



Oifig
Na
bPaitinní

The
Patents
Office

IE 2008/0271

ABSTRACT

A plasma system has a plug-in cartridge (20) having a pair of identical opposed electrode blocks (21, 22) each comprising a series of electrodes (23) in the form of ridges on one side (facing the ionisation path), and on the outside heat sink fins (24). There is a process gas inlet manifold (25). The path between the electrodes (23) outlets into a treatment conduit (26) having openings into catalytic converters (27, 29) through which waste gas is driven to atmosphere by fans (28, 30) respectively. Process gas such as air is drawn in a flow A into the manifold (25), and passes in a flow B along the path where it is ionised. Ionised air outlets into the treatment conduit (26) in a flow C where it impinges against the sample S being treated. Waste air flows (D) through the catalytic converters (27, 29) where ozone is converted to oxygen for safe discharge E to atmosphere. Each pair of opposed electrodes (23) is an ionisation stage in which a high voltage sine wave causes breakdown of the gas in the gaps between the electrodes. The output of the first stage contains some ions and a large number of excited species including metastables. Recombination occurs to some of the species while in transit to the second stage. The species arriving at the second stage cause seeding of the next discharge at that stage and a larger amount of species is created than produced by the first stage. This is because the collision frequency increases with increase in the number of ions, thus accelerating the production of further ions under an electric field. The process continues through each successive stage, yielding a much higher density of active species than would be produced by a single pair of electrodes with an equivalent surface area.

TRUE COPY
AS
LODGED

- 1 -

"A Plasma System"

OPEN TO PUBLIC INSPECTION
UNDER PROVISIONS OF RULE 23
JNL No. 2112 of 26/11/2008

Introduction **IE080271**

5 The invention relates to a plasma treatment system.

INT CL (2006)
HOSH 1/24

The art includes publications on the subject of dielectric barrier discharge (DBD) and glow discharge at atmospheric pressure. Several publications are available at the url "plasma.ee.utk.edu/publications".

10

In general, gas discharge at atmospheric pressure requires about 27000 V/cm across the electrode gap. The electrodes are coated with a dielectric material in order to prevent sparking. The coating is tough in order to reduce the pitting associated with the high voltage discharges. Also, they have rounded edges in order to avoid the creation of local high electric fields. The applied voltage frequency is above one kHz and below about thirty kHz depending on the process gas. Helium produces metastable ions that assist glow discharge while air contains O₂ which inhibits glow discharge. Using dielectric barrier discharge (DBD) a large number of active species is produced. For glow discharge a minimum flow rate of process gas is required.

20

The transfer of electrical energy from inductors or capacitors to a high frequency discharge requires the matching of impedances for maximum power transfer. The driving frequency is of the order of 5 to 30 kHz while the discharge has a current spike equivalent to several MHz for glow discharge and a large number of lesser spikes in the MHz region for DBD. The capacitor impedance must supply this high current pulse. A parallel inductor allows parallel resonance to create a high charge on the capacitor to supply the high current discharge for every half cycle. A high voltage transformer is needed to raise the voltage from a level at which the system is operated. Three phase mains electricity can be used to get a 600VDC bus thus lowering the currents being switched and simplifying the construction of wound components. Doubling the single phase mains of 230VAC to create a 650VDC bus also serves to reduce the current.

30

The invention is directed towards achieving more effective plasma generation, with a higher density of ions.

Summary of the Invention

5

According to the invention, there is provided a plasma system comprising:

at least two pairs of electrodes at different locations along a gas path; and

10

a drive circuit for driving the pairs of electrodes so that gas flowing along the path is ionized, and

an ionized gas outlet from the path.

15

In one embodiment, there are at least four pairs of electrodes.

In another embodiment, the system further comprises a feedback means for returning some active species back to the start of the path.

20

In a further embodiment, the drive circuit controls electrode drive using pulse width modulated signals.

In one embodiment, the drive circuit comprises a series resonant circuit followed by parallel resonant circuit for conversion.

25

In another embodiment, the drive circuit comprises a central controller linked with an electrode drive circuit for each pair of electrodes.

30

In a further embodiment, the electrode drive circuits are isolated from the central controller by opto-couplers.

In one embodiment, the electrodes comprise a common electrode on one side of the path for a plurality of electrode pairs and an opposing discrete electrode for each pair.

In another embodiment, the electrodes have rounded edges on a side facing the path.

In a further embodiment, the edges have a radius in the range of 2mm to 4mm.

5

In one embodiment, the electrodes are of aluminium material.

In another embodiment, the electrodes have a dielectric coating.

10 In a further embodiment, the dielectric coating is of aluminium oxide.

In one embodiment, the separation between opposed electrodes is in the range of 1.5mm to 5mm, preferably approximately 2.5mm.

15 In a further embodiment, the cross-sectional area of the path is in the range of 500mm² and 900mm².

In one embodiment, the distance between successive pairs of electrodes is in the range of 2mm and 6mm, preferably approximately 3mm.

20

In a further embodiment, the electrodes are in the form of a series of ridges on a base plate.

In one embodiment, the base plate is integral with heat sink fins.

25

In another embodiment, the drive circuit applies sufficient voltage to cause ion multiplication by collision.

30 In a further embodiment, the drive circuit applies a voltage across the electrodes in the range of 7kV to 15kV.

In one embodiment, the voltage is approximately 12kV.

In another embodiment, the circuit applies a drive frequency is in the range of 4kHz to 20kHz across the electrodes.

In a further embodiment, in the frequency is in the range of 7kHz to 15kHz.

5

In one embodiment, the system further comprises means for pumping a gas along the path.

10

In another embodiment, the gas is pumped at a pressure in the range of 0.5 bar to 1.5 bar.

In a further embodiment, the pairs of electrodes are driven in sequence, and the timing, voltage levels, and frequency of electrode driving causing an increase in ionized active species velocity and/or density.

15

In one embodiment, the drive circuit drives each pair of electrodes sequentially in a flow direction along the path.

