	Oxygen flow	300 sccm
5	Process pressure	9×10^{-3} mbar
	DC source: Al	60 A
	Pulsed current source: Al	150 A, 50 kHz, 10 μ s pulse/10 μ s pause
	Substrate bias	remains at -40 V
10		DC pulsed or AC (50-350 kHz in each case)
	Substrate temperature	approx. 500°C
	Process time	60 to 120 min,
15		individual experiments at 360 min

The coating process can also be carried out simultaneously using a low-voltage arc that has been struck. This results in greater reactivity. Furthermore, the simultaneous use of the low-voltage arc during the coating process also has the advantage that the DC component of the sources can be reduced further depending on the magnitude of the LVA current.

25 The coating process carried out in this way is stable over several hours. The target is covered with a thin, smooth oxide layer. The spark propagates more smoothly than in the case of operation without an additional pulsed signal, and is split into a plurality of smaller sparks. The amount of splatter is considerably reduced.

Arc sources from Balzers Company with a target diameter of 160 mm and a thickness of 6 mm, and with a standard MAG 6 magnet system, were used as arc sources for the adhesion layer in the same way as for the functional layer. In principle, however, any known source can be used for a process such as this, provided that an appropriate electrical power supply unit is connected.

The described process is the preferred version since this avoids stringent requirements for the pulsed electrical power supply. A DC supply produces the minimum current or holding current for the sparks, and
5 the pulsed high-current supply is used to avoid splatter.

Further examples for the deposition parameters of functional layers are described in more detail in Table
10 1. Essentially the same cleaning, heating and etching steps were carried out first of all, and an intermediate layer composed of CrN or TiN was deposited in a corresponding manner to example 1. The functional layers composed of aluminumoxide, aluminumnitride,
15 chromiumoxide, chromiumnitride, titaniumoxide and titaniumnitride were then produced, in accordance with the details in the table.

A purely metallic layer was deposited in examples 2 and
20 8 in order to compare the influence of the source voltage by the covering with an insulating coating. In this case, it was found that coating with highly-insulating oxidic layers results in particular in a major rise in the DC component of the source voltage.
25 In this case, the relative voltage rise even for relatively small additions of reactive gas containing oxygen is between approximately 20 and 50% of the value of the metallically bare source operated in pure inert gas. Even the use of nitrogen results in a rise in the
30 source voltage, although its values are lower, for example between approximately 10 and a maximum of 30%. In all cases, the simultaneous application of a pulsed voltage admittedly leads to a minor reduction in the DC source voltage in comparison to purely DC operation,
35 but the original lower voltage state of a metallically bare source is, however, never reached again.

The preferred frequency range for operation of the arc source is between 5 and 50 kHz. If required, however,

the source can also be operated at lower frequencies down to about 0.5 kHz, or at high frequencies up to 1 MHz. At even lower frequencies, the operation for the deposition of insulating layers becomes unstable, while
5 at higher frequencies the generator costs rise to an extreme level.

If additional matching layers are desirable or necessary, then these can be applied instead of the CrN
10 or other adhesion layers or between the adhesion layer and the functional layer. Examples of this which may be advantageous in addition to those already mentioned as well for the deposition of oxidic covering layers, are oxycarbides of titanium and chromium, as well as the
15 oxynitrides, oxysilicides, oxysilicon nitrides, and siliconitrides of aluminum, chromium, titanium, tantalum, niobium and zirconium.

Despite the excellent adhesion strength of adhesion and
20 matching layers produced by means of cathodic spark vapor deposition, this can also be achieved, as is known to those skilled in the art, by means of other coating techniques such as CVD, PECVD, sputtering or by vapor deposition by means of low-voltage arcs from an
25 anodically connected crucible. In this case, in principle, any combination of various techniques is possible, but plasma-assisted processes, which ensure high ionization, are preferred because of the better adhesion that can be achieved in this way.

