DC-PULSE POWER SUPPLIES

Tutorial: PPST 2003, June 9th-10th, Tokyo Japan

Titel: How to use DC-Pulse Power Supplies

Use and Application of DC Pulse Power Supplies with Superior Plasma Instant Kinetics Energy

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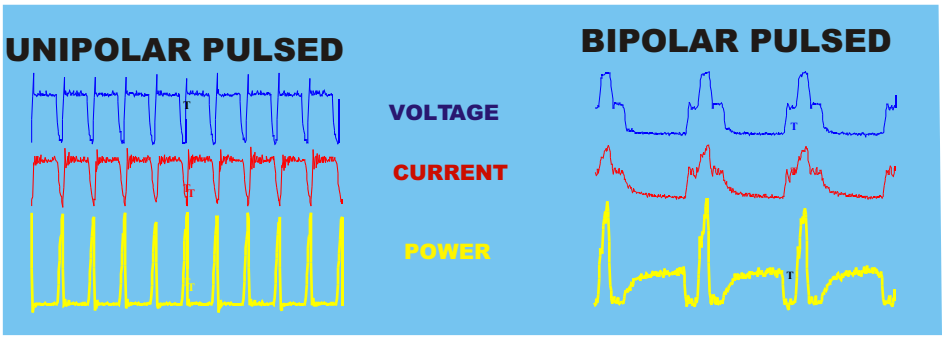
EDITION 2003

SPIK® 2000A
Superior Plasma Instant Kinetics

Patent pending: PCT WO 01/80413 A1



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A THE PRINCIPLE OF BIPOLAR PULSE TECHNOLOGY

Fields of application with the bipolar pulse technology for plasma and surface technology

Bipolar pulse technology - a new way for the plasma technology

The bipolar PULSE technology has been specifically designed for plasma surface technology and can be used for many processes.

1. **Plasma cleaning, plasma activation, plasma etching**

2. **Plasma diffusion**
   Process: Plasma nitriding

3. **Coating**
   Process: PVD, sputtering (single and dual magnetrons), plasma CVD

Figure 1 shows the fundamental connecting configuration of the bipolar pulse generator.

The output of the PULSE generator is connected to two conductive boundaries A and B inside a vacuum system. The substrate is located between A and B. The bipolar voltage pulses between the conductive boundaries supply an electric voltage (alternating E-field) around the substrate.
The negative and positive pulse times are freely adjustable which allows regulation of the plasma intensity between the conductive boundaries A and B (LOCATION and INTENSITY).

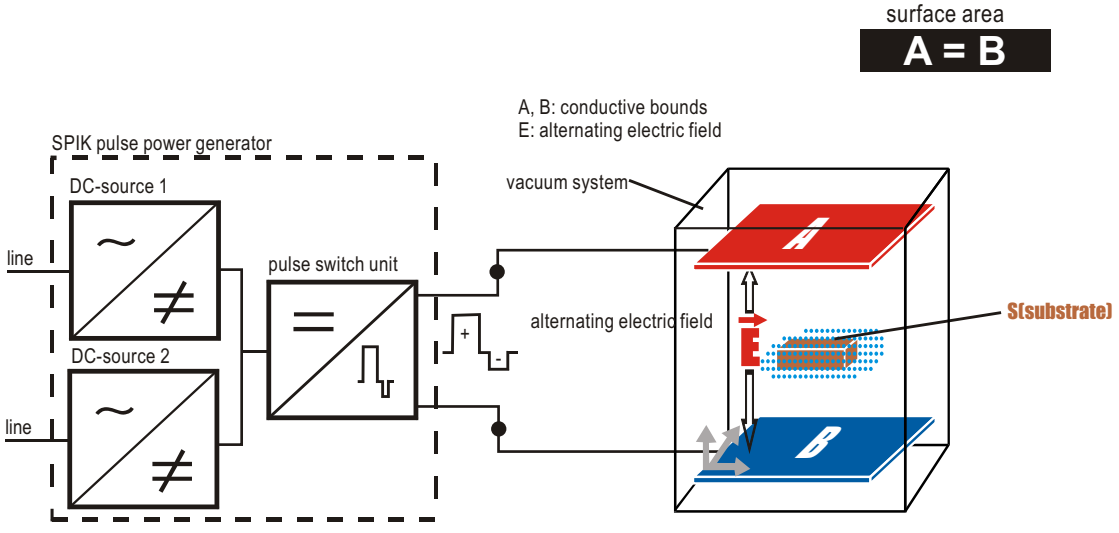


Figure 1

By using of two separate DC-power supplies the controlling of high of the pulse levels are independent controllable of each other.

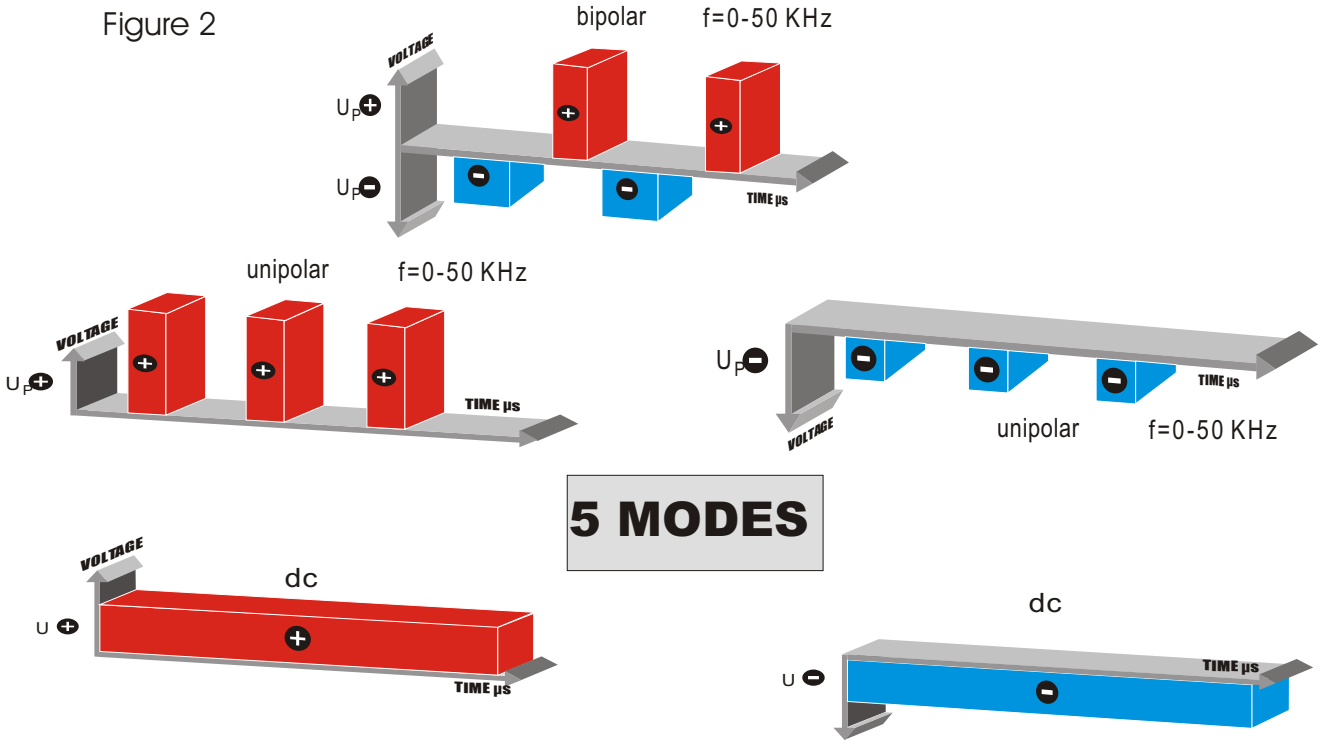
B CHOICE OF 5 DIFFERENT MODES

Our bipolar PULSE generator can be set to 5 different modes via a mode switch.

DC voltage: **-DC** ⊕
-DC ⊖
pulsed voltage: **-UP** ⊕ **unipolar positive)**
-UP ⊖ **(unipolar negative)**
-BP ± **(bipolar)**

The output voltage can be set in the range of 0 V to ±1000 V for each mode. The pulse-ON and pulse-OFF times can be set freely which gives control of the plasma intensity.

Figure 2



PULSE PARAMETER:

Ton+; Toff+;Ton-;Toff-≥ 5µs

∑(Ton+; Toff+;Ton-;Toff-) ≥ 20µs

f max = 50 kHz

In general by using of one or two DC-power supplies it is possible to use the plasma process in:

Symmetric bipolar pulse

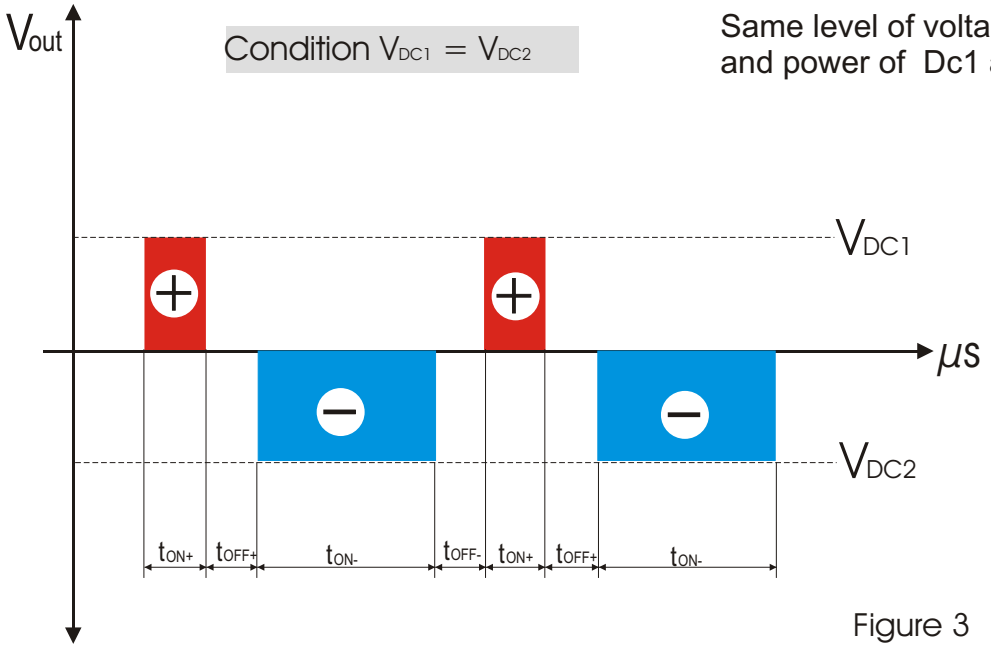


Figure 3

Asymmetric bipolar pulse

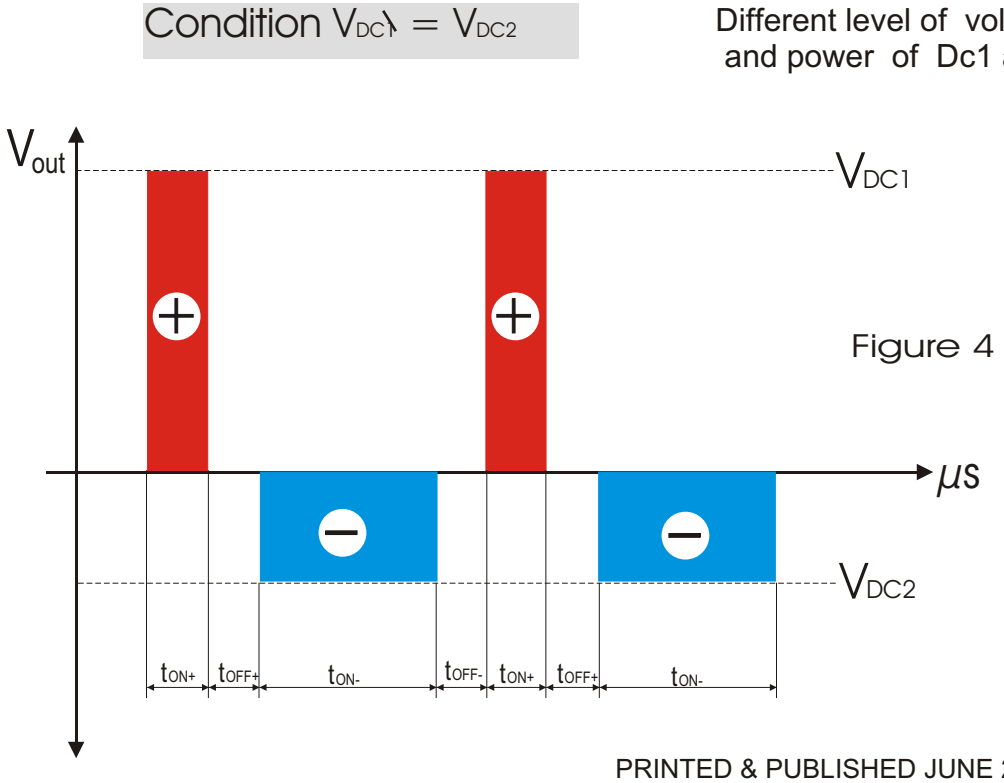


Figure 4

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PATENT PENDING
PCT WO 01/80413 A1

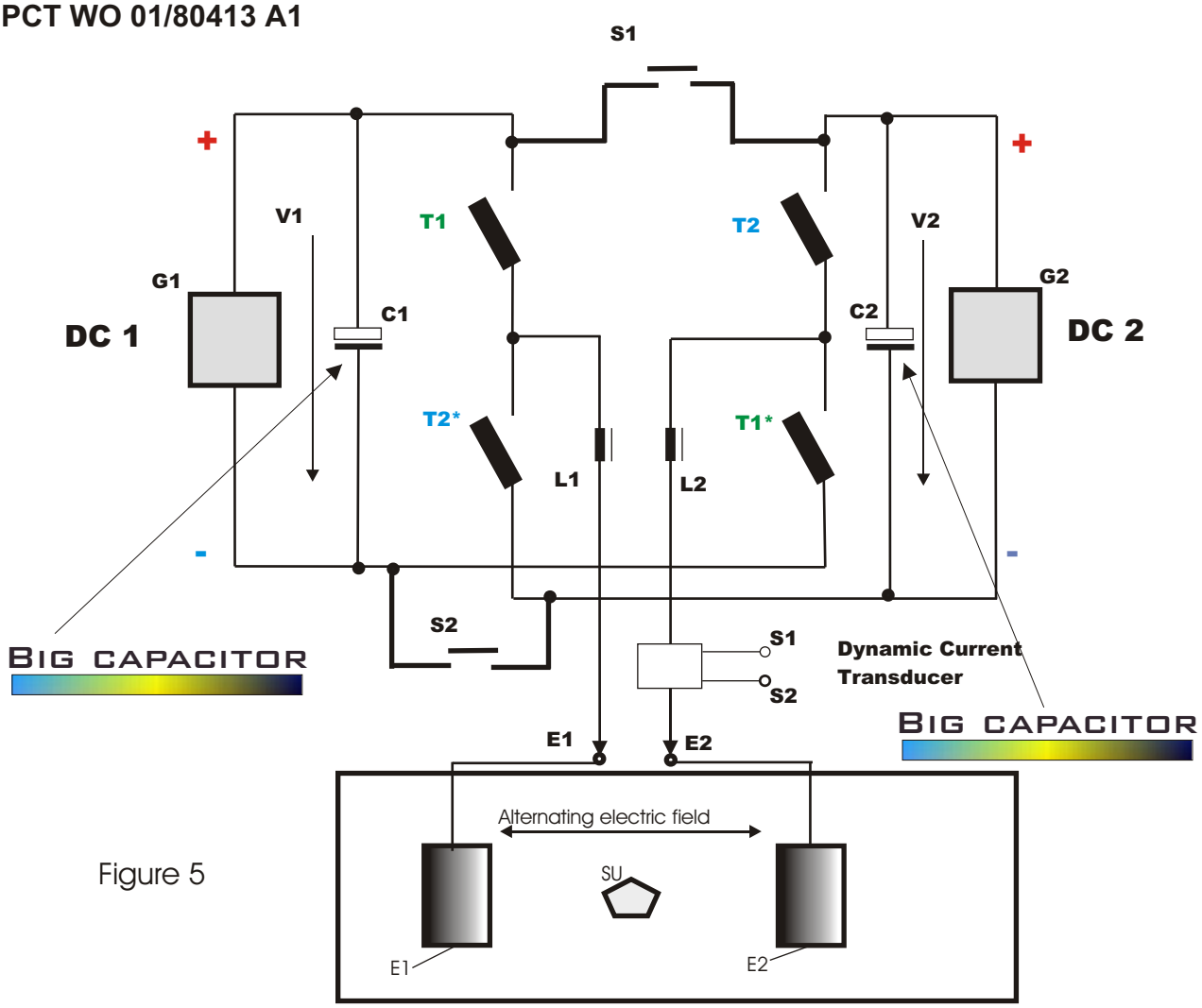


Figure 5

During the On and Off times the diagonal switches and open continualy (T1 and T1*) or (T2 and T2*). The ON and OFF times are freely adjustable from the µs range to sec. Range. The DC - source can be used in the voltage, current or power controlled mode.

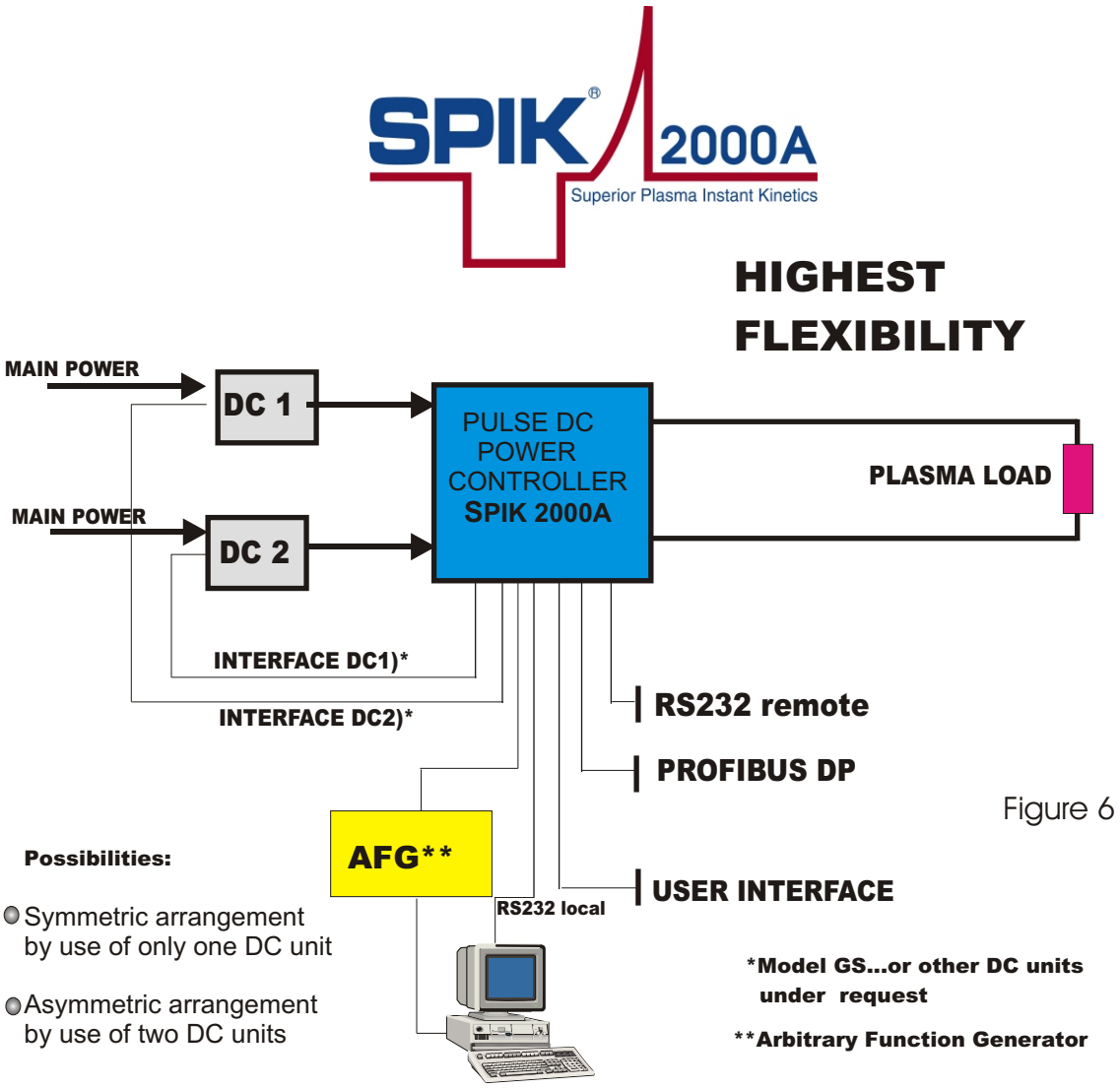


Figure 6

Create your pulse train by yourself

A brand new possibility is to control the pulse power unit by using of an Arbitrary Waveform Generator. In this case you are able to create rectangular pulse trains by yourself. The use of the Arbitrary Wave From Generator opens pulse plasma applications. To order we can supply the pulse unit separately for retrofit of existing for DC power supplies. High efficient ARC suppression is include in the pulse unit. The voltage, current and power levels of the DC1 and DC2 power supply can be set separately of each other, too (see page 5 symmetric and asymmetric pulse trains).