20

In another embodiment, the drive circuit delivers an electrical phase to each pair of electrodes.

In a further embodiment, there are four pairs of electrodes the phases are approximately 45° apart.

25

In one embodiment, orientation of the drive is changed periodically to create a swirling motion of ions in the path.

In another embodiment, the system further comprises a catalytic converter for converting waste process gas arising from used ionized gas.

30

In a further embodiment, the system comprises a treatment chamber fed by the ionized gas outlet, and the catalytic converter is fed by the treatment chamber.

In another aspect, there is provided a textile treatment system comprising a plasma system as defined above.

5 In another aspect, there is provided a sterilizer system comprising a plasma system as defined above.

In a further aspect, there is provided a chemical vapour deposition system comprising a plasma system as defined above.

10 In another aspect, there is provided an ozone generating system comprising a plasma system as defined above.

In a further aspect, there is provided a method of treating a surface or item comprising the steps of operating a plasma system as defined above and directing ions from the
15 path towards the surface or item.

In one embodiment, the ions are directed to a person's skin for cosmetic or therapeutic treatment.

20 In another embodiment, the ions are directed for sterilising medical equipment.

In a further embodiment, the ions are directed for surface treatment of natural or man-made fibres.

25 In one embodiment, the ions are directed for surface treatment of films.

In another embodiment, the ions are directed for surface treatment of engineering parts.

30 In a further embodiment, the ions are directed for surface treatment of food containers.

In one embodiment, the ions are directed for surface treatment of food.

In another embodiment, the ions are directed for surface treatment of gaskets to enhance their function.

Detailed Description of the Invention

5

The invention will be more clearly understood from the following description of some embodiments thereof, given by way of example only with reference to the accompanying drawings in which:-

10

Fig. 1 is a diagram illustrating a plasma treatment system of the invention;

Fig. 2 shows an AC waveform for driving electrodes as derived from the digital control signals;

15

Fig. 3 shows pulse width modulation timing for the system;

Fig. 4 is a block diagram illustrating how a sine wave is created from an IGBT Bridge output;

20

Fig. 5 is a diagram of an alternative electrode configuration;

Fig. 6 is a diagram illustrating barrier discharge;

Fig. 7 is a plot showing density reduction with distance from output;

25

Fig. 8 shows a plot of the electron and ion density per stage;

Fig. 9 is a sketch of an electrode cartridge of a system of the invention.

30

Figs. 10 and 11 are plots for an alternative embodiment; and

Description of the Embodiments

A plasma treatment system 1 is shown in Fig. 1. A gas enters from the left hand side and passes through four electrode pairs 2, 3, 4, and 5, each pair providing an ionisation stage along a path 6. Also, there is a feedback path 7. The electrodes are of aluminium and have an aluminium oxide coating. The axial (in the direction of the path 6) separation of the pairs of electrodes is about 3mm and is generally in the range of 2mm to 6mm. The transverse spacing between electrodes of a pair is 2mm, and more generally preferably in the range of 1.5mm to 5mm. The voltage across each pair of electrodes is in the range of 7kV to 15kV and is in this embodiment 12kV. Also in this embodiment, the gas is air and the applied pressure at entry to the path is about 1 bar. The electrodes 2, 3, 4, and 5 are shaped to provide a cross-sectional area through the path 6 of about 700mm².

A high voltage sine wave causes breakdown of the gas in the gaps between the electrodes. The output of the first stage contains some ions and a large number of excited species including metastables. Recombination occurs to some of the species while in transit to the second stage. The species arriving at the second stage cause seeding of the next discharge at that stage and a larger amount of species is created than produced by the first stage. This is because the collision frequency increases with increase in the number of ions thus accelerating the production of further ions under an electric field. The process continues through each successive stage, yielding a much higher density of active species than would be produced by a single pair of electrodes with an equivalent surface area. A new maximum density is reached after four stages depending on distance between stages, gas, and electrode material.

25

In Fig. 2 is shown the sine wave that is derived from a pulse waveform. The pulse is shown as being bipolar in order to represent the forward and reverse flows through the full bridge of insulated gate bipolar transistors (IGBTs). The sine wave peaks are centred on the midpoints of the pulse.

30

Fig. 3 shows how the percentage ON time of the pulse can vary from 52% to 98%. A short OFF time of 2% is required to allow for transistor switching delays. The

beginning of each pulse is delayed 2% from the start of the timing. This is repeated for the 100 to 200 count time when the voltage output is of the opposite polarity.

5 Fig. 4 shows how timing pulses from the pulse width modulator are used through opto-coupler circuitry to turn on pairs of transistors in the IGBT bridge. When the top right and bottom left transistors are ON current flows through a series inductor and capacitor, the parallel combination of C and the transformer primary and returns via a second series inductor. The two inductors in series with the resonant series capacitor are tuned at the resonant frequency to pass the fundamental signal. The capacitor
10 across the primary is used to tune the resonant frequency of the parallel circuit on the transformer output.

Fig. 5 shows that the electrodes may be comprised of one common electrode with a number of individual electrodes. Multiple electrodes may be constructed on one block
15 of metal with channels to isolate the electrodes and their discharges. Electrodes on one side of the flow channel may be without a dielectric barrier. Using barriers on both opposing electrodes produces a similar discharge for each polarity of applied voltage.

Fig. 6 shows the basic system for which the equations concerning dielectric barrier
20 discharge is derived. The annotation in this diagram is as follows, $E(x,t)$ is the electric field across the electrodes, $U_{ext}(t)$ is the applied voltage, and $i_{ext}(t)$ is the electrode current.

Fig. 7 shows that the density of species produced reaches a new maximum after about
25 5 stages. The number of stages required to reach this maximum depends on the gas, the electrode material, the distance between stages and the flow rate. By returning a small portion of the final stage output it is possible to achieve positive feedback and an earlier large gain in species.

