HIPIMS Power Supply Requirements: Parameters and Breakthrough Arc Management Solution

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ABSTRACT

This article describes new arc management strategy for arcs occurring during HIPIMS sputtering process. Arcing is a common problem in magnetron sputtering. Arc prevention strategy traditionally involves the detection of either high current or low voltage. This paper describes how cable inductance increases arc energy and a solution of this problem meeting customer demand to decrease arc energy. The new approach guarantees: significantly reduced arc extinguish time and energy delivered to the arc decreased by up to 90%.

HIGHPULSE POWER GENERATOR

HIPIMS provides peak power output levels in MW (Megawatt) if compared with DC, pulsed DC or RF generators which have output power levels in kW. However HIPIMS is 99.9% switch off and MW only for 0.1% of the time is switch on. So the average HIPIMS power is also in kW and can be calculated as:

$$P_{avg} = P_{pulse} * \frac{pulse\_length}{period} = P_{pulse} * duty \qquad (1)$$

For example, pulse with a duration 25 µs and repetition frequency 100 Hz (duty = 0.002) with peak pulse power 8 MW will generate an average power 20 kW. The average power usually does not exceed the power during classical DC sputtering.

From the equation (1) we can observe that if the average power will increases it means that the pulse power or duty increases. In this case the peak power or duty should be reduce in order to keep the required average power. The peak power can be controled by the output voltage level of HIPIMS and the duty, which can be controlled by repetition frequency (freq.) and the pulse time (pulse length).

HIPIMS APPLICATIONS

Typical applications of HIPIMS system is shown in Figure 1. Typical HIPIMS pulse density is 1-3 kW/cm^2 (it is 50-100 times more than conventional DC sputtering) and recently developed pulse energy up to 18MW are available (1-2 kV, 1-6 kA). This makes HIPIMS feasible on many large scale industrial applications such as: hard coating, semiconductor, decorative coating and ion etching pre-sputter treatment [1-4]. The HIPIMS system consists of following elements:

- TruPlasma HighPulse (high power pulse generator)
- Optional Cable Length Compensation unit CLC
- Dedicated biasing unit with special construction keeping constant voltage through all HIPIMS impulse cycle (patent pending).

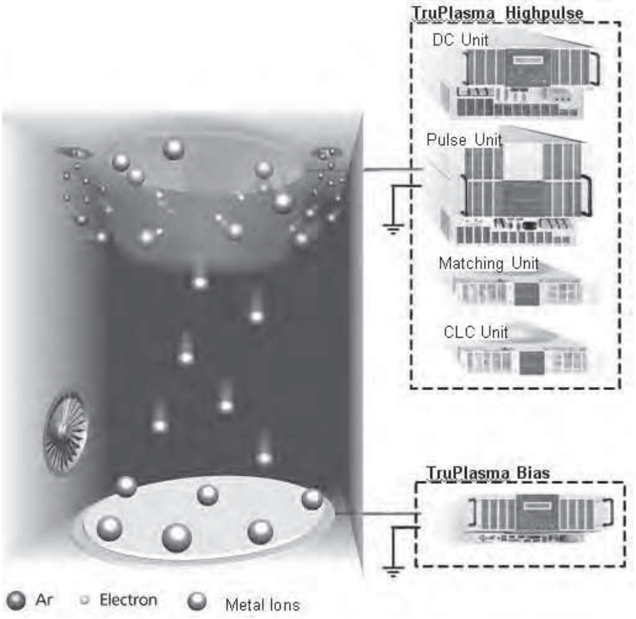

Figure 1: The HIPIMS system.

The TruPlasma HighPulse consist of: DC power unit (provides constant power to drive the HIPIMS system), Pulse unit (stores the power from DC power unit and then delivers it as a pulse), Matching unit (modifies the output pulse to prevent 'ringing' and control shape).

Figure 2 shows the voltage and current signal on the output of HighPulse system during normal operation of HIPIMS without arcing.