E

EXAMPLES OF PULSE TRAINS CREATED BY USE OF AN ARBITRARY FUNCTION GENERATOR

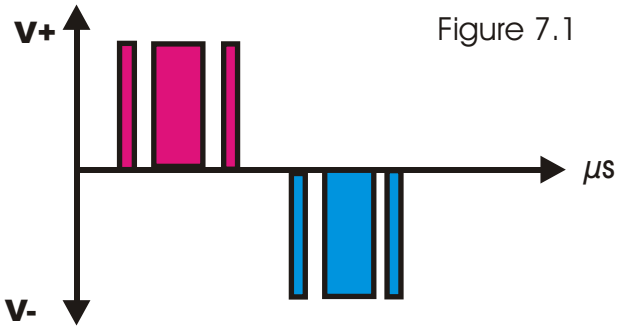


Figure 7.1

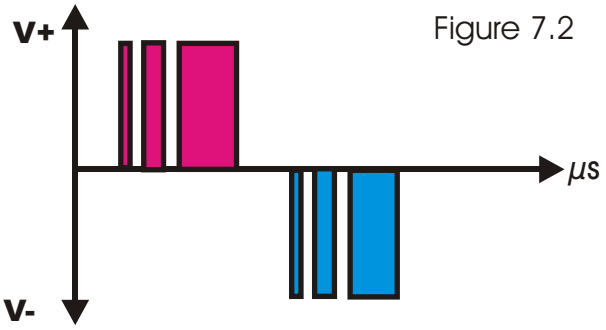


Figure 7.2

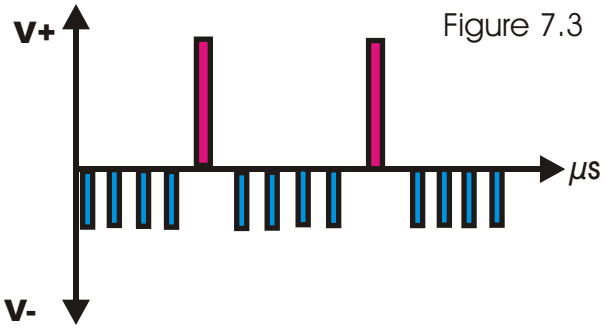


Figure 7.3

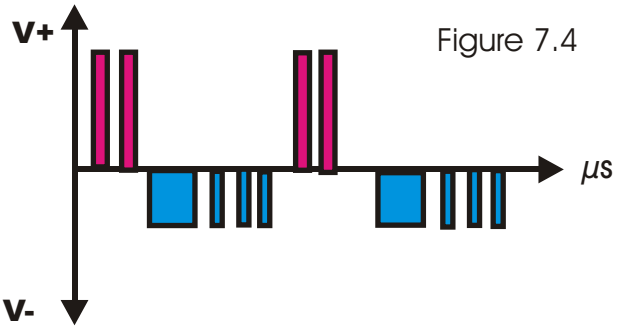


Figure 7.4

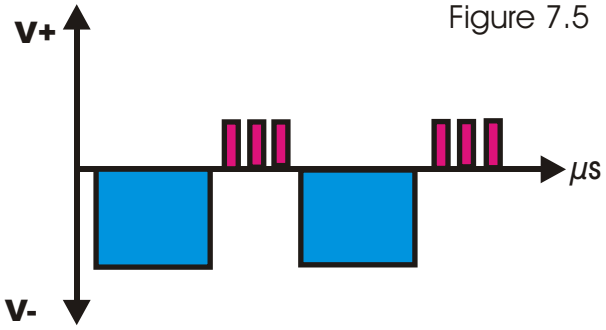


Figure 7.5

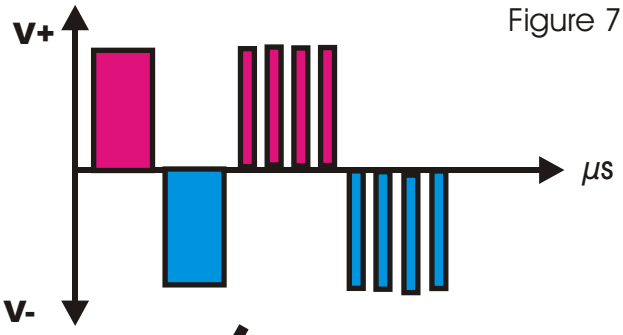


Figure 7.6

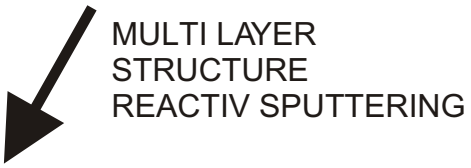
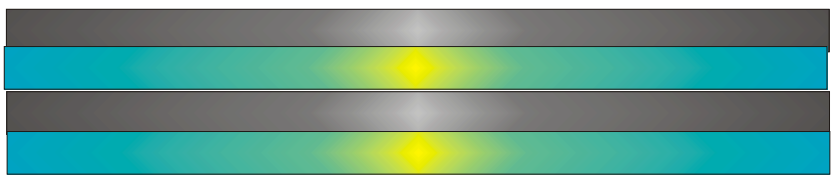


Figure 7.7



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The PULSE DC POWER CONTROLLER has a quick arc recognition and arc shut-off which sensitivity can be regulated via the adjustable arc level thus preventing the substrate surface from eventual burns caused by arc discharges. It also avoids the separation of macro particles into the substrate surface.

Figure 8.2 shows the principle of an active arc supression.

With positive voltage pulse the current increases according to the plasma impedance.

In Figure 8.2 Point 1, an arc is caused.

A conductive channel is produced due to the high concentration of charge carriers which leads to a sudden increase of the current.

When the current reaches the set arc-level in Point 2 the output voltage of the PULSE unit shuts-off within 2 µs and the current reaches 0.
The delay time is adjustable >30µs up to 10000µs

Figure 8.1

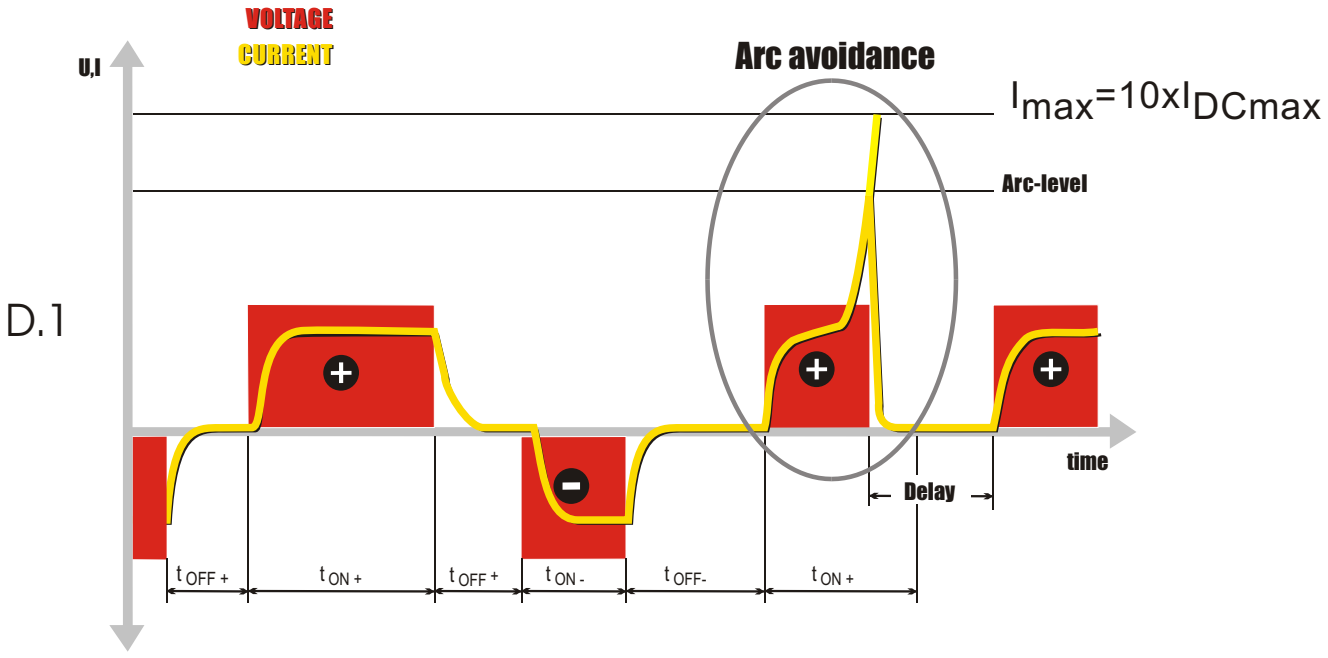
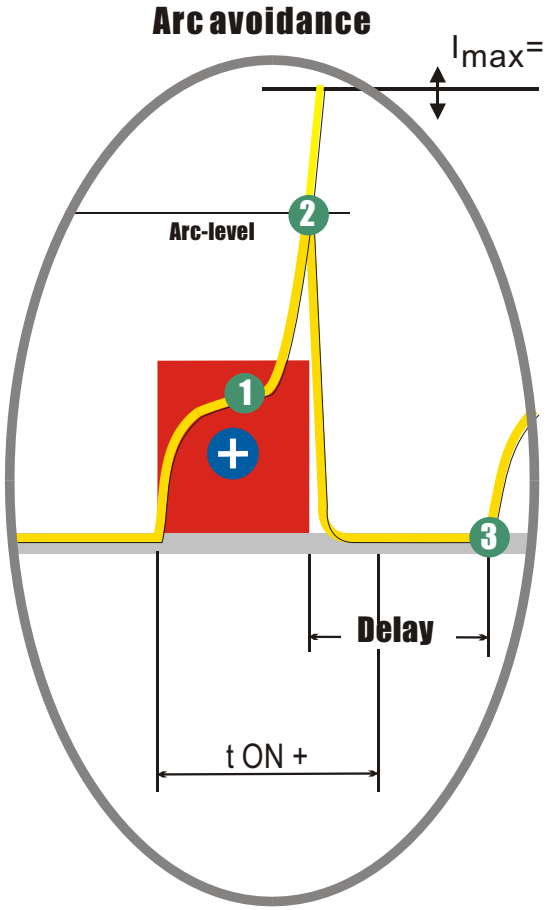


Figure 8.2



1 Arc is caused

2 The PULSE shuts off within 2µs
when the arc threshold is reached.
The arc threshold is adjustable)

Between **0 and +/- I_{max}=10 x I_{DCmax}**

3 Moment after an arc has been caused
and the delay time is over.
The PULSE unit is then switched
on again.
The delay time is adjustable
between 30µs up to 1 ms.