30 Fig. 8 shows the logarithmic decay of active species with distance travelled from the plasma system exit. The exiting species are then available to provide stronger surface treatment. With a half bar of input pressure the resultant output reaches a velocity of over 100 metres per second and carries a high density of ions for several tens of

centimetres. A species density of 10^{15} per cm^3 may be achieved which is several orders of magnitude higher than with existing technology.

5 By using an air pressure of 0.5 to 1 bar of air pressure from a compressor there is good
air flow through the gap between the electrodes. The electrodes have rounded edges of
about 3mm radius and extend over an area of 30 x 100 to 9mm x 340mm. If the
electrodes are driven by a high voltage sine wave a discharge will be created when the
10 electric field exceed 27000 volts per cm. A range of frequencies from 1kHz to 50kHz
is usable but it is more suitable to work in the region of 10kHz. It can also be helpful
if the applied voltage is modulated to form bursts of active and quiet periods. This
reduces the tendency to pitting in the electrodes. The forced flow of process gas,
usually air, also has this effect.

15 Using a single pair of electrodes and extending the area for increased power does not
achieve the high species gain available with multiple electrodes. The ions in the
plasma, both single and multi-stage, resist the flow but this is overcome by raising the
supply pressure slightly. Driving the individual stages with a sequence of phases helps
to reduce this drag effect. The benefit of extra power phases is not sufficiently high to
20 justify the use of such a scheme because of the friction due to the un-ionised gas
particles.

The system uses a full bridge of IGBTs to drive a series resonant circuit to convert the
square wave to a sine wave for the transformer primary. The timing required is
produced using programmable logic in which the 16 MHz clock signal was divided to
25 produce a pair of 20 kHz square waves for a 10 kHz square wave. The output level is
detected by measuring the primary voltage of the high-tension transformer for safety
reasons. This provides a good indication of the actual output voltage. The high-tension
output drives a parallel resonant circuit in which the capacitor impedance is close to
the impedance of the DBD discharge. Frequency Resonance tuning is provided by the
30 high-tension inductance. The primary series and secondary parallel resonant circuits
are a well known means of converting a square wave signal to sine wave for a
resistive load. Some reactive load exists and the reactive current is returned to the
reservoir capacitors through on-chip anti-parallel diodes in the IGBT full bridge.

The electrode arrangement is made so that electrodes are readily replaced and the electrode arrangement can be modified without affecting the rest of the system. Two sub-assemblies are bolted together using a spacer layer that determines the electrode gap. When these assemblies are separated it is possible to remove plates containing the electrodes. The electrodes have a ceramic coating designed to withstand the discharge current and the temperature increase.

The system has 10^5 times the output species density of DBD systems and 10^3 times the density of plasma jets. It has a homogenous output that is suitable for even treatment over the electrode length. Single stage DBD systems cannot be increased in size to compete with this performance due to physical limitations. The capacitance of wide electrodes demands very high current levels in the primary circuit. Multiple jets do not give the uniform treatment available from this homogenous output.

The power electronics system is digital so the power is created by smaller devices than would be necessary for equivalent output from a linear system. The reactive components do not need heat sinking while the semiconductors in the IGBT bridge are easily kept to a safe temperature.

The output voltage can be readily modified from 6 to 12kV using pulse width modulation of the bridge drive to allow for different gases and electrode gaps. This change is achieved in software and may be user defined.

The electrode configuration is designed for ease of service and design modification to suit a variety of uses. The electrode gap may be varied from 1.5 to 4.0 mm but preferably below 2.5mm to minimise the voltage requirement. The inter-electrode distance may be from 3mm upwards but should be as low as possible in order to minimise losses due to recombination while separating the discharges.

Scrubbing, through a catalyst, makes the system safe for a factory or laboratory environment.

All cooling fans are monitored for reliable performance and the system is shut down when defective cooling is detected. The temperature of the heat sink that cools the grounded electrode is monitored to prevent operation when the dielectric barrier deteriorates.

5

Referring to Fig. 9 gas flows are illustrated for a cartridge 20 of one embodiment. The cartridge 20 is a plug-in cartridge for insertion of the electrodes in a replaceable manner. The cartridge 20 comprises a pair of identical opposed electrode blocks 21 and 22, each comprising a series of electrodes 23 in the form of ridges on one side (facing the ionisation path), and on the outside heat sink fins 24. There is a process gas inlet manifold 25. The path between the electrodes 23 outlets into a treatment conduit 26 having openings into catalytic converters 27 and 29 through which waste gas is driven to atmosphere by fans 28 and 30 respectively. Referring to the arrows, process gas, in one embodiment air, is drawn in a flow A into the manifold 25, and passes in a flow B along the path where it is ionised. Ionised air outlets into the treatment conduit 26 in a flow C where it impinges against the sample S being treated. Waste air flows (D) through the catalytic converters 27 and 29 where ozone is converted to oxygen for safe discharge E to atmosphere. Flow into the converters is assisted by an inflow G from atmosphere, which inflow also helps to prevent direct discharge of ionized gas to atmosphere.

10
15
20

At the same time cooling air D pumped in a flow F along the heat sink fins 24 according to a temperature control scheme. In one embodiment the temperature in the path is maintained above 80° in order to reduce the extent of ozone generated. In another embodiment, the temperature is maintained below this level so that more ozone is generated, it that is desirable for the application.

25

Referring again to Figs. 3 and 4, single-phase mains electricity is fed to a switch mode power supply to create a 24 V DC supply. It also goes to a single phase rectifier and two series reservoir capacitors where it is doubled and powers a 650 volt DC bus. Provision is made to reduce noise emissions and noise susceptibility. The 650 V bus supplies current to a full bridge comprised of Insulated Gate Bipolar Transistors (IGBTs). This are driven by four opto-coupler circuits that are powered by a flyback

30

transformer for floating gate drive voltage creation and also the generation of a 5 volt DC supply for the logic circuitry. The flyback transformer operates from the 24 volt bus. The drive module also contains a transformer to convert the primary voltage of the HT transformer to a safe level for measurement. The output voltage measured is
5 the sine wave that appears across the input to a high-tension transformer after series resonance through an inductor and a capacitor. The current that comes from the base of each IGBT bridge is measured by a Hall effect device. Both of these voltage and current measurements are fed to peak detect circuits. The peak detected current is also fed to a comparator for immediate switch off if a set limit is exceeded.