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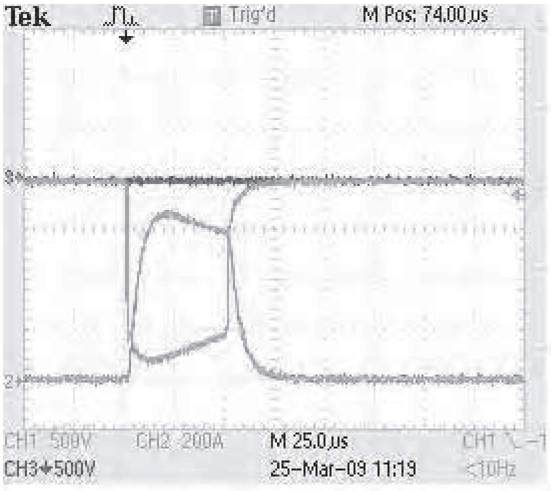


Figure 2: Waveforms on the output of HighPulse generator during normal operation (without arccing): CH1- output voltage(500V/div) CH2- output current (200A/div).

ARCING

During normal work of HighPulse generator in a chamber arcing can occur. Impurities found in target dielectric in nature will result in an arc occurrence. Arcing is especially troublesome in reactive processes.

In Figure 3 shows the moment t_1 arc is starting. From this time the current quickly grows (the limitation is only max current of HighPulse). The arc can negatively affect the sputtering process.

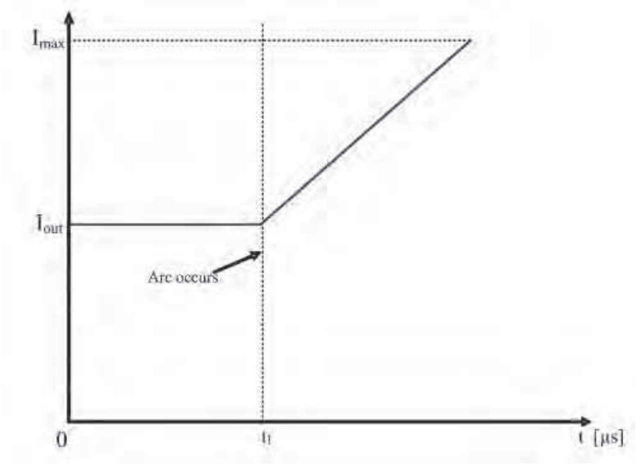


Figure 3: Current chamber waveform without an arc management.

ARC MANAGEMENT

There are many methods of detecting the arc event which are based on: current detection I, voltage detection V, and mixed current-voltage detection VxI. We will consider on the current method which is illustrated in Figure 4.

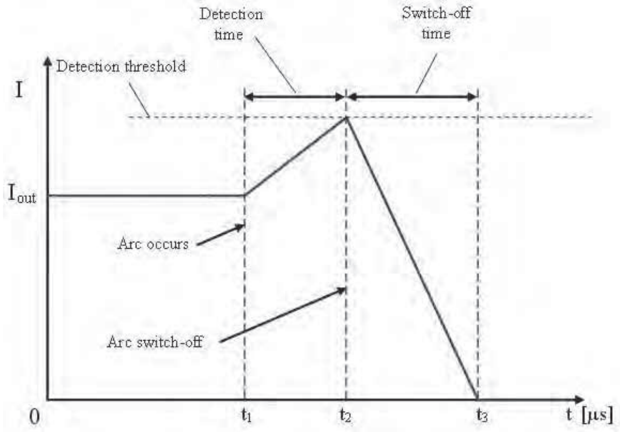


Figure 4: Current chamber waveform with an arc management.

Twenty years ago it may have taken a power supply several milliseconds to detect an arc. Today detection can take less than a single microsecond. Both fast detections and novel power supply design, the energy released to an arc has been reduced from joules down to few hundred micro-joules per kilowatt.

However if the switch-off time (see Figure 4) is long we can observe that arcs negatively affect the quality of layers built on a substrate during the sputtering process as shown in Figure 5.

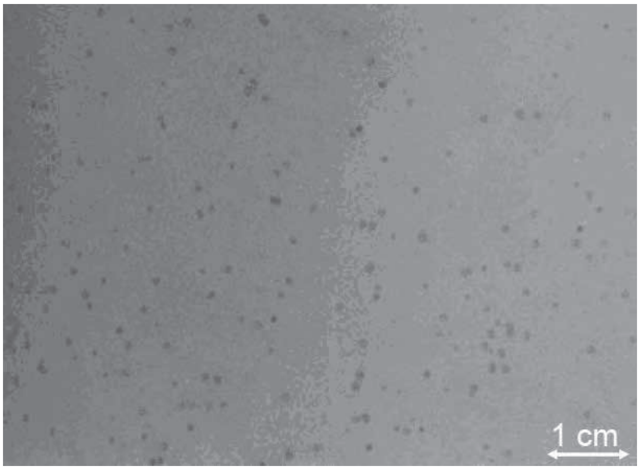


Figure 5: Effect on target of too much arc energy.