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Brief description of the drawings

The invention will be explained in more detail in the following text with reference to figures which
35 illustrate only various exemplary embodiments, and in which:

Figure 1 shows a vacuum treatment installation with an arc source

Figure 2 shows a parallel-connected DC and pulsed-current supply

Figure 3 shows target surfaces

5 Figure 4 shows two parallel-connected pulsed-current supplies

Figure 5 shows a multi-anode arrangement

Figure 6 shows electrical power supplies connected in series

10 Figure 7 shows electrical power supplies connected with a short circuit

Figure 8 shows a secondary-clocked electrical power supply

Figure 9 shows a primary-clocked electrical power supply

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The vacuum treatment installation 1 illustrated in Figure 1 shows, comparatively, an arrangement known from the prior art for operating an arc source with a DC power supply 13. The installation 1 is equipped with
20 a pump stand 2 to create the vacuum, substrate holders 3 to hold and make electrical contact with the workpieces, which are not illustrated in any more detail here, as well as a bias-current supply 4, for applying a so-called substrate voltage to the
25 workpieces. The latter may be DC or AC or a bipolar or unipolar substrate voltage supply. Inert gas or reactive gas can be introduced via a process gas inlet 11, in order to control the process pressure and the gas composition in the treatment chamber.

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The components of the arc source itself are a target 5 with a cooling plate 12 located behind it, an ignition finger 7 and an anode 6 which comprises the target. A switch 14 can be used to select between floating
35 operation of the anode and of the positive pole of the electrical power supply 13, and operation with a defined zero or ground potential.

Further optional features of the vacuum treatment installation 1 are an additional plasma source 9, in this case a source for producing LVA with a hot cathode, with an inert gas inlet 8, an auxiliary anode 10, and a further electrical power supply, which will not be described in any more detail here, for operating the low-voltage arc between the plasma source 9 and the auxiliary anode 10, and, if required, coils 17 for magnetic focusing of the low-voltage arc plasma.

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Figure 2 shows an arc source which is operated with two parallel-connected electrical power supplies, specifically a DC power supply 13' and a pulsed high-current supply 18, in order to superimpose a unipolar or bipolar pulse signal on the direct current. This circuitry allows stable operation of a reactive spark vapor deposition process even for insulating layers for which, over the course of time, the interior of the installation 1, the auxiliary anode 10 and the substrate holders 3 are filled with substrates with an insulating layer.

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If, for comparative purposes, a target 5 composed of pure aluminum is operated in an atmosphere containing argon and oxygen, just with a DC power supply 13 as shown in Figure 1, process instabilities will occur even after just a few minutes, leading to process termination with a high oxygen flow. In the process, a coating will be produced as shown in Figure 3a on the target 5, with large islands with a size of several millimeters and composed of insulating material. The layers deposited on the workpiece surfaces will be very rough and will not provide complete insulation, since this obviously does not result in a continuous reaction of the large amount of metallic splatter. If, in contrast, a target 5 is operated in an atmosphere containing oxygen in conditions which are otherwise the same, with a method according to the invention as in Figure 2, an aluminum oxide surface which provides

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insulation but is completely uniform will be formed, as shown in Figure 3b. The process can be carried out over a period of hours, can be interrupted, and can be resumed with a target that has been contaminated in this way. At the same time, this leads to a considerable reduction in the splatter on the workpiece surface.

Further options and arrangements for pulse-modulated operation of an arc source will be described in the following text. Figure 4 shows two DC power supplies 18' and 18'' connected in parallel, which are pulsed in a preferred synchronized form. By way of example, this arrangement has a number of advantages when operated in unipolar form. For example, when operated with the same pulse width, the time between two pulses can be chosen to be very short, thus making it possible to set a correspondingly high duty ratio and a very short cycle duration. The capability associated with this of limiting the energy supply per pulse, for example, also as appropriate for this specific target material, makes it possible to very effectively avoid permanent burning of the spark, and splutter formation is further counteracted.

However, even when operated in a unipolar form with the different pulse widths and different frequencies or the same frequencies, such operation allows the individual cycle phases to be set particularly well, and therefore allows very good control of the coating rate. In principle, pulsed DC power supplies can also be replaced by better alternating-current supplies. However, in this case, it is more difficult, for example, to achieve signals of a specific form and with a specific edge gradient.

