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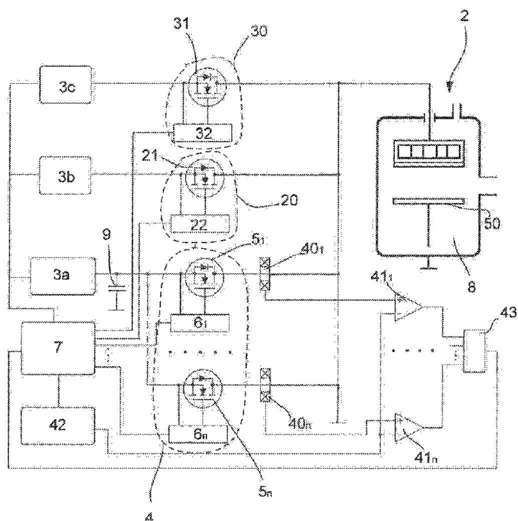

Fig. 2

(57) Abstract: A pulse generation device (1) for generating pulses for a magnetron sputtering system, such as high power impulse magnetron sputtering (HiPIMS), the pulse generation device (1) having a power input (3a, 3b, 3c) and further comprises a first switching unit (4) generating the pulses, the first switching (4) unit comprising at least two metal-insulation-semiconductor field-effect transistors (MISFETs) (5_1, 5_n) connected in parallel, the power input (3a, 3b, 3c) being split into at least two current channels, each current channel comprising a respective one of the transistors (5_1, 5_n), and a driver (6_{-1}, 6_n) assigned to each transistor (5_1, 5_n). the pulse generation device further comprising a control unit (7) which is arranged to control each transistor (51, 5n) individually and to synchronize on and off of the transistors (5_1, 5_n) through the drivers (6_{-1}, 6_n) such that current from the at least two current channels results in the pulses.

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PULSE GENERATION DEVICE AND METHOD FOR A MAGNETRON SPUTTERING SYSTEM

Technical Field

The present disclosure relates to a pulse generation device for a magnetron sputtering system, a magnetron sputtering system comprising such a pulse generation device, a method of generating pulses, a method of
5 generating plasma in a magnetron sputtering system, and a feedback system.

Technical Background

High power impulse magnetron sputtering (HiPIMS) is a physical vapor deposition (PVD) technology that combines magnetron sputtering with pulsed
10 power technology. In HiPIMS high power (power which is significantly higher than in DC or RF magnetron sputtering (up to 10^6 Watt or even more)) is applied to the magnetron target in unipolar pulses with respect to a grounded anode at low duty cycle to keep the average power much lower than the peak power. This results in a high plasma density and high ionization fraction of the
15 sputtered vapor, which allows for a good control of the film growth by controlling the energy and flux of deposition species.

It is a well-established fact that the rising time of the discharge current requires tens or sometimes more than a hundred microseconds to reach saturation. (With rising time is here meant the time period starting from the
20 beginning of the voltage pulse required for the current to reach its maximum possible peak value for the given cathode voltage and pulsing parameters.) This problem has been addressed to the imperfection of the plasma itself, i.e. to the lack of charge carriers in the plasma, which might require these long time periods to be developed.

25 Recently, however, the time lag between the voltage and current has been addressed to the imperfection of the power supply, and to the slowness of the switches used.

Traditional HiPIMS power supplies, which have existed for many years on the market, display a typical discharge current waveform like the one

shown in Fig. 1 (adapted from Hecimovic, A., et al., Plasma Sourc. Sc. and Techn., 21 (2012) 035017). Here a titanium target is sputtered and it takes more than 100 microseconds to reach saturation of the current (dashed line curve). (It should be noted that the time to reach saturation may be different for other target materials at the same pulsing parameters.) The system is slow when it comes to plasma generation at short pulse lengths. If the discharge voltage and the frequency are kept constant and the pulse length is decreased to 20 microseconds, the current behavior will not change drastically (for the current characteristics plotted for different discharge pulse lengths see for example Lundin, D., et al., Plasma Sourc. Sc. and Techn., 18 (2009) 045008). The discharge current waveform during such a pulse will look as shown in Fig. 1 and is indicated by the dashed line curve enclosing the checked pattern area. The discharge current obtained and the instantaneous power which can be delivered to the discharge during the pulse are lower than with a longer pulse. The rectangular region above the dashed line curve shows how much power can be potentially delivered to the plasma if the current rising time was shorter. Traditional HIPIMS power supplies do not have such short current rising times and the utilization of the power input is, hence, low.

In HIPIMS technology utilization of power supply units with insulated-gate bipolar transistors (IGBT) as power switches is the standard. See for example US 6,735,099 B2 in which a power supply HiPIMS unit with a switching element based on an H-bridge of four IGBTs is shown.

The slowness of IGBT switching systems do not allow for further progress in HiPIMS technology, which should be naturally achieved by increasing the power input during the pulse by decreasing its pulse length (provided that the frequency and the average power are preserved). In case of the existing knowledge, such a progress becomes impossible. Pulsing with a pulse length shorter than 50 μs is possible, but instead of receiving benefits in terms of increased ionization rate, higher deposition rate, better film structure, etc., the sputtering becomes less and less effective as the pulse length becomes shorter.

There is a problem of increasing the maximum average power with traditional HiPIMS power supplies. Higher power inputs require either more powerful IGBT transistors to be used or a larger number of them to be installed. Nowadays the progress in the development of HiPIMS power supplies is driven by the first possibility. This is because the complexity of the process of simultaneous turning on/off of the transistors requires a sophisticated control and timing unit. With high power IGBT transistors the utilization of the second option is quite difficult and is associated with unjustified risk of severe malfunction or even accidents in case of timing mismatch in turning in/off the high power switches.

Summary of the Invention

It is an object of the present disclosure to provide a pulse generation device for a magnetron sputtering system which results in a shorter rising time of the discharge current to reach saturation in comparison with known pulse generation devices. It is also an object to provide a magnetron sputtering system comprising such a pulse generation device and methods of generating pulses and of generating plasma in a magnetron sputtering system. A further object is to provide a feedback system.

The invention is defined by the appended independent claims. Embodiments are set forth in the dependent claims, in the attached drawings and in the following description.

According to a first aspect there is provided a pulse generation device for generating pulses for a magnetron sputtering system, the pulse generation device having a power input and further comprises a first switching unit generating the pulses, the first switching unit comprising at least two metal-insulation-semiconductor field-effect transistors (MISFETs) connected in parallel, the power input being split into at least two current channels, each current channel comprising a respective one of the transistors and a driver assigned to each transistor. The pulse generation device further comprises a control unit which is arranged to control each transistor individually and to synchronize on and off of the transistors through the drivers such that current from the at least two current channels results in the pulses.