In Figure 6 presents waveforms of the output voltages (on the chamber and output of HighPulse generator) and the current in the vacuum chamber. We can observe that during an arc the voltage on the chamber reduces to several volts and the current grows to I max detection level. From this time an arc quenching process starts, and finishes with current reaching zero.

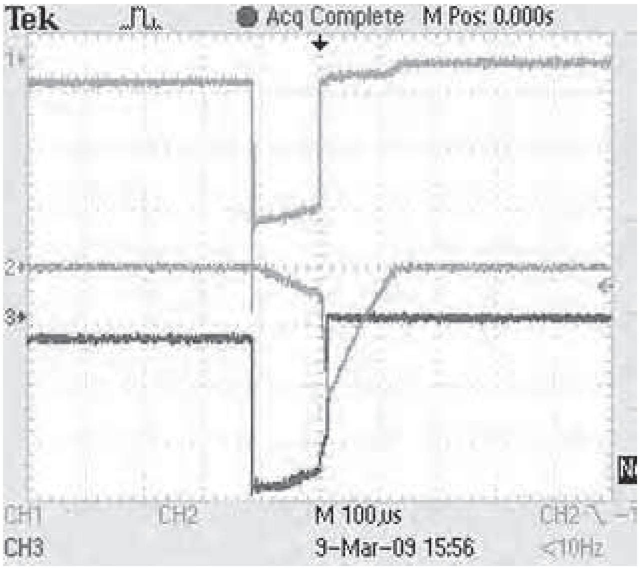


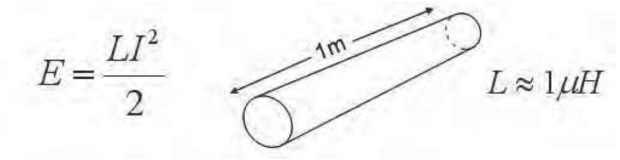
Figure 6: Waveforms on the output of HighPulse generator during arc occur: CH1- output voltage on the chamber (1000V/div) CH2- output current (1000A/div) CH3- output voltage(1000V/div).

The time when the current drops to zero depends on:

- Value of the current when it is switched off
- Length of cables, which connect the HighPulse generator to the chamber.

ENERGY STORED IN LEAD INDUCTANCE

Taking in to account that 1m of cable is around we can calculate the energy stored in the cable in the following formula, which is shown in Figure 7.



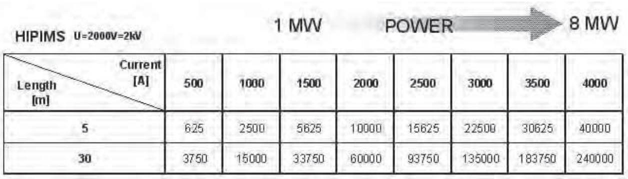
$$E = \frac{LI^2}{2}$$

$$L \approx 1\mu H$$

Figure 7: The principle of calculation energy stored in the cable inductance.

It's obvious that cable inductance and energy related to it contributes to the arc energy. As an example Table 1 illustrates how much energy is stored in the cable (for 5, 10 meters long cable and several current values).

Table 1: Energy stored in cable inductance versus cable length and the switch-off current.



HIPIMS U=2000V=2kV

1 MW POWER → 8 MW

Length [m] \ Current [A]	500	1000	1500	2000	2500	3000	3500	4000
5	625	2500	5625	10000	15625	22500	30625	40000
30	3750	15000	33750	60000	93750	135000	183750	240000

One negative effect of arc high energy is long quenching time (Figure 8), which results in reduction of sputtering time. In other words the energy stored in the cable inductance increases time needed for arc quenching. The effect of that is a decrease of the total energy supplied to sputtering process.