Pulse parameters t_{OFF+}, t_{On+}, t_{OFF-}, t_{ON-} can be
set separately and independently of each

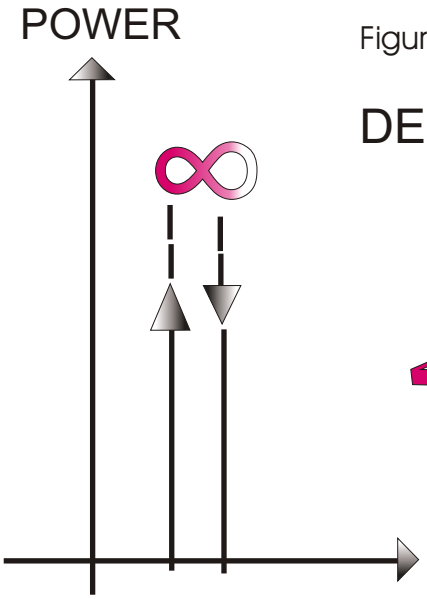


Figure 9.1

DELTA IMPULSE FUNCTION

By using of the fast fourier transformation (FFT) it can be shown that the delta function contains the highest number of frequency components.

Control of the acceleration of ions in sputtering by use of the bipolar constant voltage power supply.

Example of 40kW DC average power of reactive dual magnetron sputtering

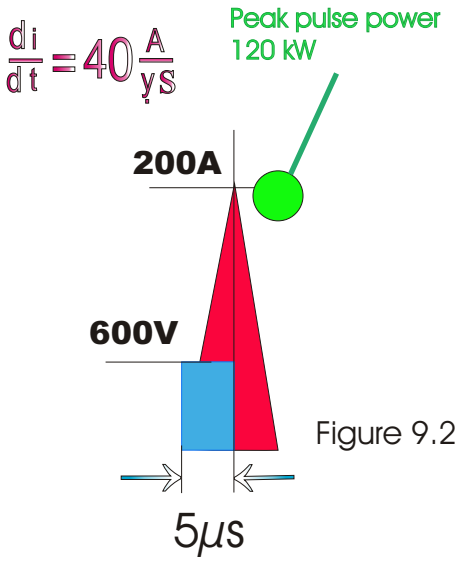


Figure 9.2

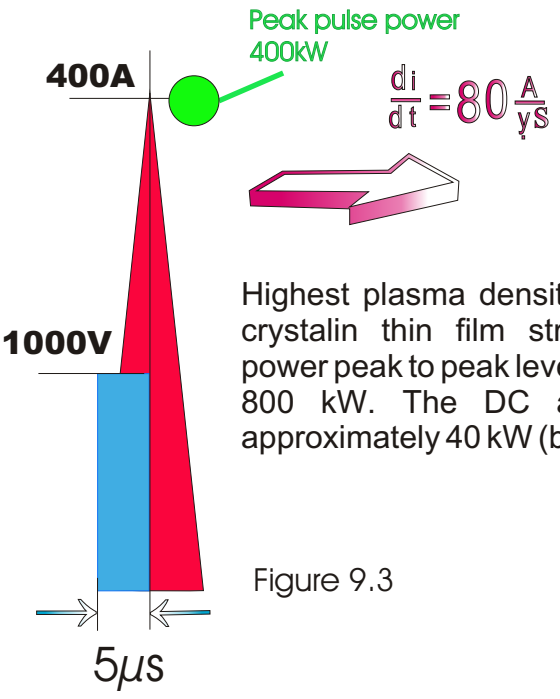


Figure 9.3

Highest plasma density results in highest crystalin thin film structure mode. The power peak to peak level in this case is 800 kW. The DC average power is, approximately 40 kW (bipolar pulse mode).

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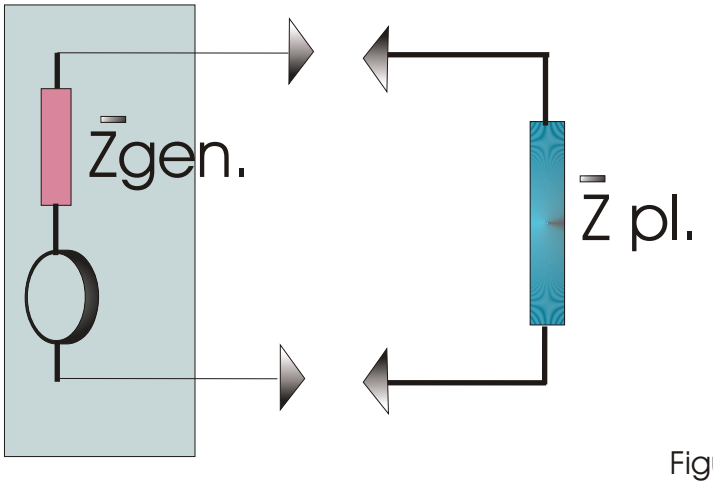


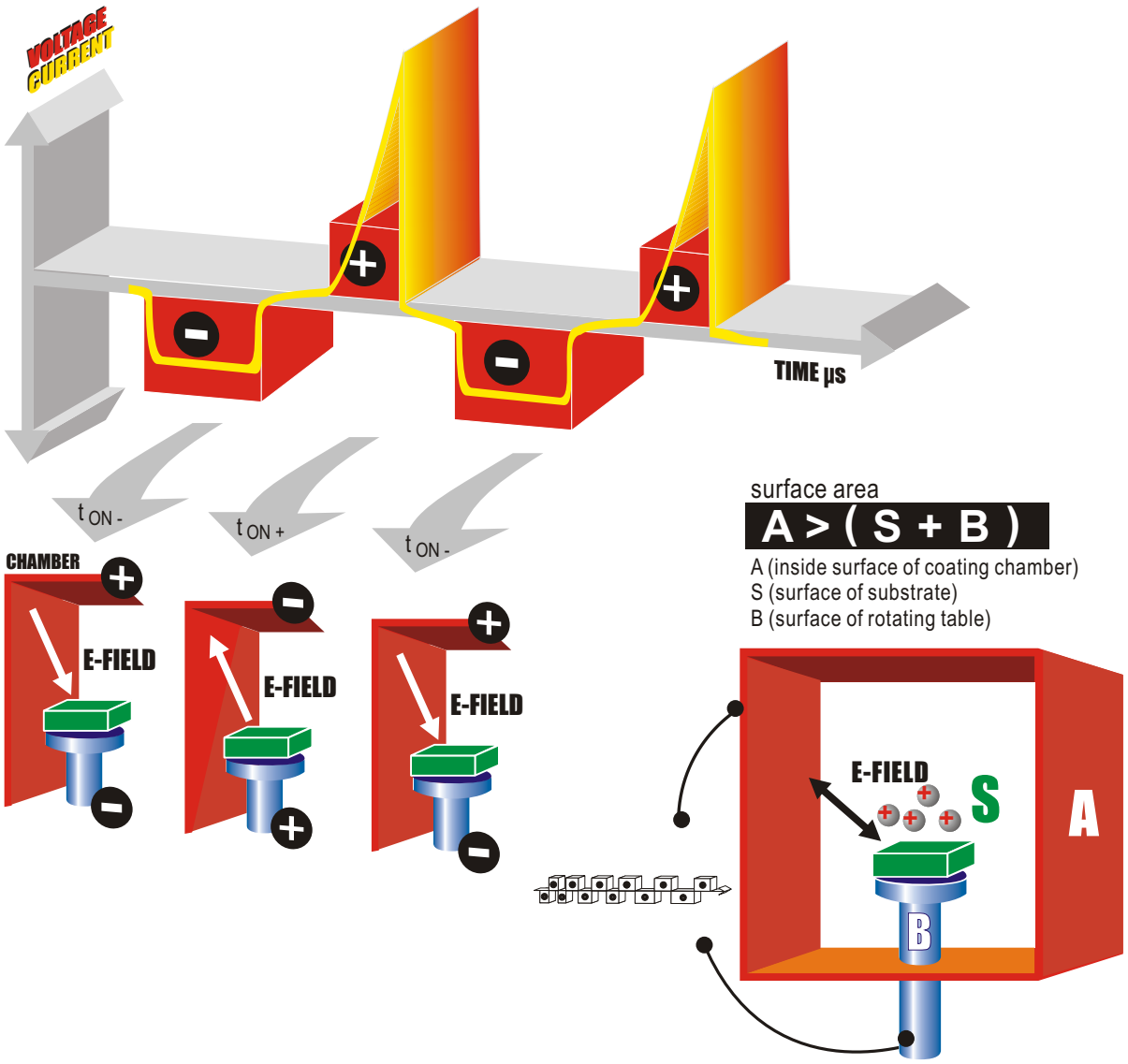
Figure 9.4

Conditions to generate highest pulse power impulses:

$$\underline{Z}pl. \geqq \underline{Z}gen.$$

For cleaning the voltage between the chamber wall A and the substrate holder B is connected to the substrate (see Figure 10.1).
Normally the surface of the chamber wall is bigger than the surface of substrate S and substrate holder B together, which leads to a higher current in the positive pulse than in the negative pulse.

Figure 10.1



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With t_{ON-} the substrate is negative and the chamber wall positive. The electrons can only move to the surface **A** (inside the chamber wall)

With t_{ON+} the polarity is changed so that due to the bigger chamber surface many electrons are available which move in direction of the substrate with high speed, whereas the positive ions are available which move in direction of the chamber inside surface **A**, whereas the negativ electrons move in opposite direction with much speed . Depend of the kind of gas ions, the speed of the electrons are 150 times higher compare to the ions.

This high mobility of electrons leads to a high increase in current during the t_{ON+} time. The process is continued periodically with the t_{ON-} time.
Using a conductive substrate the heavy ions (e.g. argon) are accelerated during the t_{ON-} time and hit the surface knocking out clusters.