10

The power circuit is controlled by the logic circuit which has a user interface to an LCD display and some key-switches. It also applies power to cooling fans as appropriate and monitors the fan current to assure reliable operation. A master/slave configuration is created using an RS485 bus that communicates with other plasma
15 units to build a larger system capable of treating wide surfaces.

The electrodes are arranged in two vertical columns so that the ion flow produces a strong electric wind downwards from the electrodes. This output is used to indirectly treat material. The treatment area can be closed in so that the ions do not escape to
20 the environment. They are sucked in to a pair of scrubbers either side of the output. Suction is achieved by fans that pull the process gas through appropriate catalysts that cause ozone to recombine as oxygen molecules.

The process gas can be normal air, dry air or any other gas mixture. Using long
25 electrodes we get a homogenous jet of high relative strength. This is more suitable for many purposes than a small round jet or a line of such jets.

The use can be for surface modification of plastic, metal, textile or other surfaces, destruction of bacteria or viri or prions, chemical vapour deposition, efficient ozone
30 generation or any other application that may arise.

The invention finds many applications. The applications call for different mechanical solutions and operating parameters. To raise the surface energy of textiles a wide jet is

required. To sterilise Yoghurt containers a deep jet is required. To achieve chemical vapour deposition we must have both so that we can ionize another gas and deposit parts of it on a surface. Other possibilities such as purifying recycled air in an aeroplane require different electrode arrangements.

5

Tests on wetability and on bacteria destruction show major improvements over single stage treatment both direct and indirect. In 30 seconds the oxygen content of a polypropylene surface was doubled. Bacteria destruction in 5 seconds using indirect treatment equalled that achieved in 30 seconds with direct treatment and in 5 minutes using single stage electrodes for indirect treatment.

10

Theory of Operation

Consider the electrode configuration in Fig. 6. The number of collisions per unit time, or collisional frequency n_c is

$$n_c = n_1(\sigma v) \quad (\text{collisions / s}) \quad (1)$$

where v is the flow velocity of the incoming gas, σ is the collisional cross-sectional area and n_1 is the number of particles of type 1 per unit volume.

A system of equations describing the homogeneous barrier discharge is now formulated. The discharge burns between two flat electrodes covered by a dielectric. The scheme of the discharge is shown below.

20

The discharge current is only limited by dielectric barriers; there is no external resistance. The discharge is supplied by the external voltage $U_{ext}(t)$, which is an

25

The charged particles (electrons and ions) are described by the continuity equations,

$$\frac{dn_e}{dt} + \frac{d}{dx} \left(-b_e n_e E - \frac{b_e}{e} \frac{d(n_e T_e)}{dx} \right) = n_e n_{ion} + n_e n_c - a_{rec} n_i n_e + \sum_j k_j n_q n_r \quad (2)$$

$$\frac{dn_i}{dt} + \frac{d}{dx} \left(b_i n_i E - \frac{b_i}{e} \frac{d(n_i T_i)}{dx} \right) = n_e n_{ion} + n_e n_c - a_{rec} n_i n_e + \sum_j k_j n_q n_r \quad (3)$$

where $b_{e(i)}$ are the mobilities of electrons and ions, respectively, E is the axial electric field, n_{ion} is the frequency of direct ionization and $a_{rec} = 1.1 \cdot 10^{-7} T_i^{-0.5} \text{ cm}_3 \text{ s}^{-1}$ is the coefficient of dissociative recombination. The values b_e , T_e and n_{ion} are assumed to be functions of the local electric field. They are determined by the electron distribution function, which is obtained from the Boltzmann kinetic equation. The quantity n_c is the collisional frequency. Prior to the application of the first high voltage pulse to the system, this quantity is equal to zero given that ion flow will only commence after the initial stage. Kinetic theory is incorporated into the model by means of atmospheric reactions numbered 1,2,...,j. The product of rate coefficient k_j with the densities of respective species q and r gives the number of charged particles given by specific reactions in atmospheric air plasma.

The surface densities of charged particles at both dielectric barriers are described by the following equations:

$$\frac{ds_e}{dt} = n_e n_e - s_e n_e - a_{rw} s_e^+ s_e \quad (4)$$

$$\frac{ds^+}{dt} = (1+g)n_i n_i - a_{rw} s^+ s_e \quad (5)$$

The electric field in the volume is described by the Poisson equation,

$$\frac{\partial E}{\partial x} = 4\pi e (n_i - n_e) \quad (6)$$

Integration of this equation in x , using a fourth order Runge-Kutta algorithm, whilst taking into account the surface charges yields

$$E(x, t) = 4\pi q_{ext}(t) + 4\pi e \left[\sigma_0^+(t) - \sigma_{e0}(t) + \int_0^L (n_i(x', t) - n_e(x', t)) dx' \right] \quad (7)$$

where $q_{ext}(t)$ is the surface charge at the external metal electrode.

The system of equations (16) - (21) describes the homogeneous barrier discharge completely as the profile of external voltage is given. This system is solved

numerically. For the four electrode phases, the output of one stage is taken to be the input for the next stage and so on. Collisional frequencies are calculated and these are applied to equations (2) and (3) as shown above.

5 Results of the application of multi-stage ion flow to the system are shown in figure 7. These take recycling into account, whereby a small percentage of the output species are fed back to the first electrode stage, essentially forming a feedback loop. Due to the fact that the species densities will continuously be increasing at the output due to feedback, it is conceivable that these values for electron and ion densities respectively
10 will be even greater than those currently being predicted. A feedback efficiency of 1% was assumed for these calculations. The results show a gain of approximately 10^5 as opposed to a single electrode stage DBD reactor and also depict a gain of approximately double what would be expected for a four-stage electrode system without feedback. However, as already stated, it is conceivable that this gain could
15 considerably increase due to varying the feedback portion.