At the same time, as is shown in Figure 5, the concept of two electrical power supplies 19, 19'' particularly advantageously allows a plurality of anodes 20, 20' to

be positioned to achieve a better distribution of the plasma in the coating chamber. This allows the electrons to be guided better, thus making it possible to increase the plasma density and the reactivity of the process.

Figure 6 shows an arc source which is fed by two series-connected electrical power supplies 19', 19'', at least one of which is a pulsed or AC supply. This arrangement allows the rate control for the arc source to be adapted particularly easily.

The further exemplary embodiments relate to the electrical power supplies in which the pulsed current or the direct-current component is produced by means of switched-mode power supply technology. In the case of electrical power supplies such as these, the ripple, which is otherwise undesirable, of the resulting DC signal can be amplified in such a way that a signal which complies with the requirements described above is produced at the output of the electrical power supply. For example, as is illustrated schematically in Figure 7, a secondary-clocked electrical power supply can in this case be used as a step-up converter 21 or, as is illustrated in Figure 8, an electrical power supply which is likewise secondary-clocked can be used as a step-down converter 21'. In contrast, Figure 9 shows a primary-clocked electrical power supply 22 for producing the desired signal.

Of all of the supplies using switched-mode power supply technology, the supply illustrated in Figure 8 is that which can be implemented with the least technical complexity, and that which is therefore used by preference.

List of reference symbols

	1	Vacuum treatment installation
	2	Pump stand
5	3	Substrate holder
	4	Bias-current supply
	5	Target
	6	Anode
	7	Ignition finger
10	8	Inert gas inlet
	9	Plasma source
	10	Auxiliary anode
	11	Process gas inlet
	12	Cooling plate
15	13,13'	DC electrical power supply
	14	Switch
	17	Magnet coils
	18,18',18''	Pulsed-current supply
	19,19',19''	Electrical power supply
20	20,20'	Anode
	21	Step-up converter
	21'	Step-down converter
	22	Primary-clocked electrical power supply

PATENT CLAIMS

1. A method for operating an arc source, in which an electrical spark discharge is ignited or operated
5 on a surface of a target, with the spark discharge being fed at the same time with a direct current and with a pulsed or alternating current, **characterized in that** the surface of the target is at least partially covered by an insulating
10 coating.
2. The method as claimed in claim 1, **characterized in that** the insulating coating is produced by operating the source in an atmosphere containing
15 reactive gas.
3. The method as claimed in claim 2, **characterized in that** the insulating coating results in an increase in the DC component of the source voltage by at
20 least 10%, preferably by at least 20%, in comparison to operation with a surface without an insulating coating.
4. The method as claimed in claim 2, **characterized in that** the atmosphere containing reactive gas
25 comprises at least one of the following components, a gas containing oxygen, nitrogen, silicon, boron or carbon, in particular oxygen, nitrogen, acetylene, methane, a silane,
30 tetramethylsilane, tetramethylaluminum, diborane.
5. The method as claimed in claim 2, **characterized in that** the proportion of reactive gas is greater
35 than that of the inert gas, preferably more than 70%, furthermore preferably more than 90% or approximately 100%.
6. The method as claimed in claim 1, **characterized in that** the target material comprises at least one of

the following materials: a transition metal from the IVth, Vth, VIth group in the periodic table or aluminum, boron, carbon or silicon, or an alloy or compound of the abovementioned materials, such as
5 TiAl, CrAl, TiAlCr, TiSi, TaSi, CrSi, WC.

7. The method as claimed in claim 6, **characterized in that** the insulating coating is composed of an oxide, nitride, boride, silicide, carbide of the
10 target material or of a mixture of the compounds of the target material mentioned.
8. A method for operating an arc source, in which an electrical spark discharge is ignited or operated
15 on a surface of a target, with the spark discharge being fed at the same time with a direct current and with a pulsed or alternating current, **characterized in that** the DC component of the current flow is set in a range between 100% to
20 300% of a holding current, preferably between 100 and 200%.
9. A method for operating an arc source, in which an electrical spark discharge is ignited or operated
25 on a surface of a target, with the spark discharge being fed at the same time with a direct current and with a pulsed or alternating current, **characterized in that** the DC component of the current flow is set in a range between 30 and 90
30 A, preferably between 30 and 60 A.
10. The method as claimed in one of claims 8 or 9, **characterized in that** reactive gas, inert gas, or reactive gas and inert gas is or are added.
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11. The method as claimed in one of claims 8 or 9, **characterized in that** the target material comprises at least one of the following materials: a transition metal from the IVth, Vth, VIth group

in the periodic table or aluminum, boron, carbon or silicon, or an alloy or compound of the abovementioned materials, such as TiAl, CrAl, TiAlCr, TiSi, TaSi, CrSi, WC.