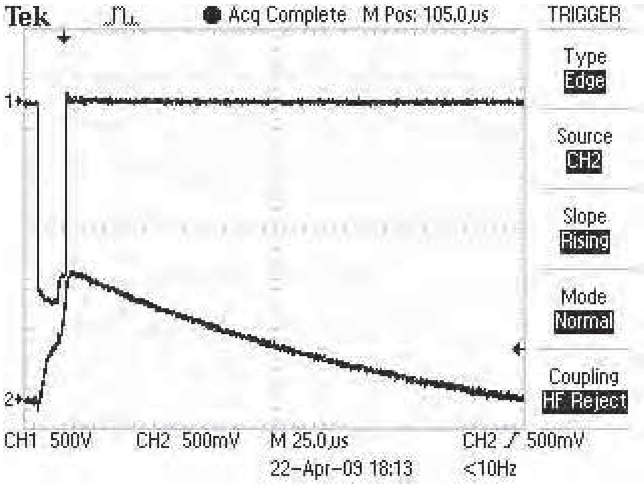


Figure 8: Waveforms on the output of HighPulse generator during arc occur: CH1- output voltage (500V/div) CH2- output current (500A/div).

CABLE LENGTH COMPENSATION

The CLC unit gives the additional possibility to generate reverse output voltage during the time when the chamber current fades to zero. The reverse output voltage significantly reduces the switch-off time (Figure 9).

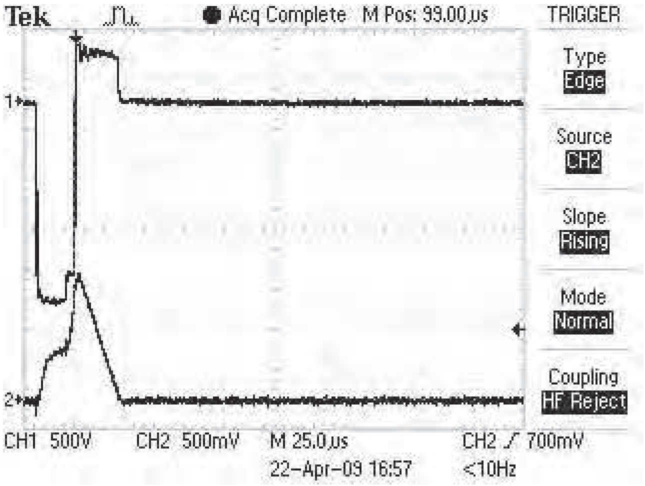


Figure 9: Waveforms on the output of HighPulse generator during arc: CH1- output voltage (500V/div) CH2- output current (500A/div).

COMPARISON - WITH AND WITHOUT CABLE LENGTH COMPENSATION

In order to compare arc energy delivered to the chamber a comparison is done for the HighPulse generator without a CLC unit (Figure 11) and with CLC unit (Figure 12). Energies for 'detection' and 'switch-off' times are calculated for both cases (see Figure 10).

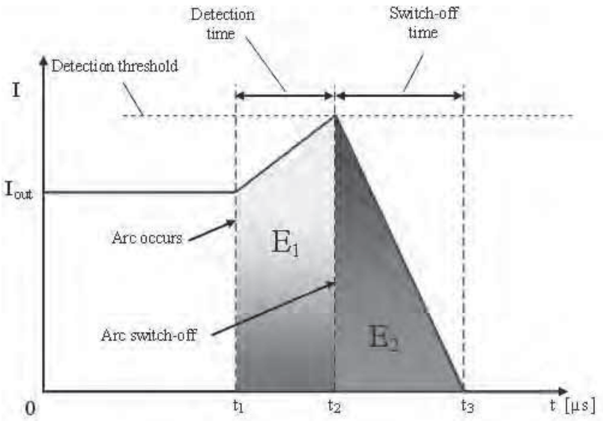
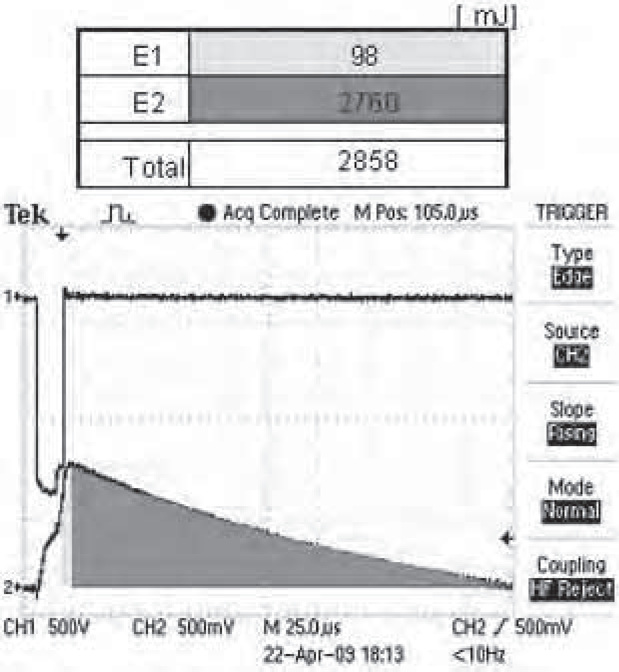