The high output density makes the system suitable for applications where direct treatment may be damaging to the treated surface or where other indirect treatment methods are much weaker. This is best demonstrated in the use for treating the skin of
20 living people or animals. It also applies to textile treatment where DBD filaments can damage fibres under direct treatment. The following are other applications:

- treatment of irregular shapes up to several centimetres,
- treatment of fibres in a web so that all surfaces are treated,
- treatment of wet cement for increased hardness by wetting not drying,
- 25 treatment of seeds prior to planting so that surface bacteria are destroyed,
- treatment of wounds on skin surfaces in medicine.
- destruction of bacteria on a person, such as on hands or feet,
- destruction of bacteria on surfaces such as in food factories or in hospitals, or
- destruction of prions on surfaces such as on medical instruments or knives.

30

The invention is not limited to the embodiments described but may be varied in construction and detail. For example, the drive circuit could drive the stages in sequence, an electrical phase being delivered to each stage. Referring to Fig. 10, the

phases may be 45° apart. In such an embodiment as the discharge due to voltage phase 1 is ending there is a discharge on the electrodes driven by phase 2. The first four discharges may be of one orientation and the next four discharges of opposite orientation, thus swirling the ions from side to side as they travel from stages one to 5 four. The voltage phases result from pulse width modulated signals. The peak of each phase is centred on the mid-point of each square wave and depends on the width. The conversion is produced by series resonant circuits followed by parallel resonant circuits.

10 The timing for the square wave circuits is shown in Fig. 11. Puls5 creates the timeframe for each cycle at 10kHz. Puls1 is co-incident with Puls5 but the duration of each high in Puls1 varies from 50 to 98% depending on the level of output voltage required. Output1 shows the square wave of voltage that appears on the IGBT full bridge. It is a pulse width modulated signal that is converted to sine wave by resonant 15 circuits. Pulse1 and Output1 are delayed by 2 clock pulses from the start of Puls5. This delay is repeated at 100+2 for the second half of the cycle. For 10kHz this is a 2 microsecond delay to allow the IGBT bridge to settle and it could easily be changed to a value of 3 for slower transistors.

20 The rising edge of Puls1 clocks the status of Puls5 into a D flip-flop whose output determines the direction of Output1. While this flip-flop is not necessary for Puls1 it is required for Puls2, 3 & 4. They are delayed by increments of 25 and a rising Puls3, for instance, clocks in the Puls5 status so that the Output3 (not shown) will have the necessary polarity.

25

Puls5 is a divide by 2 stage at the output of a counter that counts from 0 to 100. The count is compared to hardwired numbers 2, 27, 52 & 77 that initiate Puls1, 2, 3 & 4. The count is compared to four registers containing the endpoints 2-0, 77-25, 2-50 & 25-75 representing 52-100, 77-125, 102-150 & 125-175 on the timing diagram. Puls2 30 starts at 27 and ends between 77 and 99 or between 0 and 25 for a width of 50 to 98. Timing for the second and successive phases may be obtained by using the start of both halves of phase 1 to save the status, so as to know whether the first or second half of the waveform should be generated. This status is loaded by the arrival of a later

IE0 80271

- 17 -

phase and the correct alignment is maintained. This minimises the number of signal wires needed for a multiphase system.

Claims

1. A plasma system comprising:
5 at least two pairs of electrodes at different locations along a gas path; and
a drive circuit for driving the pairs of electrodes so that gas flowing along the
path is ionized, and
10 an ionized gas outlet from the path.
2. A plasma system as claimed in claim 1, wherein there are at least four pairs of
electrodes.
- 15 3. A plasma system as claimed in claims 1 or 2, further comprising a feedback
means for returning some active species back to the start of the path.
4. A plasma system as claimed in any preceding claim, wherein the drive circuit
controls electrode drive using pulse width modulated signals.
20
5. A plasma system as claimed in claim 4 wherein the drive circuit comprises a
series resonant circuit followed by parallel resonant circuit for conversion.
6. A plasma system as claimed in any preceding claim, wherein the drive circuit
25 comprises a central controller linked with an electrode drive circuit for each
pair of electrodes.
7. A plasma system as claimed in claim 6, wherein the electrode drive circuits are
isolated from the central controller by opto-couplers.
30
8. A plasma system as claimed in any preceding claim, wherein the electrodes
comprise a common electrode on one side of the path for a plurality of
electrode pairs and an opposing discrete electrode for each pair.

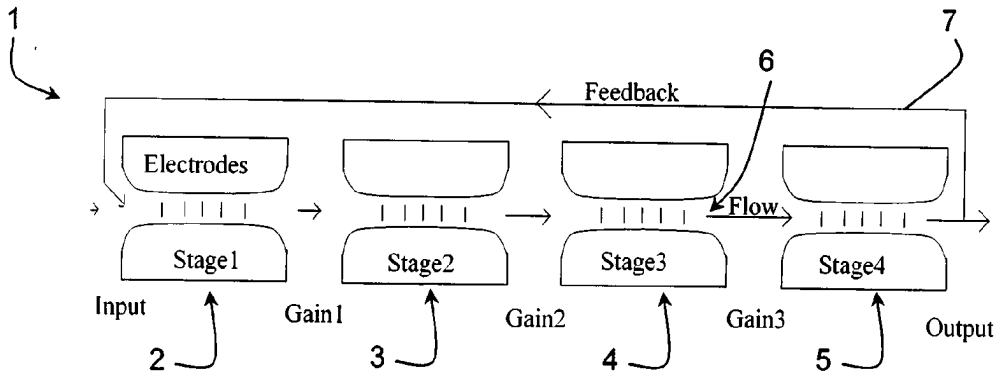
9. A plasma system as claimed in any preceding claim, wherein the electrodes have rounded edges on a side facing the path.
- 5 10. A plasma system as claimed in claim 9, wherein the edges have a radius in the range of 2mm to 4mm.
11. A plasma system as claimed in any preceding claim, wherein the electrodes are of aluminium material.
- 10 12. A plasma system as claimed in any preceding claim, wherein the electrodes have a dielectric coating.
13. A plasma system as claimed in claim 12, wherein the dielectric coating is of aluminium oxide.
- 15 14. A plasma system as claimed in any preceding claim, wherein the separation between opposed electrodes is in the range of 1.5mm to 5mm.
- 20 15. A plasma system as claimed in claim 14, wherein the separation is approximately 2.5mm.
16. A plasma system as claimed in any preceding claim, wherein the cross-sectional area of the path is in the range of 500mm² and 900mm².
- 25 17. A plasma system as claimed in any preceding claim, wherein the distance between successive pairs of electrodes is in the range of 2mm and 6mm.
18. A plasma system as claimed in claim 16, wherein the distance is approximately 3mm.
- 30 19. A plasma system as claimed in any preceding claim, wherein the electrodes are in the form of a series of ridges on a base plate.