The pulse generation device may be used for generating pulses for a high power impulse magnetron sputtering (HiPIMS) system.

That on and off of the transistors is synchronized is meant that there is a simultaneous turning on/off of the transistors. In other words the current 5 from the at least two channels is merged into one current.

Compared to known power generation solutions using IGBT, a higher energy output can be obtained with this pulse generation device during a single pulse, more current may be delivered to the plasma, with the same cathode voltage average power input and pulsing parameters, i.e. a discharge 10 current is developed faster/current rising time is shorter.

Due to better pulsing characteristics of the MISFETs (such as turn-on delay time, rise time, turn-off delay time and fall time) compared to IGBTs at the stage of their opening a faster switching time is achieved with the present pulse generation device. A discharge current is developed faster than with 15 IGBT based pulse generating devices.

The MISFET may be a metal oxide semiconductor field effect transistor (MOSFET).

Due to the parallel scheme of the pulse generation device a transistor failure does not mean a failure of the whole pulse generation device. The 20 maximum current/power of the pulse generation device is decided by the number of parallel connected current channels/transistors in the first switching unit and makes the device scalable.

The range of the discharge current may be increased by increasing the number of transistors (and the corresponding number of assigned drivers) in 25 the pulse generation device.

The pulse generation device may further comprise a second and/or a third switching unit, each of the second and third switching units comprising a transistor and a driver assigned to each transistor, wherein the second and third switching units are arranged to generate respective pulses.

30 The transistors of the second and third switching units may be metal–insulation–semiconductor field-effect transistors (MISFETs).

The MISFET may be a metal oxide semiconductor field effect transistor (MOSFET).

The pulse generation device may further comprise a protection system arranged to generate a feedback signal to the control unit based on current values of the at least two current channels.

The protection system may comprise a measuring device arranged to measure a current value of each current channel. A comparing unit may be assigned to each current channel and be arranged to compare a voltage value from the measuring device corresponding to the current value for a respective current channel with a reference voltage, wherein if the voltage value is lower than the reference voltage, the comparing unit is arranged to generate an output signal of a first type, and if the voltage value is higher than the reference voltage for a current channel, the comparing unit is arranged to generate an output signal of a second type. The control unit may be arranged to in response to an output signal of the second type at least turn off the transistor(s) in the current channel(s) causing output(s) of the second type.

It is, hence, possible to turn off only the malfunctioning transistor(s) causing the output value(s) of the second type. If one or more transistors are broken the whole protection system does not have to be turned off.

The transistor(s) may be turned off for a predetermined period of time, which for example may be the end of the current pulse (minimum duration). Alternatively, the transistor may be turned off for a predetermined number of periods or until the transistor(s) has reached a certain temperature.

With this protection system overcurrent (i.e. an excess current) above an automatically set threshold limit can be detected immediately and will not put in danger the consistency of the whole pulse generation device.

The main advantage with this protection system is that there is no need to adjust the reference voltage in each current channel every time the pulsing parameters or the discharge voltage is changed. The protection system calculates automatically what reference voltage to use at given pulsing condition based on pulsing parameters and cathode voltage.

The measuring device may be a sweeping device sweeping all current channels.

Alternatively, the measuring device may comprise a measuring unit assigned to each current channel.

The protection system may further comprise a receiving unit arranged to receive output signals from each comparing unit and arranged to generate and send a resulting output signal to the control unit if any of the output signals from the comparing units is an output signal of the second type.

5 In response to this resulting output signal all transistors in the first switching unit may be turned off.

According to a second aspect there is provided a magnetron sputtering system comprising a sputtering chamber and a pulse generation device as described above, wherein the first switching unit is arranged to generate

10 pulses for generation of a glow discharge in the sputtering chamber.

The second switching unit may be arranged to generate pulses to create a discharge ignition in the sputtering chamber.

The third switching unit may be arranged to generate pulses to maintain glow discharge in the sputtering chamber between pulses.

15 The pulse generation device may further comprise a substrate biasing unit for biasing a substrate in the sputtering system.

The substrate biasing unit may have a power input and may further comprise a fourth switching unit, the fourth switching unit comprising: a current channel comprising a transistor and a driver assigned to the

20 transistor. The substrate biasing unit further comprising a control unit controlling on and off of the fourth switching unit through the driver based on a current value of the current channel.

The magnetron sputtering system may be a high impulse magnetron sputtering system (HiPIMS).

25 According to a third aspect there is provided a method of generating pulses, the method comprising the steps of:

- providing a main power input;

- splitting the main power input in at least two channels, each channel comprising a respective metal-insulation-semiconductor field-effect transistor

30 (MISFET);

- providing a driver assigned to each transistor;

- providing a control unit for controlling each transistor individually and

for synchronizing on and off of the transistors through the drivers such that current from the at least two transistors results in the pulses.

The method may comprise a step of generating a feedback protection signal to the control unit based on current values of the at least two current channels.

The step of generating a feedback protection signal to the control unit may comprise the steps of:

- measuring a current value of each current channel;
- comparing voltage values corresponding to the current values from each current value measurement with a reference voltage;
- generating a comparative output signal of a first type if the voltage value is lower than the reference voltage;
- generating a comparative output signal of a second type if the voltage value is higher than the reference voltage;
- at least turning off the transistor(s) in the channel(s) causing output(s) of the second type.

According to a fourth aspect there is a method of generating plasma in a magnetron sputtering system, the method comprising the steps of

- generating pulses as described above;
- delivering the pulses to a sputtering chamber of the sputtering system;
- generating a glow discharge in the sputtering chamber.

With the method of generating plasma a saturation of a discharge current for a titanium target may be reached within a pulse length of less than 50 μs, or less than 40 μs, or less than 30 μs, or less than 20 μs.

According to a fifth aspect there is provided a feedback system having at least two parallel current cannels, wherein the feedback system comprises:

- a measuring device arranged to measure a current value of each current channel,
- a comparing unit assigned to each current channel and arranged to compare a voltage value from the measuring device corresponding to the current value for a respective current channel with a reference voltage, wherein if the voltage value is lower than the reference voltage, the

comparing unit is arranged to generate an output signal of a first type, and if the voltage value is higher than the reference voltage for a current channel, the comparing unit is arranged to generate an output signal of a second type;

- a control unit being arranged to receive the resulting output signal.