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12. The method as claimed in one of claims 1, 8 or 9, **characterized in that** the target material is composed of a single crystallographic phase.

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13. The method as claimed in one of the preceding claims, **characterized in that** the direct-current component is produced by a direct-current generator, and the pulsed- or alternating-current component is produced by a pulsed- or alternating-current generator, with the two generators being connected either in parallel or in series between an arc cathode and at least one anode or ground.

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14. The method as claimed in one of claims 1 to 12, **characterized in that** the direct-current component and the pulsed-current component are produced by two pulsed- and alternating-current generators which are operated superimposed and synchronized, with the two generators either being connected in parallel or in series between an arc cathode and at least one anode or ground.

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15. The method as claimed in one of claims 1 to 12, **characterized in that** the direct-current and the pulsed-current component are produced by a secondary-clocked current generator, with the generator being connected either in parallel or in series between an arc cathode and at least one anode or ground.

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16. The method as claimed in one of claims 1 to 12, **characterized in that** the direct-current and the pulsed-current component are produced by a primary-clocked current generator, with the

generator being connected either in parallel or in series between an arc cathode and at least one anode or ground.

- 5 17. A coating method, **characterized in that** an arc source as claimed in one of the preceding claims is operated in order to deposit one or more layers on a workpiece.
- 10 18. The coating method as claimed in claim 17, **characterized in that** the layer is composed of at least one of the following materials: a transition metal from the IVth, Vth or VIth group in the periodic table and aluminum, and their compounds with oxygen, nitrogen, carbon, boron or silicon.
- 15 19. The coating method as claimed in claim 17, **characterized in that** the layer is composed of at least one of the following materials:
- 20 aluminumoxide, aluminumnitride, aluminumoxynitride, chromiumoxide, chromiumnitride, chromiumoxynitride, aluminumchromiumoxide, aluminumchromiumnitride, aluminumchromiumoxynitride, aluminumchromiumoxycarbonitride,
- 25 siliconoxide, siliconnitride, siliconoxynitride, siliconaluminumoxide, siliconaluminumnitride, siliconaluminumoxynitride, titaniumsiliconnitride, titaniumsiliconoxynitride, tantalumsiliconnitride, tantalumoxide, tantalumoxynitride, tungsten-
- 30 siliconnitride, tungstensiliconcarbide, niobiumsiliconnitride, titaniumcarbide, tungstencarbide or an alloy or compound of the abovementioned materials.
- 35 20. The coating method as claimed in claim 17, **characterized in that** a DC, a pulsed or an alternating-current bias is applied to the workpiece.

21. The coating method as claimed in claim 20,
characterized in that a pulsed or alternating-
current bias is applied, synchronized to the
pulsed current or alternating current from the
source.
22. The coating method as claimed in claim 17,
characterized in that at least one inert gas or
reactive gas is added at a first flow rate at
least once, and at least one further reactive gas
is then added at a second flow rate, or vice
versa, in order to vary the layer composition.
23. The coating method as claimed in claim 22,
characterized in that the first flow rate is
reduced before, during or after setting the second
flow rate, and the second flow rate is set from a
low value to a higher value, or vice versa.
24. The coating method as claimed in claim 22,
characterized in that the addition or setting
process is carried out in the form of a ramp or a
step, in order to produce a substantially constant
or stepped variation in the layer composition.
25. The coating method as claimed in claim 22,
characterized in that a layer with two or more
layer elements is deposited by alternately
increasing and decreasing the first and the second
flow rate.
26. The coating method as claimed in claim 17,
characterized in that a plurality of sources are
operated at the same time, with identical or
different target material.
27. An etching method for etching with **metal ions**
characterized in that an arc source as claimed in
one of claims 1 to 15 is operated with DC, a

pulsed or an alternating-current bias being applied, in order to etch at least one workpiece.