20. A plasma system as claimed in claim 19, wherein the base plate is integral with heat sink fins.
- 5 21. A plasma system as claimed in any preceding claim, wherein the drive circuit applies sufficient voltage to cause ion multiplication by collision.
22. A plasma system as claimed in any preceding claim, wherein the drive circuit applies a voltage across the electrodes in the range of 7kV to 15kV.
- 10 23. A plasma system as claimed in claim 22, wherein the voltage is approximately 12kV.
- 15 24. A plasma system as claimed in any preceding claim, wherein the circuit applies a drive frequency is in the range of 4kHz to 20kHz across the electrodes.
- 20 25. A plasma system as claimed in claim 24, wherein the frequency is in the range of 7kHz to 15kHz.
- 25 26. A plasma system as claimed in any preceding claim, further comprising means for pumping a gas along the path.
27. A plasma system as claimed in claim 26, wherein the gas is pumped at a pressure in the range of 0.5 bar to 1.5 bar.
- 30 28. A plasma system as claimed in any preceding claim, wherein the pairs of electrodes are driven in sequence, and the timing, voltage levels, and frequency of electrode driving causing an increase in ionized active species velocity and/or density.
29. A plasma system as claimed in claim 28, wherein the drive circuit drives each pair of electrodes sequentially in a flow direction along the path.

30. A plasma system as claimed in either of claims 28 or 29, wherein the drive circuit delivers an electrical phase to each pair of electrodes.
- 5 31. A plasma system as claimed in claim 30, wherein there are four pairs of electrodes the phases of which are approximately 45° apart.
32. A plasma system as claimed in any of claims 28 to 31, wherein orientation of the drive is changed periodically to create a swirling motion of ions in the path.
- 10 33. A plasma system as claimed in any preceding claim, further comprising a catalytic converter for converting waste process gas arising from used ionized gas.
- 15 34. A plasma system as claimed in claim 33, wherein the system comprise a treatment chamber fed by the ionized gas outlet, and the catalytic converter is fed by the treatment chamber.
- 20 35. A textile treatment system comprising a plasma system as claimed in any preceding claim.
36. A sterilizer system comprising a plasma system as claimed in any of claims 1 to 34.
- 25 37. A chemical vapour deposition system comprising a plasma system as claimed in any of claims 1 to 34.
38. An ozone generating system comprising a plasma system as claimed in any of claims to 1 to 34.
- 30 39. A method of treating a surface or item comprising the steps of operating a plasma system of any of claims 1 to 34 and directing ions from the path towards the surface or item.

IE0 80271

40. A method as claimed in claim 39, wherein the ions are directed to a person's skin for cosmetic or therapeutic treatment.
- 5 41. A method as claimed in claim 39, wherein the ions are directed for sterilising medical equipment.
42. A method as claimed in claim 39, wherein the ions are directed for surface treatment of natural or man-made fibres.
- 10 43. A method as claimed in claim 39, wherein the ions are directed for surface treatment of films.
44. A method as claimed in claim 39, wherein the ions are directed for surface treatment of engineering parts.
- 15 45. A method as claimed in claim 39, wherein the ions are directed for surface treatment of food containers.
- 20 46. A method as claimed in claim 39, wherein the ions are directed for surface treatment of food.
47. A method as claimed in claim 39, wherein the ions are directed for surface treatment of gaskets to enhance their function.



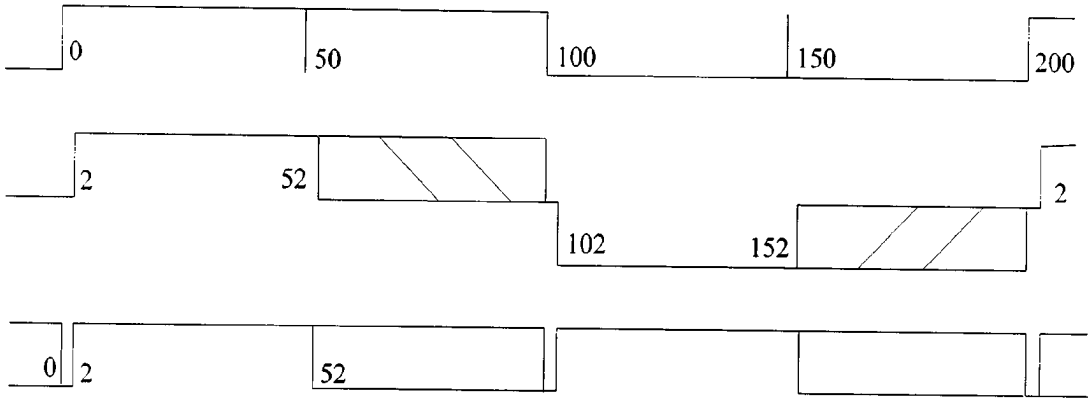
Multi-stage electrodes driven by multiple phases of voltage.