5 The measuring device may comprise a measuring unit assigned to each current channel.

The feedback system may further comprise a receiving unit arranged to receive output signals from each comparing unit and arranged to generate and send a resulting output signal to the control unit if any of the output
10 signals from the comparing units is an output signal of the second type.

Brief Description of the Drawings

Fig. 1 shows a typical discharge current waveform for a prior art HiPIMS power supply for a titanium target material.

15 Fig. 2 shows an electrical scheme of a pulse generation device generating pulses to a sputtering system.

Fig. 3 shows an electrical scheme of a substrate biasing unit for biasing a substrate in a sputtering chamber.

Fig. 4a schematically shows a method of generating a pulse and a
20 plasma in a sputtering chamber.

Fig. 4b schematically shows a method of generating a feedback protection signal to the control unit based on current values of current channels.

Fig. 5a and 5b show an illustrative comparison of how fast peak
25 current is reached with a plasma generating system comprising a prior art pulse generation device and the pulse generation device shown in Fig. 2.

Fig. 6 shows saturation of the discharge current with the pulse generation device of Fig. 2 at power inputs from 45.5 to 6.5 Watt when the target material in the sputtering system is titanium.

30

Detailed Description

In Fig. 2 an electrical scheme for a pulse generation device 1

generating pulses to a magnetron sputtering system 2 is shown. The magnetron sputtering system 2 may be a magnetron sputtering system such as a high power magnetron sputtering system (HiPIMS). The pulse generation 1 device could also be used for example in electrical filters, ozonizers and other plasma related applications characterized by non-linear electrical loads (not shown).

The electrical scheme comprises a power input 3a, 3b, 3c (DC mode in the range of 0-1200V), which could be provided by any type of power supply, to power the pulse generation device 1.

The pulse generation device 1 comprises a first switching unit 4 comprising at least two metal-insulation-semiconductor field-effect transistors (MISFETs) 5_1, 5_n connected in parallel. The power input is split in at least two current channels, each current channel comprising a respective one of the transistors 5_1, 5_n. Due to the split of the power input 3a a current in each channel/through each transistor 5_1, 5_n is lower than the current of the power input 3a. The transistors 5_1, 5_n may be placed physically apart from each other to facilitate cooling thereof.

The number of transistors 5_1, 5_n connected in parallel in the pulse generation device 1 may be any number. The upper limit is defined only by the required output power P_{max} or by the required output current I_{max}. The number of transistors n can be estimated by the formula $n=I_{max}/I_D+0.2(I_{max}/I_D)$, where I_D is the maximum allowed continuous drain current, 0.2 is the assurance coefficient. The MISFETs may be metal oxide semiconductor field effect transistors (MOSFETs).

A driver 6_1, 6_n, i.e. a gate driver, is assigned to each transistor 5_1, 5_n and used to regulate current flowing through the respective transistor. The driver 6_1, 6_n may comprise a level shifter in combination with an amplifier. The driver amplifies a signal from a control unit 7 to an amplified signal for the gate of the transistor 5_1, 5_n.

The control unit 7 is arranged to control each transistor 5_1, 5_n individually and to synchronize on and off of the transistors through the drivers 6_1, 6_n such that current from the at least two current channels results in the pulses, i.e. there is a simultaneous turning on/off of the transistors. In

other words the current from the at least two channels is merged into one current.

The control unit 7 may be a microprocessor comprising functions such as memory, calculation ability, logic unit etc. It may also serve as a master clock generator, which defines pulse frequency, pulse duration, off times, and delay times for all transistors. Apart from that, the control unit 7 may receive data from the measuring device/units 40_1, 40_n and may define the adaptive reference (or threshold) voltages. For example, the higher pulse duration, the lower reference voltage is required. The output from the pulse generation device 1 may be increased by adding more parallel channels each comprising a respective transistor 5_1, 5_n.

The control unit 7 may automatically increase/decrease the maximum allowed current passing through a transistor 5_1, 5_n by analyzing changes of pulsing parameters (duty cycle, pulse length, off-time, frequency etc.).

The magnetron sputtering system 2 may further comprise a sputtering chamber 8 and the first switching unit 4 of the pulse generation device 2 may be arranged to generate a glow discharge in the sputtering chamber 8.

A storage capacitor 9 may be arranged to provide the power input 3a to the transistors 5_1, 5_n. The nominal value and characteristics of the storage capacitor 9 should be sufficient to maintain the discharge voltage in the sputtering chamber 8 during the pulse.

The pulse generation device 1 may further comprise a second and/or a third switching unit 20, 30, each of the second and third switching units comprising a transistor 21, 31 and a driver 22, 32 assigned to each transistor, wherein the second and third switching units 20, 30 are arranged to generate respective pulses. The transistors 21, 31 of the second and third switching units may be field-effect transistors (MISFETs), such as metal oxide semiconductor field effect transistors (MOSFET).

The second switching 20 unit may generate pulses to create a discharge ignition in the sputtering chamber 8 of the sputtering system 2. The third switching 30 unit may generate pulses to maintain glow discharge in the sputtering chamber 8 between pulses.

The second and/or third switching units 20, 30 may be optional in the pulse generation device 1 and in the sputtering system 2.

Compared to known power generation solutions using IGBT, a higher energy output can be obtained with the present pulse generation device 1 during a single pulse, more current may be delivered to the plasma, with the same cathode voltage average power input and pulsing parameters, i.e. a discharge current is developed faster/current rising time is shorter.

Due to better pulsing characteristics of the MISFETs (such as turn-on delay time, rise time, turn-off delay time and fall time) compared to IGBTs at the stage of their opening a faster switching time is achieved with the present pulse generation device 1. A discharge current is developed faster than with IGBT based pulse generating devices.

Due to the parallel scheme of the pulse generation device 1 a transistor failure does not mean a failure of the whole pulse generation device 1. The maximum current/power of the pulse generation device 1 is decided by the number of parallel connected current channels/transistors 5_1, 5_n in the first switching unit 4 and makes the device scalable.

The range of the discharge current may be increased by increasing the number of transistors 5_1, 5_n (and the corresponding number of assigned drivers (6_1, 6_n)) in the pulse generation device 1.

With a sputtering system 2 comprising a pulse generation device 1 as described above it is possible to reach saturation of a discharge current for a titanium target with a pulse length of less than 50 µs, or less than 40 µs, or less than 30 µs, or less than 20 µs, see Figs. 5 and Fig. 6.