The potential gradient to be accelerated can be up to 2 kV (+ 1.000 V / - 1.000 V) which leads to a high acceleration of ions and a cluster (non-conductive oxyde films and rest particles after pre-cleaning) is knocked out of the surface. The cluster, which is normally electrically neutral, is sucked off by the vacuum pumping system.

With stubborn soiling there might be areas where such clusters are not immediately removed from the surface during the pulse t250
due to the pole reversal.
The surface is now free of any positive charge carriers and is ready for the

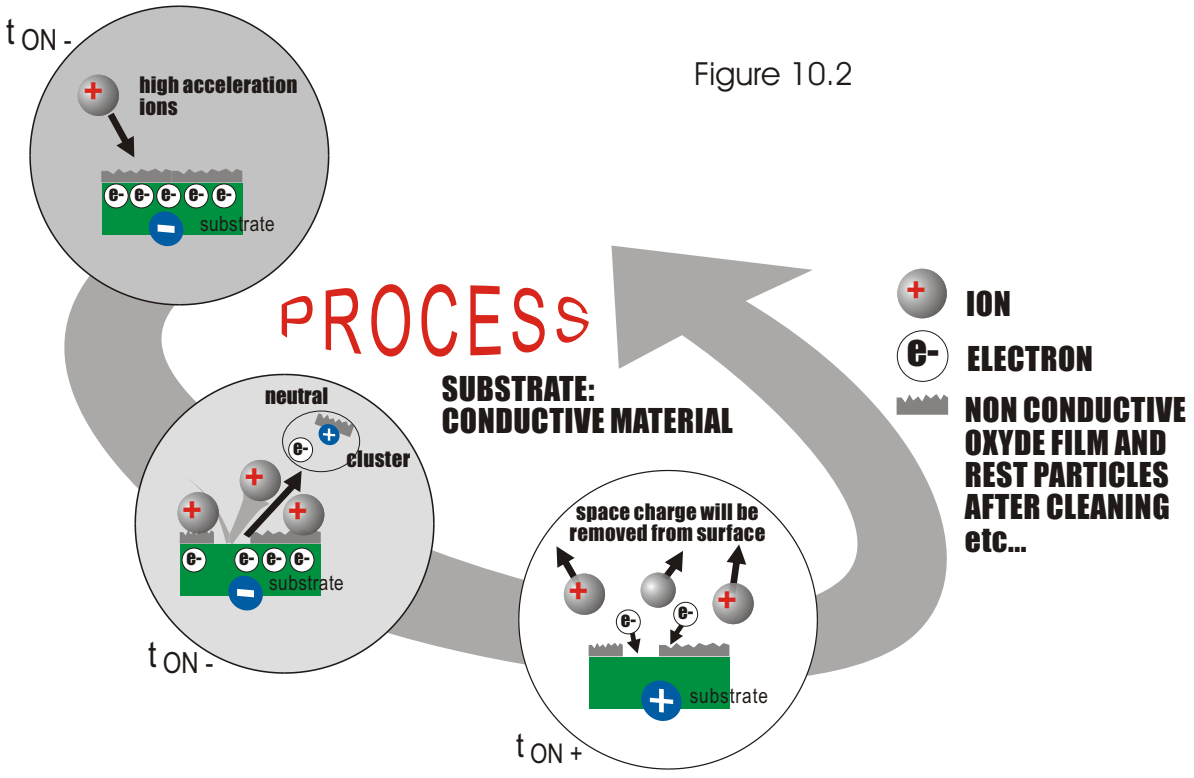

Figure 10.2

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I PVD BIAS APPLICATION

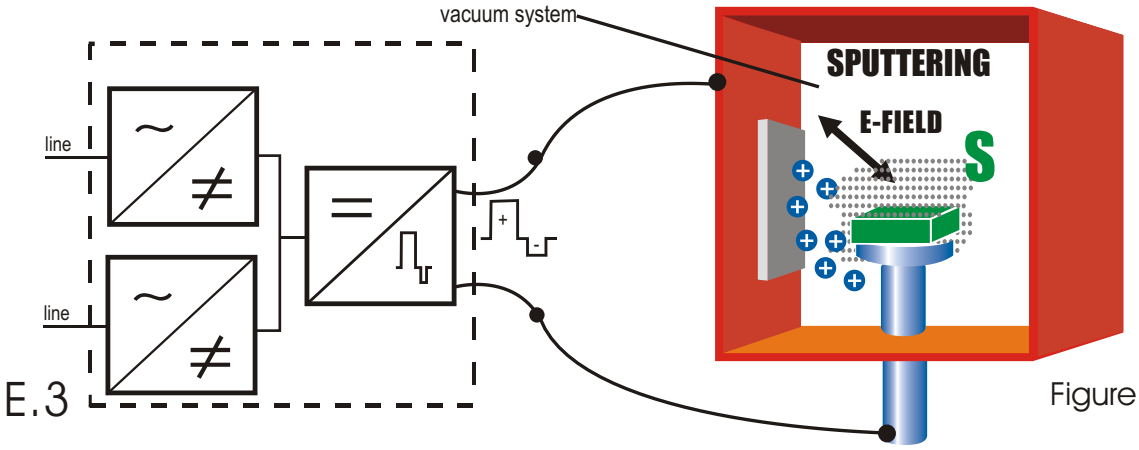
The figures 11.1 and 11.2 show the PULSE POWER SUPPLY as a bias supply for a sputtering process as well as an arc-evaporation process.
In both cases the released metal ions of the sputter target and of the evaporation unit are accelerated in direction of the substrate surface with high energy and are combinated with the top atomic layers of the substrate. During the coating process a defined layer is built up..

surface area

A > (S + B)

A (inside surface of coating chamber)
S (surface of substrate)
B (surface of rotating table)

PVD (BIAS - VOLTAGE) for sputtering



E.3

Figure 11.1

PVD (BIAS-VOLTAGE) for arc evaporations

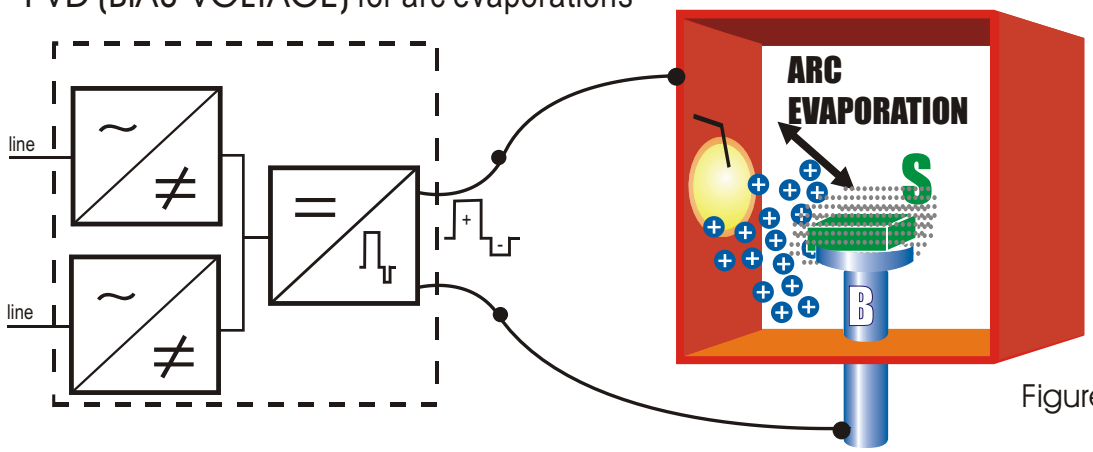
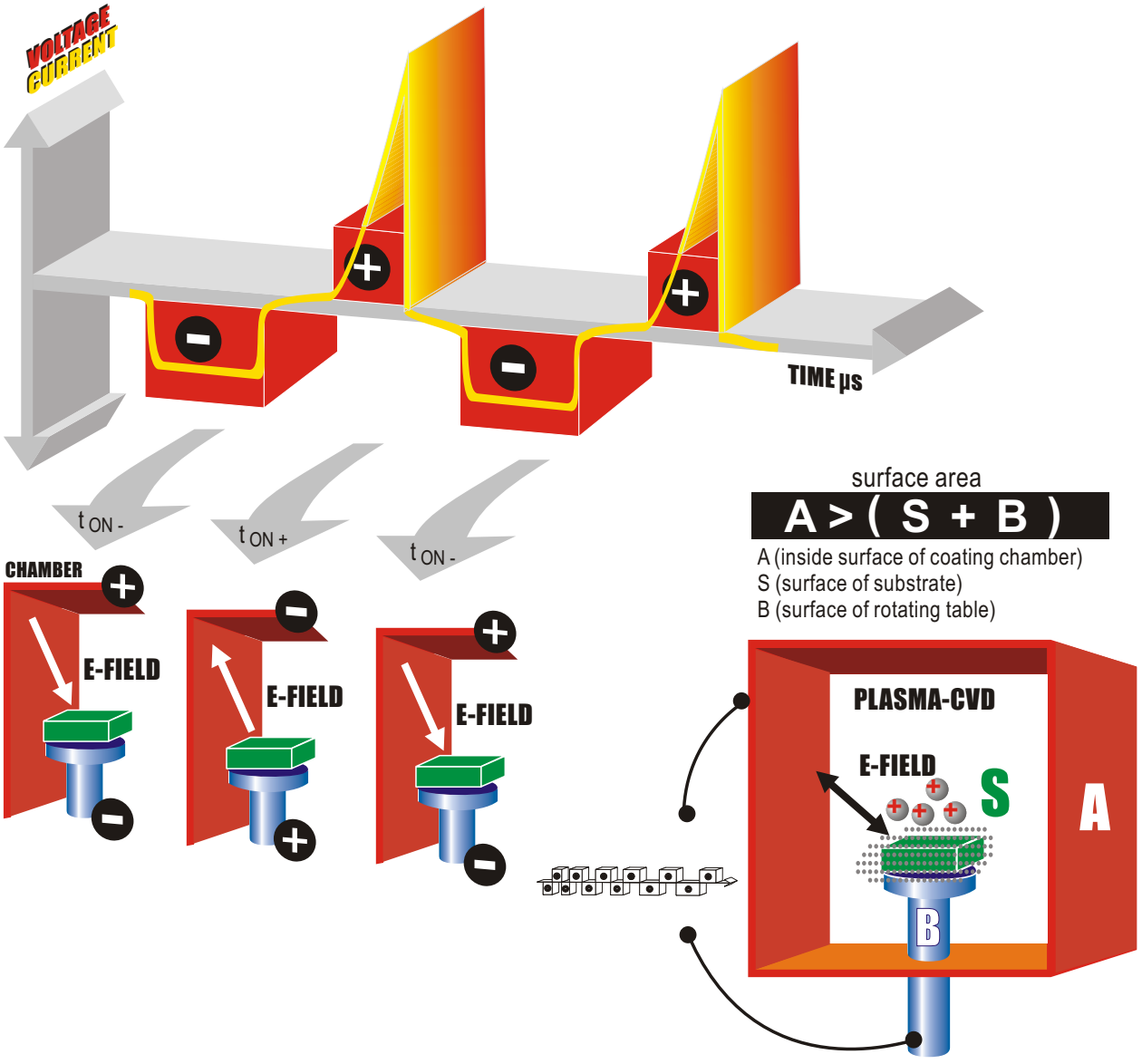


Figure 11.2

Use of our bipolar pulse generators with plasma CVD processes (page H). Under the conditions that the surface of a chamber A is bigger (S + B), a high current impulse in the positive voltage pulse is produced.