- 5 28. The etching method as claimed in claim 27, **characterized in that** a DC bias between -50 and -2000 V, preferably between -200 and -1500 V, is set on the workpiece.
- 10 29. The etching method as claimed in one of claims 27 or 28, **characterized in that** an additional etching gas is introduced.
- 15 30. The etching method as claimed in claim 29, **characterized in that** the etching gas contains at least one of the following components: helium, argon, krypton, oxygen, nitrogen, hydrogen, halogen (for example chlorine, fluorine, bromine, iodine) or a compound containing halogen.
- 20 31. The coating or etching method as claimed in one of claims 17 to 30, **characterized in that** the coating rate and the energy introduced into the workpiece are set by adjusting at least one of the following parameters: the pulse width of the current pulse, the magnitude of the current pulse, the duty ratio.
- 25 32. The coating or etching method as claimed in one of claims 17 to 31, **characterized in that** the workpiece is a tool or a component.
- 30 33. The coating or etching method as claimed in one of claims 16 to 28, **characterized in that** the workpiece is composed essentially of silicon or of some other semiconductive material.
- 35 34. An arc source having a target (5) and at least one opposing electrode (6, 20, 20') and an electrical power supply unit which is connected to the target

(5), **characterized in that** the electrical power supply unit comprises at least one first pulsed high-current supply (18, 18') and a further electrical power supply (13', 18'').

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35. The arc source as claimed in claim 34, **characterized in that** the electrical power supply unit additionally comprises a DC current supply (13'), which is designed at least to maintain a holding current.

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36. The arc source as claimed in claim 34, **characterized in that** the electrical power supply unit additionally comprises a DC current supply (13') which is designed at least to maintain a holding current.

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37. The arc source as claimed in claim 34, **characterized in that** the electrical power supply unit additionally comprises a second, pulsed high-current supply (18''), which can be synchronized with the first pulsed arc source such that a holding current with a superimposed pulsed signal can be set.

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38. The arc source as claimed in claim 36, **characterized in that** the pulsed arc sources (18', 18'') can be synchronized such that the holding current has one or more holding-current pauses in individual pulse pauses or in all of the pulse pauses, in which no voltage is applied to the target or to the electrode, in which case the holding-current pauses can be set to be so short that the arc plasma is not quenched in the pauses.

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39. The arc source as claimed in claim 37, **characterized in that** the holding-current pauses can be set between 1 ns and 1 μ s, in particular between 1 and 100 ns.

40. The arc source as claimed in claim 34,
characterized in that the first pulsed high-
current supplies (18, 18') and the further
5 electrical power supply (13', 18'') are connected
in parallel or in series.
41. The arc source as claimed in claim 34,
characterized in that the first pulsed high-
10 current supplies (18, 18') and the further
electrical power supply (13', 18'') are connected
in parallel or in series.
42. The arc source as claimed in claim 34,
15 **characterized in that** at least the first pulsed
high-current supplies (18, 18') or at least the
further electrical power supply (13', 18'') is
connected between the target (5) and an electrode
(6) which comprises the target, or further
20 electrodes (20, 20').
43. An arc source having a target (5) and at least one
opposing electrode (6, 20, 20') and an electrical
power supply unit which is connected to the target
25 5, **characterized in that** the electrical power
supply unit is a secondary-clocked electrical
power supply (21, 21'), by means of which the
signal of the secondary-clocked electrical power
supply (21, 21') is modulated such that a DC
30 holding current is produced, with a pulsed signal
or AC signal superimposed on it.
44. The arc source as claimed in claim 42,
characterized in that the secondary-clocked
35 electrical power supply is in the form of a step-
down converter (21') or a step-up converter (21).
45. An arc source having a target (5) and at least one
opposing electrode (6, 20, 20') and an electrical

power supply unit which is connected to the target
(5), **characterized in that** the electrical power
supply unit is a primary-clocked electrical power
supply (22), by means of which the signal of the
5 primary-clocked electrical power supply (22) is
modulated such that a DC holding current is
produced, with a pulsed signal or AC signal
superimposed on it.