Fig. 5a and 5b show a comparison of rising times with a sputtering system comprising a prior art pulse generation device and the pulse generation device 1 as described above. As is illustrated in these figures the present pulse generation device 1, Fig. 5b, is more effective because more power can be delivered into the discharge than with the prior art pulse generation device, Fig. 5b, in the same time.

Fig. 6 shows the results of measurements confirming the saturation of the discharge current with the present pulse generation device at power inputs from 45.5 to 6.5 Watt and within 10 to 15 microseconds when the

target material in the sputtering system 2 is titanium. In the pulse generation device used for this particular experiment nine C2M SiC MOSFET transistors with Continuous Drain Current of 36 A were used in parallel. For each transistor a driver (Gate Driver Optocoupler) HCPL 3120 was assigned. The
5 capacitor used was a metalized polypropylene capacitor (WIMA DC-LINKMKP 6 from WIMA). A HiPIMS compatible magnetron system was used. The Ar pressure in the sputtering chamber was 12 mTorr. The pulsing frequency was 1 kHz. The target was a 2 inch Ti target. The power, current and voltage are shown in Fig. 6.

10 Comparing Fig. 6 with diagrams of conventional pulse generation systems and titanium as the target material, see Fig. 1, it was found that the time to reach saturation of the discharge current was about 10 times faster with the present power generation device 1 than with the prior art pulse generation device. The results proved the possibility to use much higher
15 currents during the on-time compared to conventional systems based on IGBT transistors. The deposition rate of the corresponding sputtering process, HiPIMS, showed that it is comparable to DC discharge, while the sputtering efficiency was even higher than in DC discharge. The deposition rate of HiPIMS discharge is known to be much lower than the rate of DC sputtering,
20 especially at pulse lengths of 20 μs and shorter. The experiments with the pulse generation device showed that the HiPIMS discharge can be as effective as DC sputtering in terms of deposition rate, while proposing all known benefits of HiPIMS in terms of film quality.

The pulse generation device 1 may further comprise a protection
25 system arranged to generate a feedback signal to the control unit 7 based on current or voltage values of the at least two current channels.

The protection system may be an external protection system or an integrated closed loop protection system.

The protection system may comprise a measuring device comprising a
30 measuring unit 40_1, 40_n assigned to each current channel and arranged to measure a current value or a voltage value.

Alternatively, the measuring device may be a sweeping measuring device sweeping all current channels.

The measuring unit 40_1, 40_n may be a current sensor measuring a current in the current channel and generating a voltage which is proportional to the current in the current channel. The current sensor may for example be a Hall effect sensor.

5 A comparing unit 41_1, 41_n may be assigned to each current channel and the comparing unit may be arranged to compare a voltage value corresponding to the current value from the respective measuring unit 40_1, 40_n (or sweeping measuring device) with a reference voltage. The comparing unit may be a comparator, such as a voltage comparator. A digital-to 10 analogue converter 42 may be arranged for transferring the reference voltage from the control unit 7 to the comparing units 41_1, 41_n. Alternatively, the comparing unit 41_1, 41_n may be built from different logical elements, but will have the same function of detecting the overcurrent in every channel. A separate case is when the function of the comparing unit is performed by the 15 control unit (7). The reference voltage may be determined by the pulsing parameters, such as the duty cycle, pulse length, off-time, frequency etc. If, for example, the pulse duty cycle is changed the reference voltage should be changed. The control unit 7 regulates the reference voltage to adapt to new pulsing parameters. At lower duty cycle the reference voltage can be higher. 20 At higher duty cycle it should be settled to lower values to protect the transistors 5_1, 5_n.

The reference voltage is the same for all current channels controlled with transistors of the same type. If the voltage value corresponding to the current in the current channel is lower than the reference voltage, the 25 comparing unit 41_1, 41_n is arranged to generate an output signal of a first type, and if the voltage value is higher than the reference voltage for a current channel, the comparing unit 41_1, 41_n is arranged to generate an output signal of a second type.

A receiving unit 43 may be arranged to receive output signals from 30 each comparing unit 41_1, 41_n and be arranged to generate a resulting output signal if any of the output signals from the comparing units 41_1, 41_n is an output signal of the second type.

The receiving unit 43 may be a function in the control unit 7. The receiving unit may alternatively be a separate unit such as a logical disjunction element, e.g. an N-channel disjunctor, providing the signal for the control unit to stop pulse generation in an electrical circuit. The disjunction element may be an OR logical element. Alternative schemes with other logical elements are possible. For example, logical conjunction element instead of the logical disjunction element can be used if for example the signals from the comparing units 41_1, 41_n are inverted before they reach the logical conjunction element.

For an OR logical element, if the voltage generated by the measuring unit 40_1, 40_n is lower than the reference voltage for the current channels, the comparing unit 41_1, 41_n is arranged to send an output signal of a first type to the receiving unit 43, a logical zero (“0”). If the voltage generated by the measuring unit 40_1, 40_n is higher than the reference value, the comparing unit 41_1, 41_n is arranged to send a signal of a second type to the receiving unit 43, a logical 1 (“1”). The receiving unit 43 monitors all these signals from the comparing units 41_1, 41_n and as soon as it receives a “1” it generates “1” to the control unit 7.

Alternatively the receiving unit 43 may be an AND logical element. If the voltage generated by the measuring unit 40_1, 40_n is lower than the reference voltage for the current channels, the comparing unit 41_1, 41_n is arranged to send an output signal of a first type to the receiving unit 43, a “1”. If the voltage generated by the measuring unit 40_1, 40_n is higher than the reference value, the comparing unit 41_1, 41_n is arranged to send a signal of a second type “0” to the receiving unit 43. The receiving unit 43 monitors all these signals from the comparing units 41_1, 41_n and as soon as it receives a “0” it generates “0” to the control unit 7.

The control unit 7 may be arranged to receive the resulting output signal and to turn off the transistors 5_1, 5_n through the drivers 6_1, 6_n in response to the resulting output signal. In response to this resulting output signal all transistors in the first switching unit may be turned off.

The transistor may be turned off for a predetermined period of time, which for example may be the end of the current pulse (minimum duration).

Alternatively, the transistor may be turned off for a predetermined number of periods or until the transistor(s) has reached a certain temperature.

Alternatively the control 7 unit may be arranged to directly receive the output signals of the first and second type from the comparing unit without there being a separate receiving unit in the pulse generation device and at least turn off the transistor(s) 5_1, 5_n in the current channel(s) causing output(s) of the second type for a predetermined length of time. With this alternative it is possible to turn off only the malfunctioning transistor(s) causing the output value(s) of the second type. With this set up of the protection system, if one or more transistors are broken the whole protection system is not turned off.