Plasma-CVD (C_2H_2 Acetylene, CH_4 Methane)

Figure 12.1



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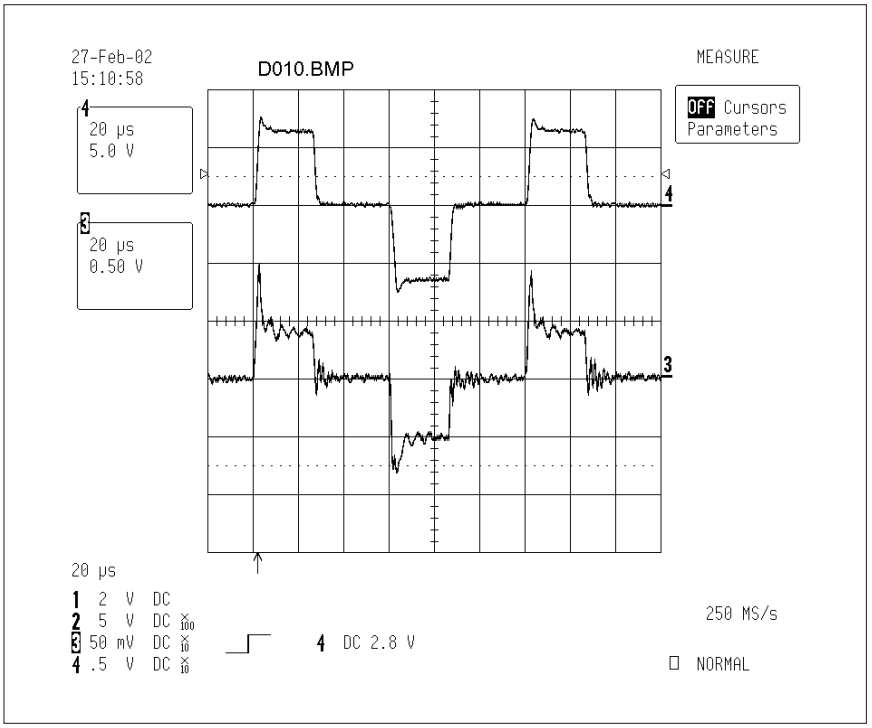
Described is the process with a conductive substrate. At the time t_{ON-} a non-conductive layer has been built up.The ions are taken up slowly by the surface until space charge is built up during the negative voltage pulse time, which avoids any further taking up of ions. With the next pole reversal t_{ON+} the disturbing space charge is removed from the surface, so that the surface is free of any charge carriers.

Figure 12.2
PARALLEL ELECTRODES ARRANGEMENT



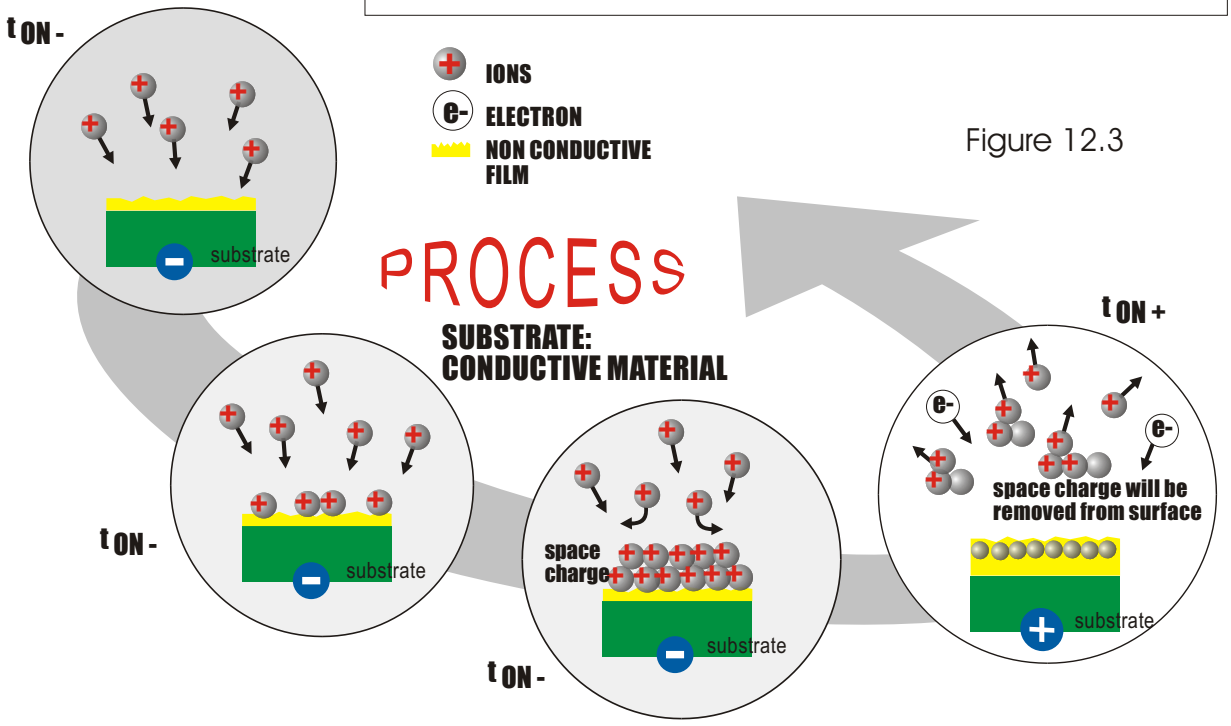


Figure 12.3

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With our bipolar pulse technique the double magnetron is highly suitable for e.g. Al_2O_3, SiO_2, SnO_2, TiO_2, Ti(Al)N, ZrO_2.

Figure 13 shows the principle of a double magnetron arrangement, whereas a magnetron is connected to the output pole of the PULSE UNIT.. Using different materials for the magnetron A and B these materials can be mixed as desired due to the different pulse/ pause conditions in the positive and negative voltage range in the plasma which produces totally new layers.
The occurance of arcs and the additional oxydation of the targets is prevented. The processes are much more stable especially with reactive sputtering.

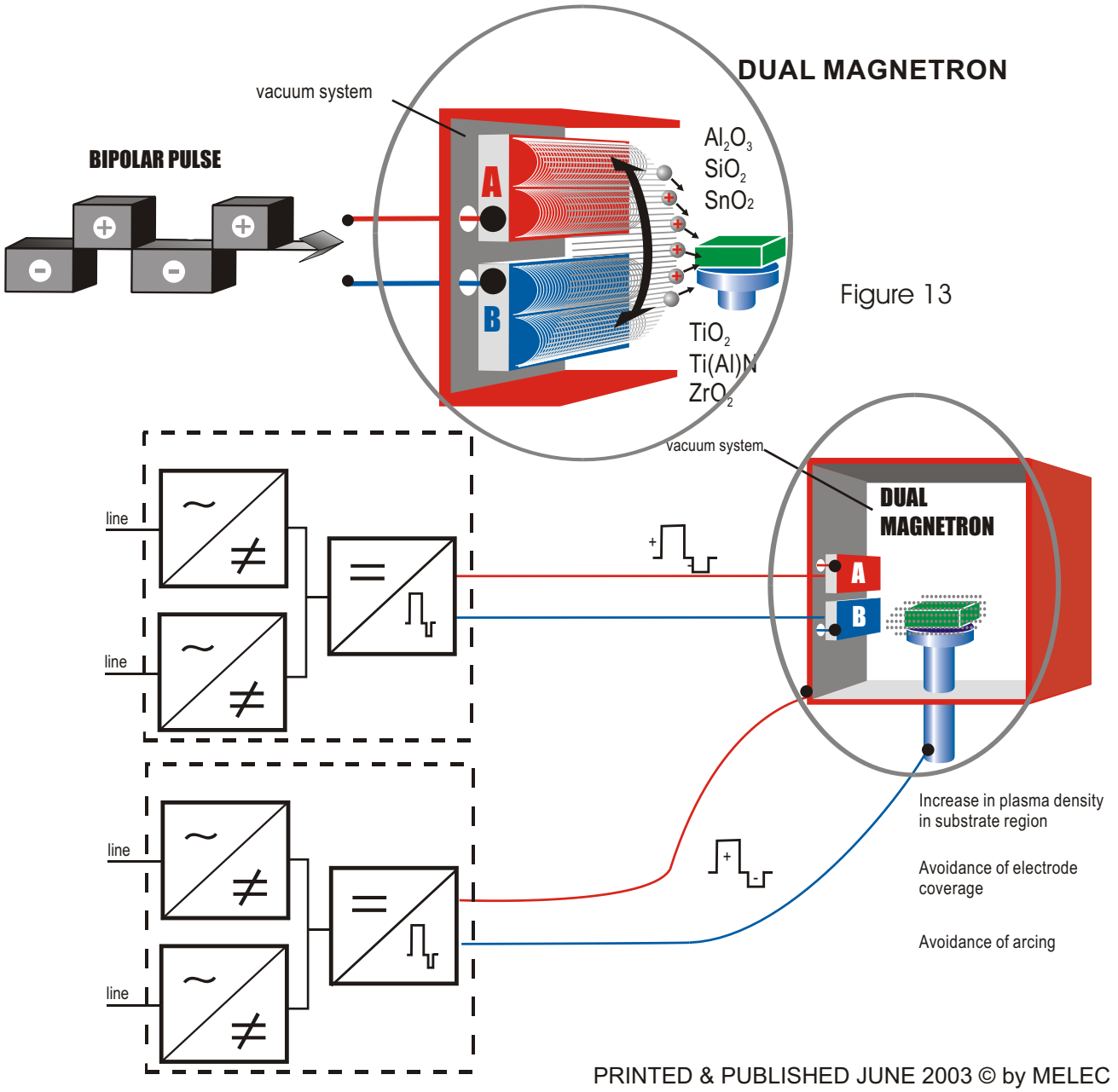

Figure 13

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With the acceptance of the bipolar pulse technology the discussion has focused on which frequencies are best switched. Bipolar pulsed constant current, bipolar pulsed constant voltage and sine current waves generated by different power supplies provides the opportunity for development of new plasma technologies. The following pictures show the basic structures of the various power supplies:

CONSTANT CURRENT BIPOLAR GENERATOR:

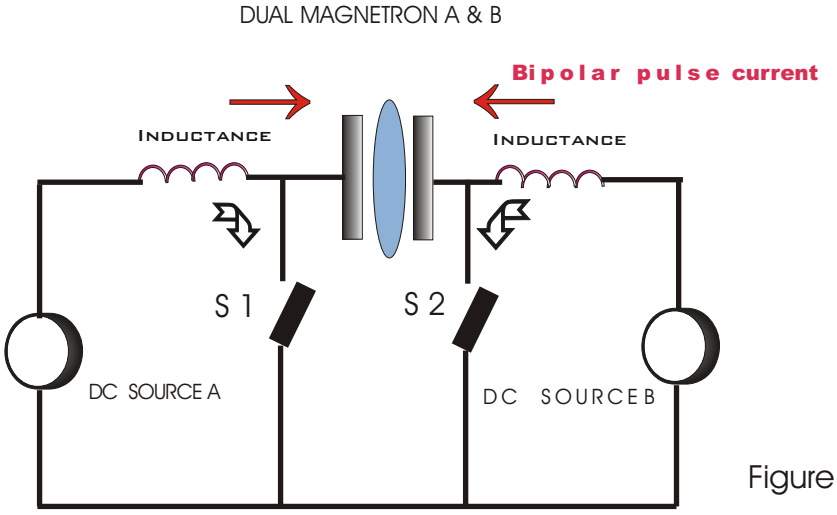


Figure 14.1

S1 and S2 are alternative open and closed in an asynchronous mode. That means if S1 is closed , than S2 is open. Otherwise, if S1 is open than S2 is closed. The OFF - Times and duty circle are limited. The two inductance hold and set the level of the pulse current constant.

SINE WAVE GENERATOR:

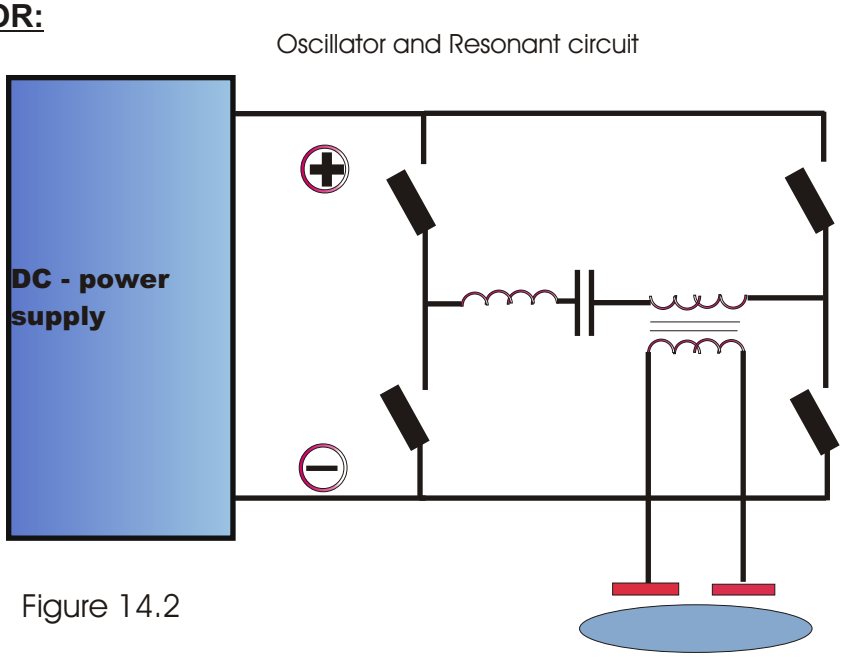


Figure 14.2

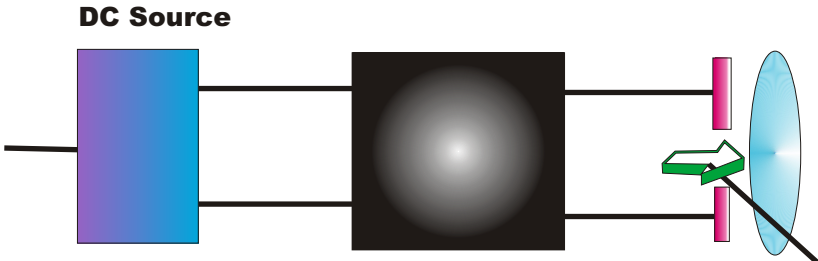
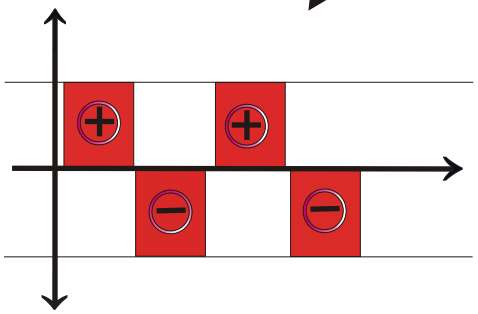


Figure 15

DIFFERENT PRINCIPLES

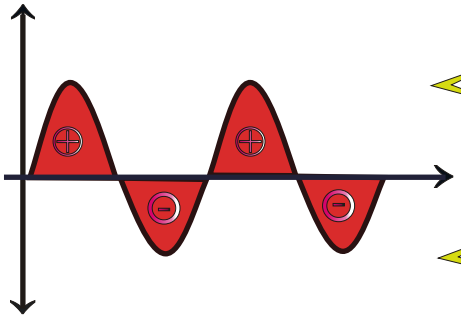
Example:
20kW with 1000V



+20 A

- 20 A

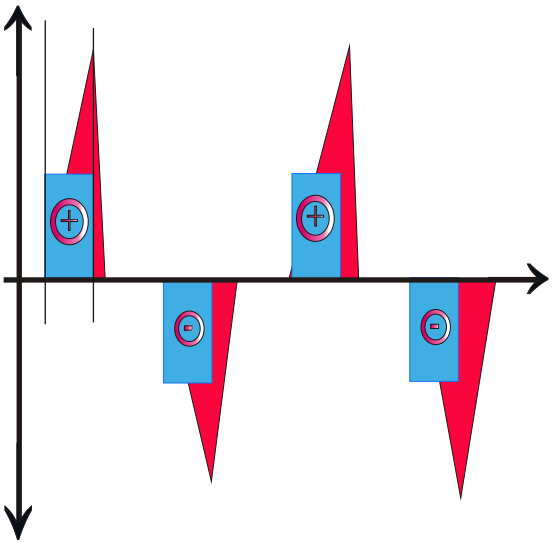
So called :
Bipolar pulse constant current Generator



+20 A*SQRT(2)

SINE Wave Genrator

- 20 A * SQRT (2)