Fig. 1



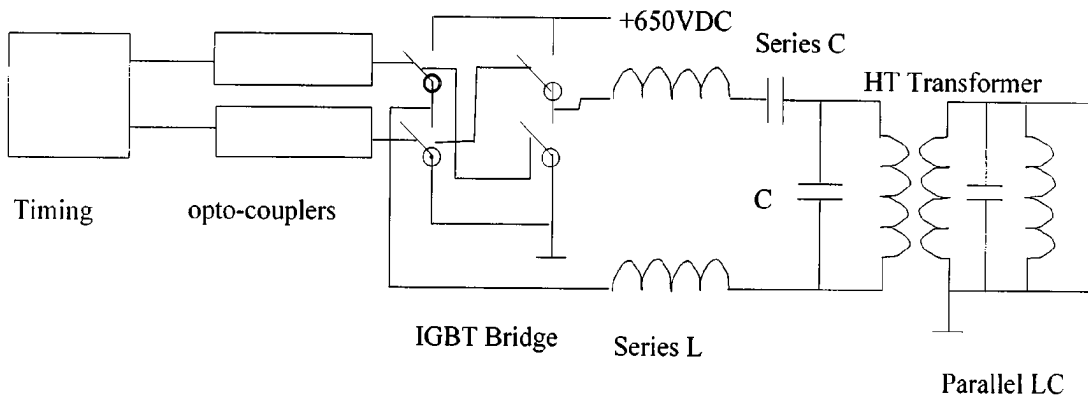
Square wave to sine wave conversion by resonant circuits

Fig. 2



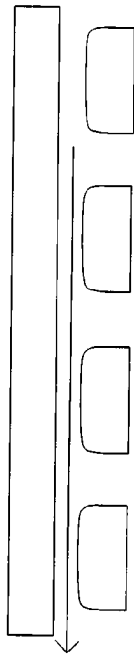
Plasma timing for four phases.

Fig. 3



Square wave to sine wave circuits.

Fig. 4



Electrode Configurations.