One advantage of a separate receiving unit 43 is that the scheme of the pulse generation device 1 is simpler.

With this protection system the overcurrent above an automatically set threshold limit can be detected immediately and will not put in danger the consistency of the whole pulse generation device 1.

The main advantage with this protection system is that there is no need to adjust the reference voltage in each current channel every time the pulsing parameters or the discharge voltage is changed. The protection system calculates automatically what reference voltage to use at given pulsing condition based on pulsing parameters and cathode voltage. Prior art do not use adaptive voltages, but instead a constant voltage level determined by a user.

The sputtering system 2 may also comprise a substrate biasing unit 60, see Fig. 3, for biasing a substrate 50 in the sputtering system 2.

The substrate biasing unit 60 has a power input 3d and may further comprise a fourth switching unit 61 comprising a current channel comprising a transistor 62 and a driver 63 assigned to the transistor. The power input 3d for the biasing unit 60 could be provided by a separate power supply. A control unit 64 may control on and off of the fourth switching unit 61 through the driver 63 based on a current value of the current channel.

The control unit 64 may be the same control unit 64, 7 as in the pulse generation device 1. The biasing unit 60 may comprise a storage capacitor 65 to store electrical power to be delivered through the transistor 62.

The biasing unit 60 may comprise a measuring unit 66 such as a current sensor measuring a current value in the current channel. The output voltage value from the sensor is sent to the control unit 64. If there is a shortcut this value is a high voltage and the control unit 64 turns off the substrate bias.

A method of generating pulses is illustrated in Fig. 4a, the method comprising the steps of:

- providing a main power input 100;

- splitting the main power input into at least two channels 101, each channel comprising a respective transistor;

-providing a driver assigned to each transistor 102;

- providing a control unit for controlling each transistor individually and for synchronizing on and off of the transistors through the drivers such that current from the at least two transistors results in the pulses 103.

To scale up the maximum power output of the pulses the main power input may be split into more channels, each provided with a respective transistor assigned with a respective driver.

The method may further comprise a step of generating a feedback protection signal to the control unit based on current or voltage values of the at least two current channels.

The step of generating a feedback protection signal to the control unit may comprise the steps of (see Fig. 4b):

- measuring a current value of each current channel 200;

- comparing voltage values corresponding to the current values from each current value measurement with a reference voltage 201;

- generating a comparative output signal of a first type if the voltage value is lower than the reference voltage 202;

- generating a comparative output signal of a second type if the voltage value is higher than the reference voltage 203;

- at least turning off the transistor(s) in the current channel(s) causing output(s) of the second type for a predetermined length of time 204.

In Fig. 4a is also a method of generating a plasma in a sputtering system illustrated, the method comprising the steps of

- generating pulses according to the method described above 100, 101, 102, 103;
- delivering the pulses to a sputtering chamber of the sputtering system 104;
- generating a glow discharge in the sputtering chamber 105.

A feedback system having at least two parallel current channels is shown in Fig. 2, the feedback system comprising:

- a measuring unit 40_1, 40_n assigned to each current channel and arranged to measure a current value,
- a comparing unit 41_1, 41_n assigned to each current channel and arranged to compare a voltage value corresponding to the current value from the respective measuring unit 40_1, 40_n with a reference voltage, wherein if the voltage value is lower than the reference voltage, the comparing unit 41_1, 41_n is arranged to generate an output signal of a first type, and if the voltage value is higher than the reference voltage for a current channel, the comparing unit 41_1, 41_n is arranged to generate an output signal of a second type;
- a control unit 7 being arranged to receive the output signals.

The feedback signal may further comprise a receiving unit 43 arranged to receive output signals from each comparing unit 41_1, 41_n and arranged to generate and send a resulting output signal to the control unit if any of the output signals from the comparing units 41_1, 41_n is an output signal of the second type.

CLAIMS

1. A pulse generation device (1) for generating pulses for a magnetron sputtering system, the pulse generation device (1) having a power input (3a,
5 3b, 3c) and further comprises:

- a first switching unit (4) generating the pulses, the first switching (4) unit comprising:
  - at least two metal-insulation-semiconductor field-effect transistors (MISFETs) (5_1, 5_n) connected in parallel, the power
10 input (3a, 3b, 3c) being split into at least two current channels, each current channel comprising a respective one of the transistors (5_1, 5_n);
  - a driver (6_1, 6_n) assigned to each transistor (5_1, 5_n); and
- a control unit (7) which is arranged to control each transistor (5_1, 5_n)
15 individually and to synchronize on and off of the transistors (5_1, 5_n) through the drivers (6_1, 6_n) such that current from the at least two current channels results in the pulses.

2. The pulse generation device (1) according to claim 1, wherein the
20 pulse generation device (1) further comprises a second and/or a third switching unit (20, 30), each of the second and third switching units comprising a transistor (21, 31) and a driver (22, 32) assigned to each transistor (21, 31), wherein the second and third switching units (20, 30) are arranged to generate respective pulses.

25

3. The pulse generation device (1) of claim 2, wherein the transistors (5_1, 5_n, 21, 31) are metal–insulation–semiconductor field-effect transistors (MISFETs).

30 4. The pulse generation device (1) of any of the preceding claims, further comprising a protection system arranged to generate a feedback signal to the control unit based on current values of the at least two current channels.

5. The pulse generation device (1) of claim 4, wherein the protection system comprises:

- a measuring device (40_1, 40_n) arranged to measure a current value of
5 each current channel,

- a comparing unit (41_1, 41_n) assigned to each current channel and arranged to compare a voltage value from the measuring device (40_1, 40_n) corresponding to the current value for a respective current channel with a reference voltage, wherein if the voltage value is lower than the reference
10 voltage, the comparing unit (41_1, 41_n) is arranged to generate an output signal of a first type,

and if the voltage value is higher than the reference voltage for a current channel, the comparing unit (41_1, 41_n) is arranged to generate an output signal of a second type;

15 - the control unit (7) being arranged to in response to an output signal of the second type at least turn off the transistor(s) (5_1, 5_n) in the current channel(s) causing output(s) of the second type.

6. The pulse generation device of claim 5, wherein the measuring
20 device (40_1, 40_n) comprises a measuring unit (40_1, 40_n) assigned to each current channel.

7. The pulse generation device of claim 5 or 6, wherein the protection system further comprises:

25 - a receiving unit (43) arranged to receive output signals from each comparing unit (41_1, 41_n) and arranged to generate and send a resulting output signal to the control unit if any of the output signals from the comparing units (41_1, 41_n) is an output signal of the second type.