+ 200A

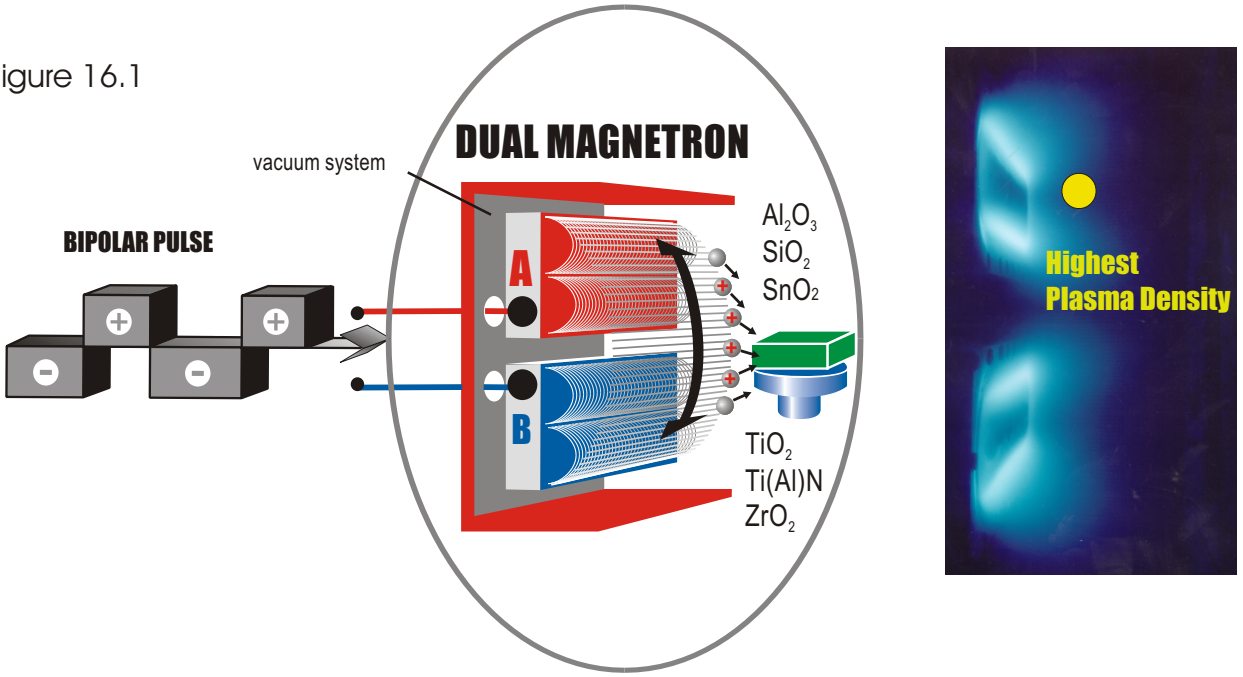
+ 1000 V

So called :Bipolar pulse constant voltage generator

- 1000V

-200 A

Figure 16.1



Reactive dual magnetron sputtering application of $AL_2 O_3$

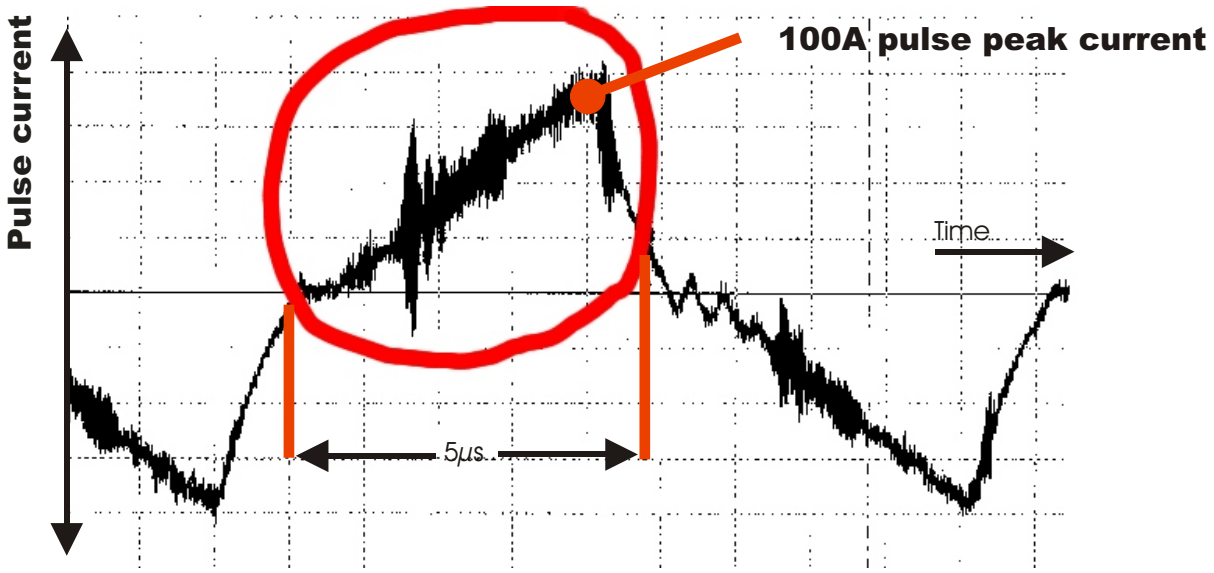


Figure 16.2

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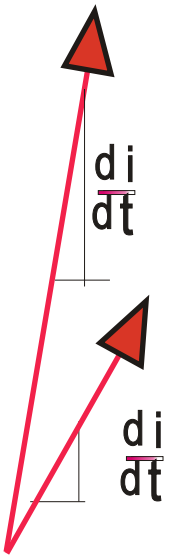
I RISE TIME OF PULSE CURRENT IS CONTROLABLE



Sputtering processes are functions of the frequency, ON- and Off-times, pulse peak current, pressure, temperatur .....

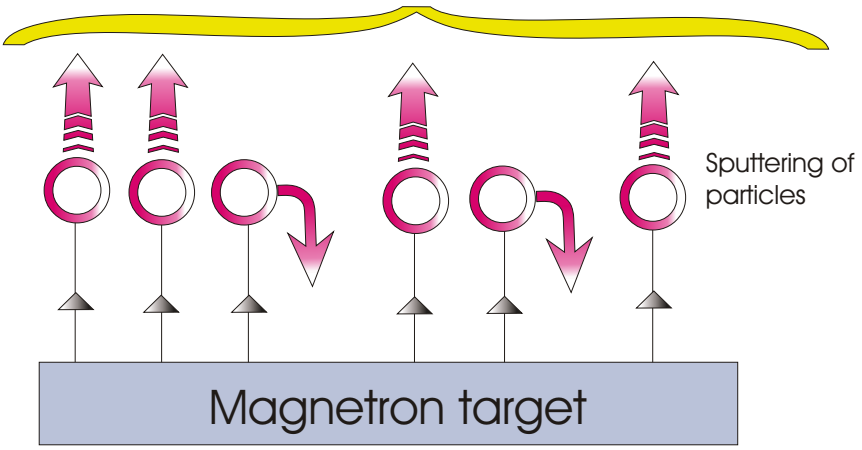


Figure 17.1

The conventional DC and rf- technologies will be replaced by bipolar pulse technology

EXAMPLE: 20 kW AVERAGE POWER (SiO_2)

CURRENT

VOLTAGE

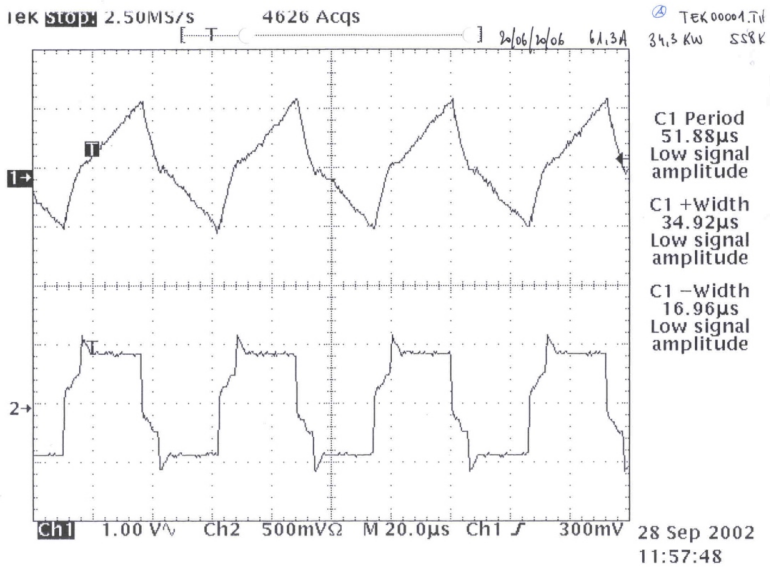


Figure 17.2

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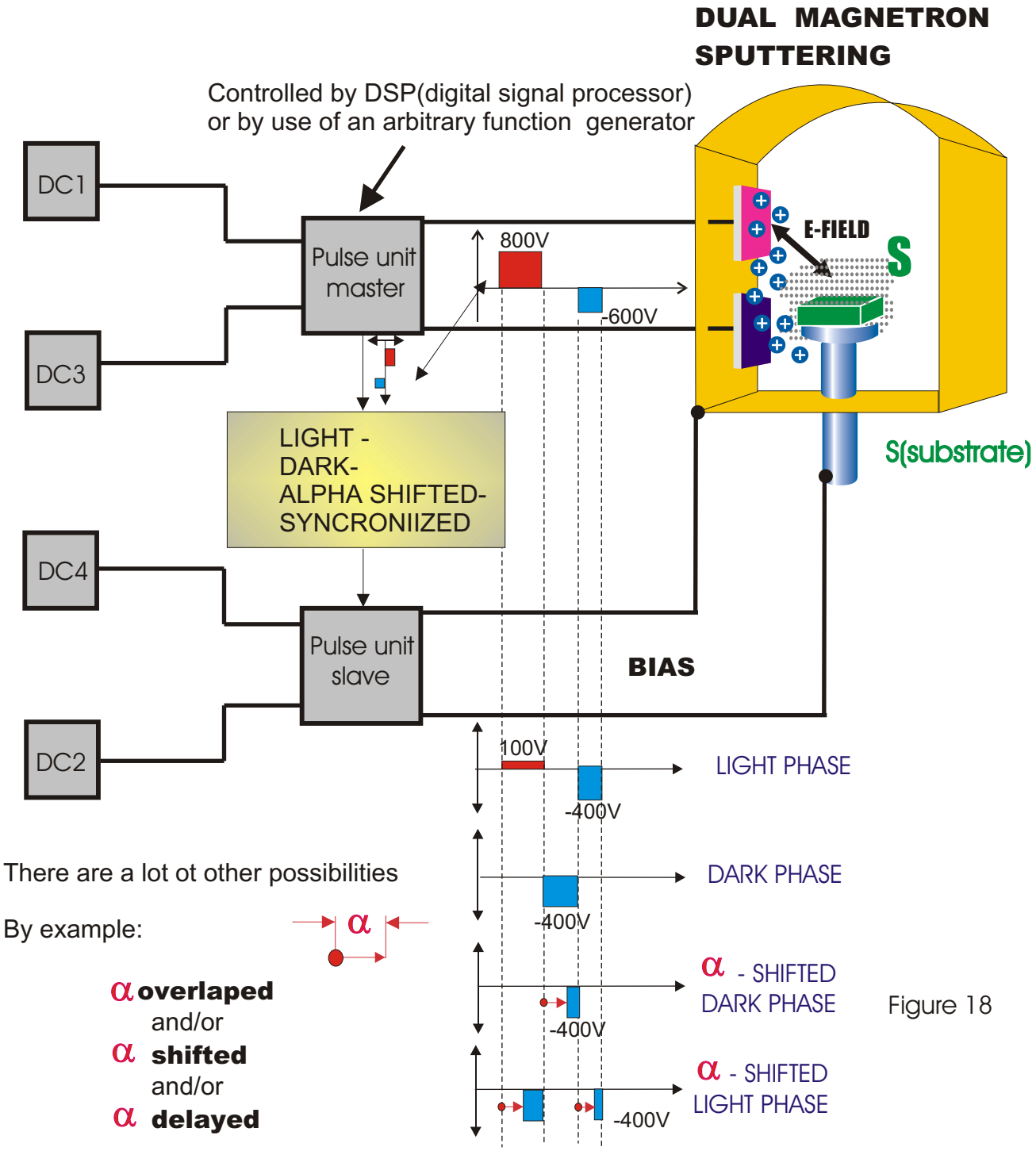
P SYNCHRONISATION OF BIPOLAR PULSE TRAIN OF REACTIVE DUAL MAGNETRON SPUTTERING AND BIAS

This is an additional "process knop " for the R & D process technologiy t o found out which are the best conditions of a welll synchronized BIAS voltage in relation of the magetron sputtering impulse train.



There are a lot ot other possibilities

By example:

α **overlaped**
and/or
α **shifted**
and/or
α **delayed**

synchronized

Figure 18

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Q SUMMARY / CONCLUSIONS

Full controlling of electric pulsed fields without any kind of impedance matching network

Different modes DC+, DC-, unipolar pulsed+, unipolar pulsed-, bipolar pulsed

Pulse parameters t_{OFF+}, t_{On+}, t_{OFF-}, t_{ON-} can be set separately and independently of each other

Create by yourself rectangular pulse trains by use of an external Arbitrary Wave Form Generator (AWFG)

Highest pulse peak power generates a fully ionized plasma and metal-species will be dominate

Symmetric and Asymmetric power arrangement are possible

Sychronisation of sputtering pulse power supply and pulse power supply of BIAS open new advantages

Retrofit: Use your existing DC power supplies.

For more information contact us.

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