Fig. 5

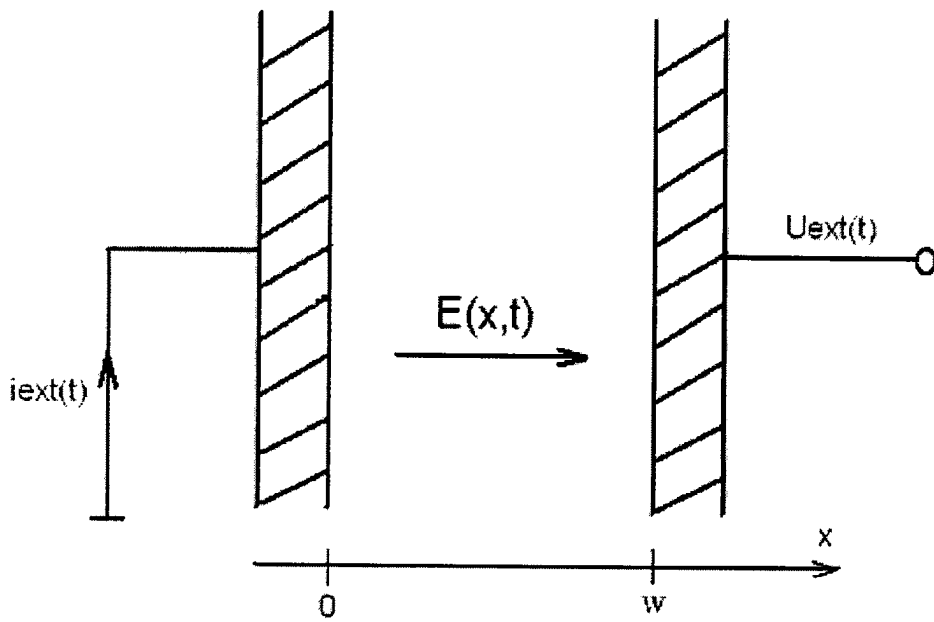


Fig. 6

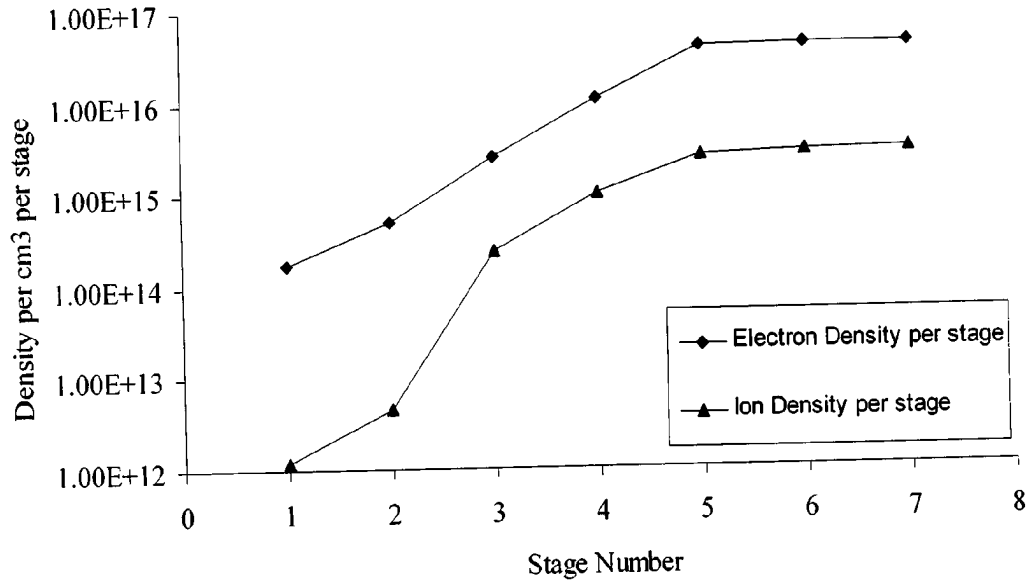
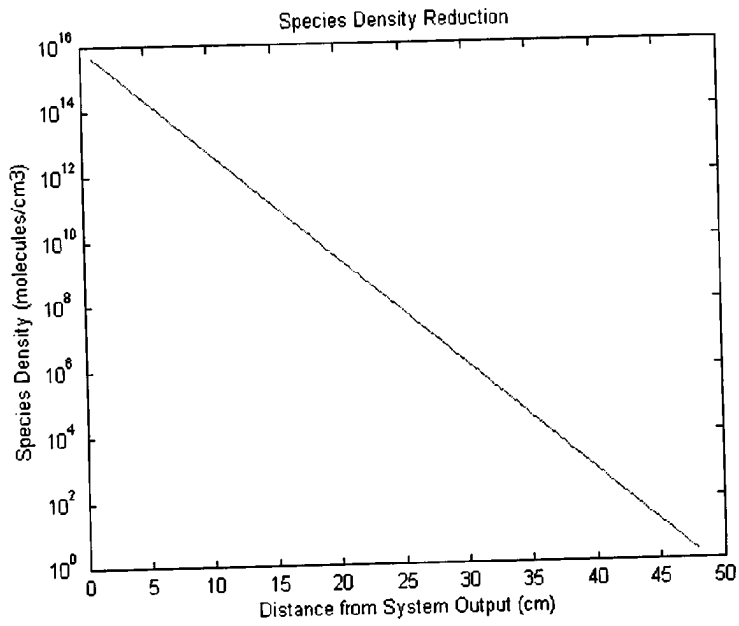
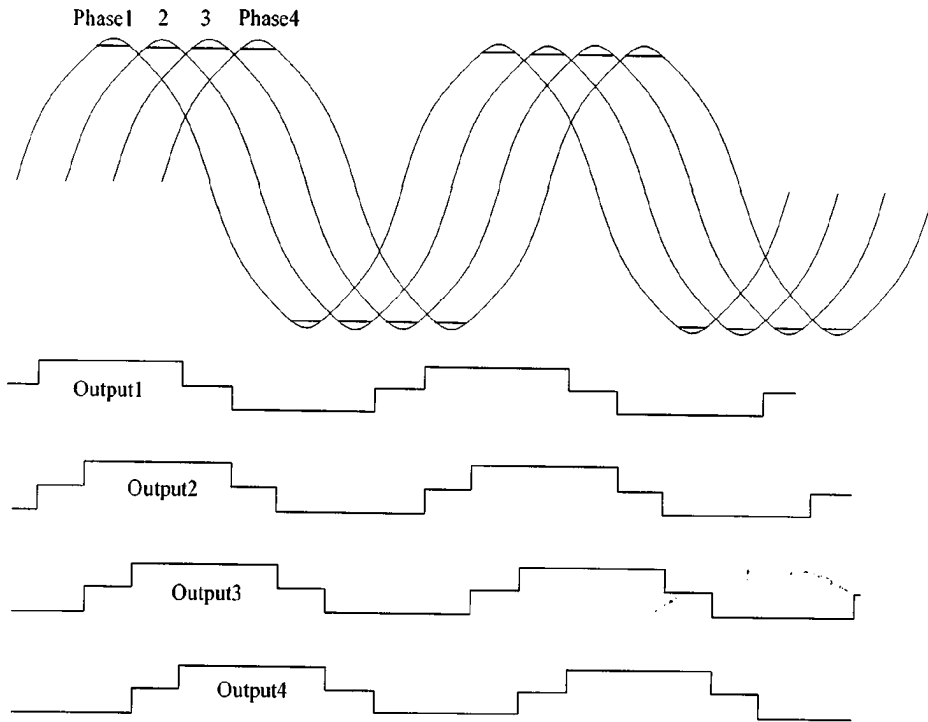


Fig. 7



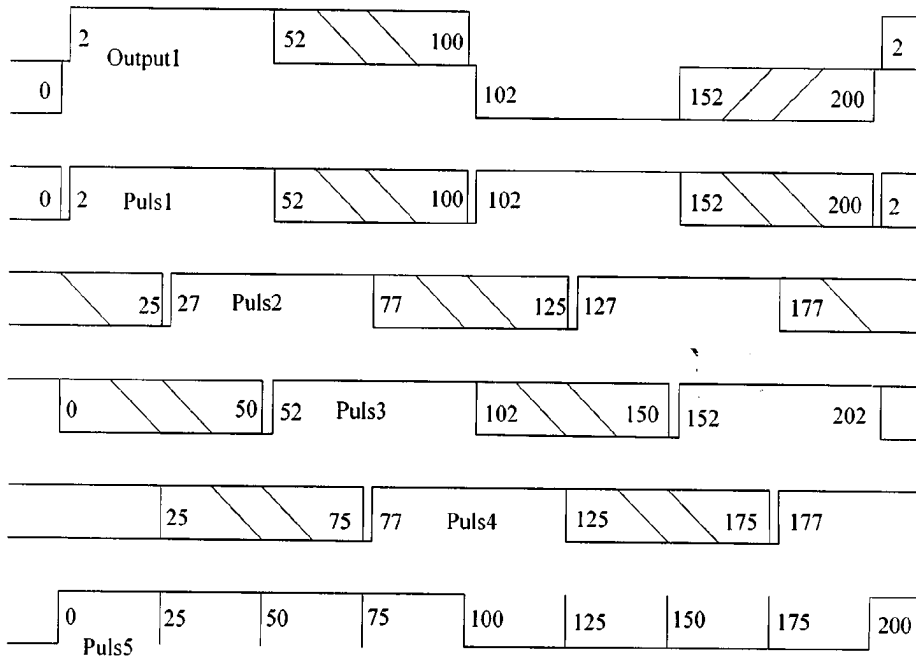
Density reduction with distance from output.

Fig. 8



Square wave to sine wave conversion by resonant circuits.

Fig. 10



Plasma timing for four phases.

Fig. 11