30 8. A magnetron sputtering system (2) comprising a sputtering chamber (8) and a pulse generation device (1) according to any of the preceding claims, wherein the first switching unit (4) is arranged to generate pulses for generation of a glow discharge in the sputtering chamber (8).

9. The magnetron sputtering system (2) according to claim 8 when dependent on any of the claims 2 to 7, wherein the second switching unit (20) is arranged to generate pulses to create a discharge ignition in the sputtering
5 chamber (8).

10. The magnetron sputtering system (2) according to claim 8, when dependent on any of the claims 2 to 7, or according to claim 9, wherein the third switching unit (30) is arranged to generate pulses to maintain glow
10 discharge in the sputtering chamber (8) between pulses.

11. The magnetron sputtering system (2) according to any of the preceding claims 8 to 10, wherein the pulse generation device (1) further comprises a substrate biasing unit (60) for biasing a substrate (50) in the
15 sputtering system (2).

12. The magnetron sputtering system (2) according to claim 11, wherein the substrate biasing unit (60) has a power input and further comprises:
20 - a fourth switching unit (61), the fourth switching unit comprising:
- a current channel comprising a transistor (62);
- a driver (63) assigned to the transistor (62),
- a control unit (64, 7) controlling on and off of the fourth switching unit (61) through the driver (62) based on a current value of the current channel.
25

13. The magnetron sputtering system according to claim 12, wherein the magnetron sputtering system is a high impulse magnetron sputtering system (HiPIMS).
30

14. Method of generating pulses, the method comprising the steps of:
- providing a main power input (100);

- splitting the main power input into at least two channels, each channel comprising a respective metal-insulation-semiconductor field-effect transistor (MISFET) (101);
- providing a driver assigned to each transistor (102);
5 - providing a control unit for controlling each transistor individually and for synchronizing on and off of the transistors through the drivers such that current from the at least two transistors results in the pulses (103).

15. The method of claim 14, further comprising a step of generating
10 a feedback protection signal to the control unit based on current or voltage values of the at least two current channels.

16. The method of claim 15, wherein the step of generating a feedback protection signal to the control unit comprises the steps of:
15 - measuring a current value of each current channel (200);
- comparing voltage values corresponding to the current values from each current value measurement with a reference voltage (201);
- generating a comparative output signal of a first type if the voltage value is lower than the reference voltage (202);
20 - generating a comparative output signal of a second type if the voltage value is higher than the reference voltage (203);
- at least turning off the transistor(s) in the current channel(s) causing output(s) of the second type (204).

25 17. Method of generating plasma in a magnetron sputtering system, the method comprising the steps of
- generating pulses according to any of the claims 15 to 17 (100, 101, 102, 103);
- delivering the pulses to a sputtering chamber of the sputtering system
30 (104);
- generating a glow discharge in the sputtering chamber (105).

18. The method of claim 17, wherein saturation of a discharge current for a titanium target is reached within a pulse length of less than 50 μs, or less than 40 μs, or less than 30 μs, or less than 20 μs.

5 19. A feedback system having at least two parallel current cannels, wherein the feedback system comprises:

- a measuring device (40_1, 40_n) arranged to measure a current value of each current channel,

- a comparing unit (41_1, 41_n) assigned to each current channel and
10 arranged to compare a voltage value from the measuring device (40_1, 40_n) corresponding to the current value for a respective current channel with a reference voltage, wherein if the voltage value is lower than the reference voltage, the comparing unit (41_1, 41_n) is arranged to generate an output signal of a first type, and if the voltage value is higher than the reference voltage for
15 a current channel, the comparing unit is arranged to generate an output signal of a second type;

- a control unit (7) being arranged to receive the output signals.

20. The feedback system of claim 19, wherein the measuring device
20 (40_1, 40_n) comprises a measuring unit (40_1, 40_n) assigned to each current channel.

21. A feedback system according to claim 19 or 20, further comprising:

- a receiving unit (43) arranged to receive output signals from each
25 comparing unit (41_1, 41_n) and arranged to generate and send a resulting output signal to the control unit (7) if any of the output signals from the comparing units (41_1, 41_n) is an output signal of the second type.