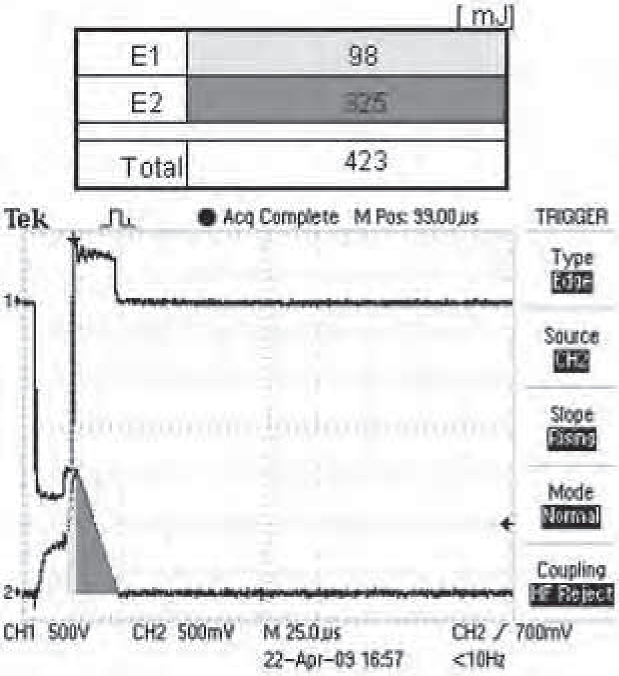
Figure 10: Definition of energy supplied to an arc corresponding with detection time (green) and switch off time (pink).



[mJ]

E1	98
E2	2760
Total	2858

Figure 11: Experimental results for Pulse Power Generator without CLC and energy calculation.



[mJ]

E1	98
E2	325
Total	423

Figure 12: Experimental results for Pulse Power Generator with CLC and energy calculation.

E_1 is calculated from an arc beginning t_1 until detection moment. Energy E_2 is calculated from detection moment until the current drops to zero (Figure 10). In both experimental testes were done in the same conditions. The switch-off current level is 1200A and the cable length is 10m.

From Figures 11 and 12 we can see that energy E_1 is in both cases the same, and is low as detection time is short due to very quick detection hardware/software solutions. The difference is only in energy E_2. Energy E_2 corresponds with energy stored in output circuits. Using CLC unit we have reduced the arc energy roughly 8.5 times. Also we reduced the switch-off time from 225 µs to 25 µs.

The last experimental results are made for a HighPulse unit with a CLC and without a CLC (condition the same as in previous experimental) for different lengths of connection cable. The results are illustrated in the diagram in Figure 13.

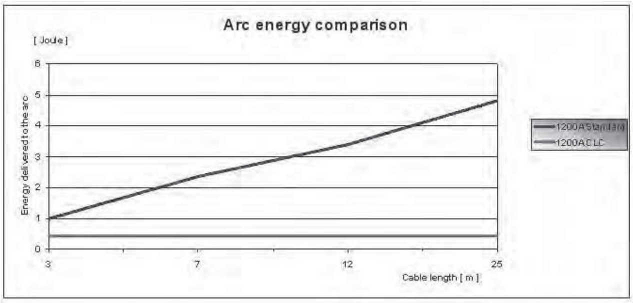


Figure 13: An arc energy comparison in the chamber with and without using the CLC unit.

From Figure 13 we can see that using a CLC unit allows reduction of the energy and that the energy does not depend on the length of the cable.

CONCLUSIONS

New approaches to reduce energy of arcs and therefore arcing consequences in HIPIMS sputtering process was shown. The Cable Length Compensation can reduce both arc energy and switch of time, both by roughly 8.5 times. This should allow new applications for HIPIMS technology, especially in the field of reactive processes.

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