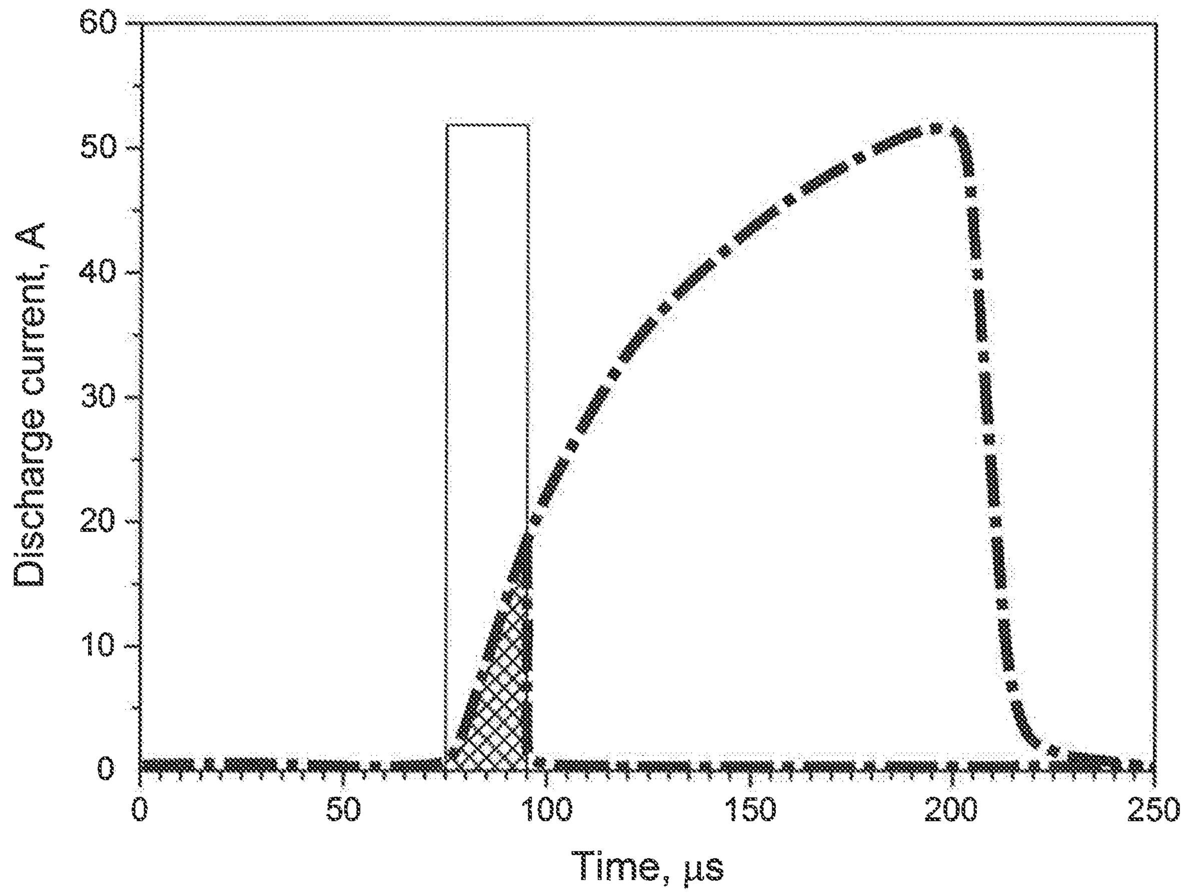


Fig. 1
Prior art

31 30 2

3c

32

21

3b

20

22

50

9 5_1 40_1

3a

8

41_1

43

6_1

7

42

6_n

40_n

41_n

5_n

4

Fig. 2

1

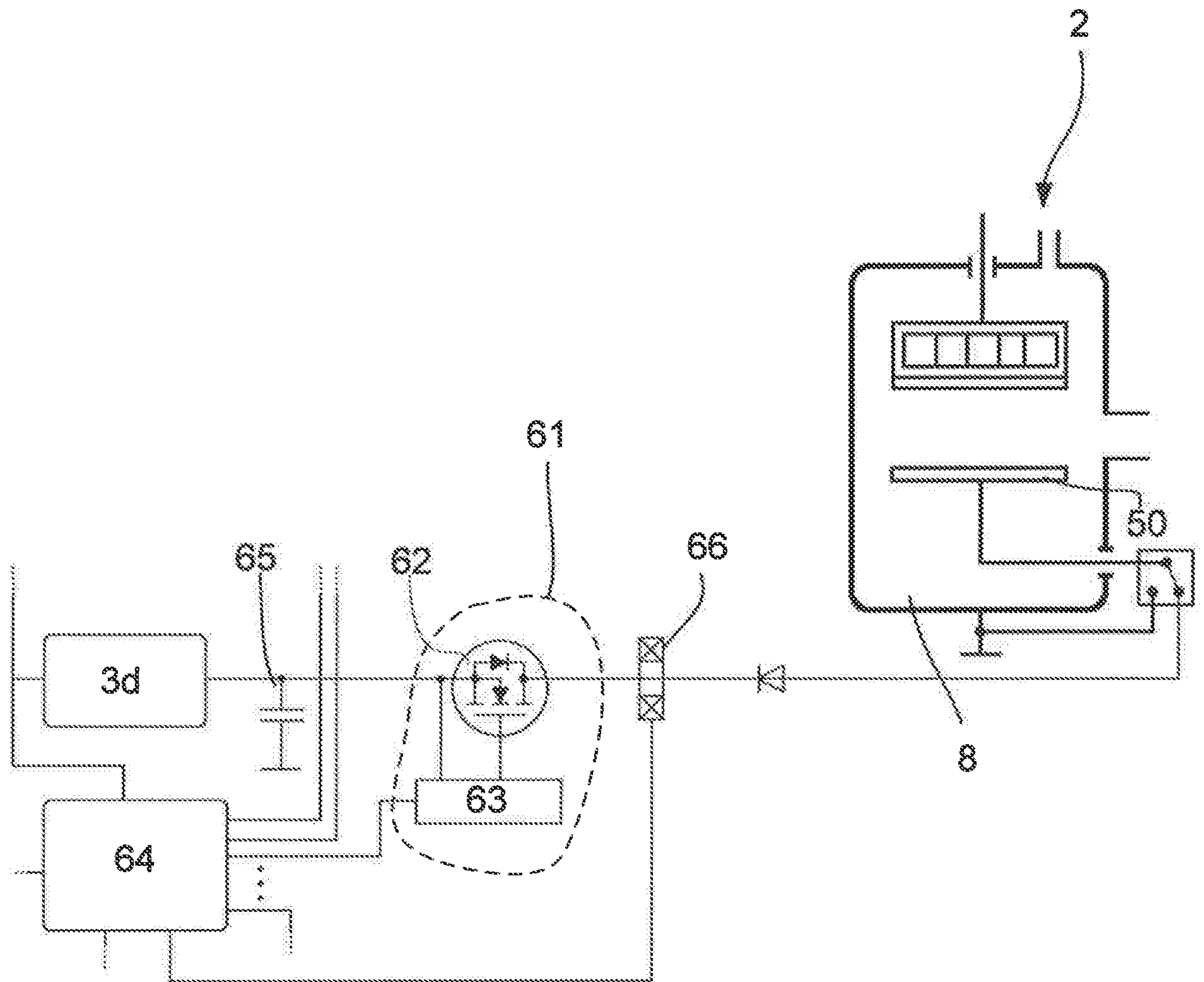


Fig. 3

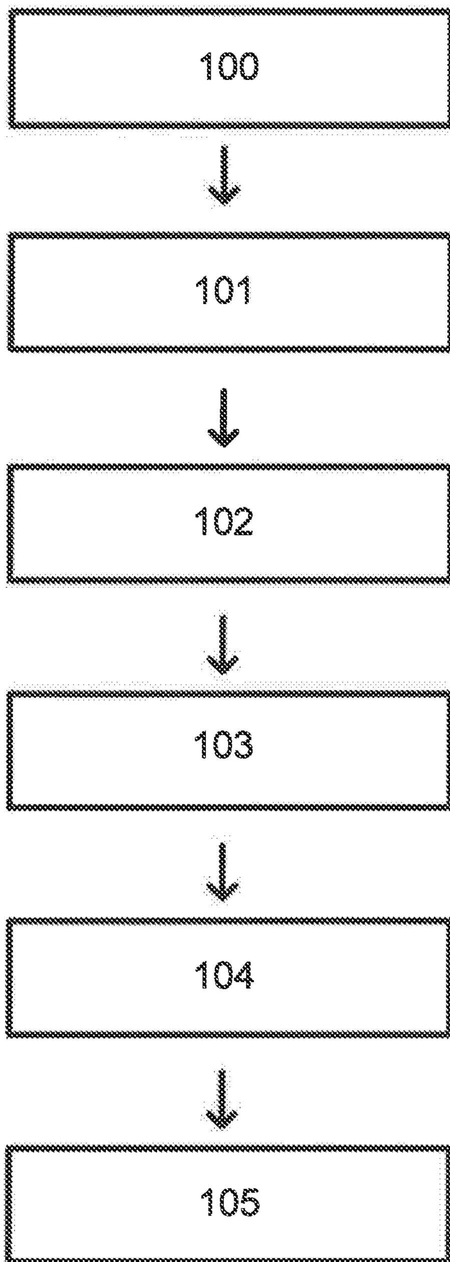


Fig. 4a

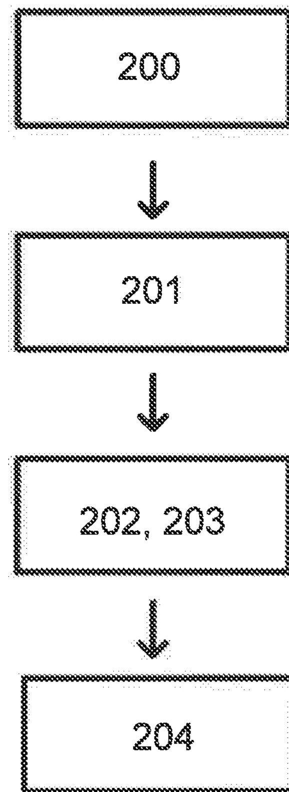
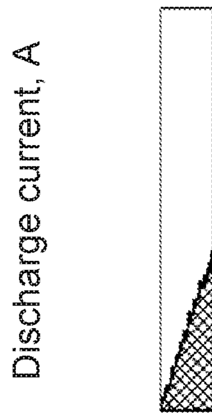
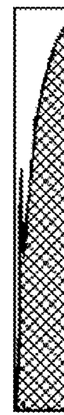


Fig. 4b





Time µs

Fig. 5a
prior art

Fig. 5b

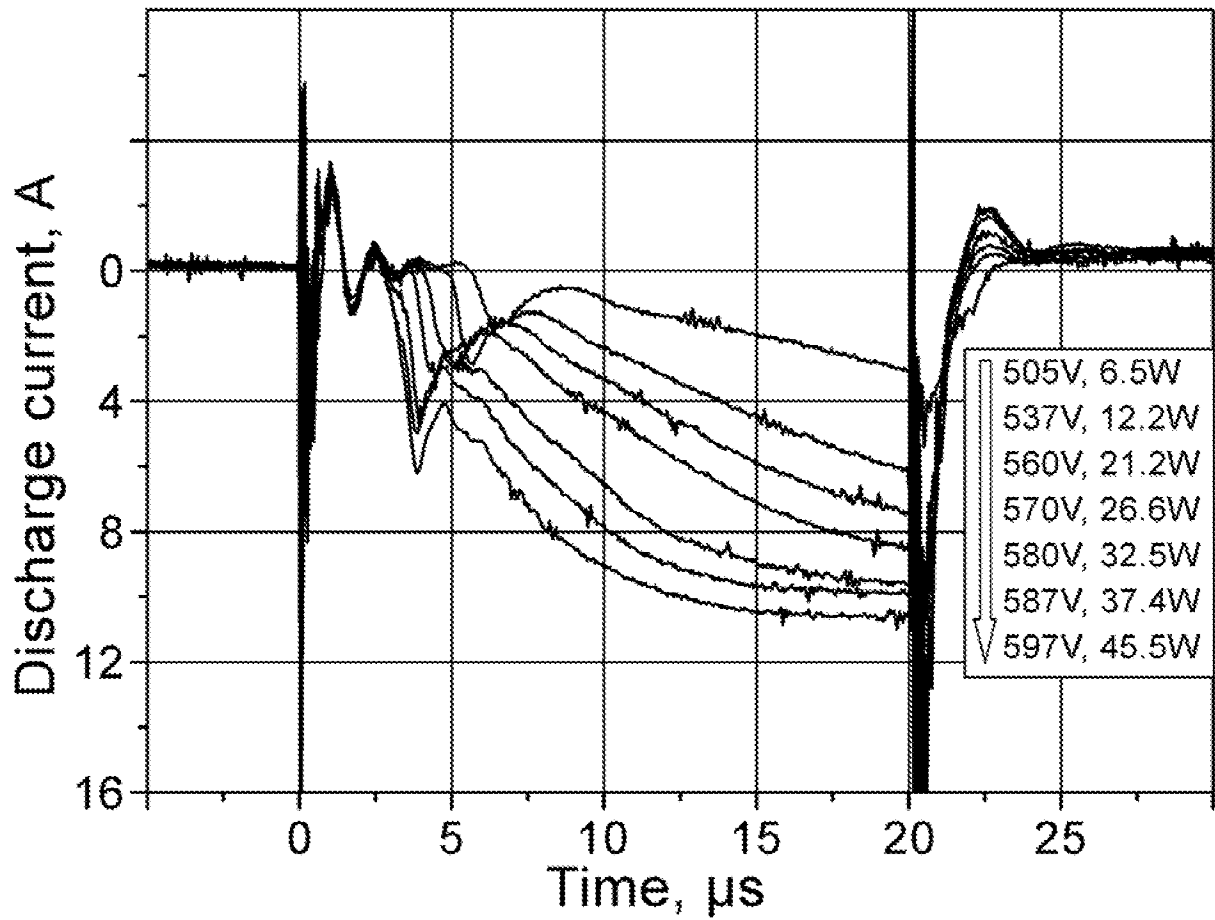


Fig. 6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE2015/050779

A. CLASSIFICATION OF SUBJECT MATTER

IPC: see extra sheet

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC: C23C, H01J, H01L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE, DK, FI, NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, PAJ, WPI data, COMPENDEX, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	WO 03079397 A1 (UNAXIS BALZERS AG ET AL), 25 September 2003 (2003-09-25); abstract from WPI; page 16, line 29 to page 17, line 10. --	1-21

☒ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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

"&" document member of the same patent family

Date of the actual completion of the international search
30-03-2016

Date of mailing of the international search report
31-03-2016

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE2015/050779

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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Continuation of: second sheet

International Patent Classification (IPC)

C23C 14/02 (2006.01)
C23C 14/35 (2006.01)
H01J 37/34 (2006.01)
H01L 29/66 (2006.01)

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