State-of-the-art plasma source with ultra-fast arc quenching circuit for pulsed magnetron sputtering applications

M. Brogniaux [1], D. Deckers [1], M. Michiels [1]

[1] Haute Ecole en Hainaut, ESTISIM, Avenue Maistriau 8A, B-7000 Mons, Belgium.

Contact email: matthieu.michiels@heh.be

Abstract

Arcing on sputter targets and negatively biased substrates is known as one of the most challenging issues in magnetron sputtering applications. This is particularly relevant when reactive gases, large target surfaces or high-power pulsed sputtering processes are considered. To address these issues, the technological advances in the field of power electronics during the last decades resulted in manufacturing of more complex systems for plasma generation that can manage arcing events with minimal damage to target and substrate.

In the framework of the 'Plasmagen' project, the conception of a (bipolar) high-power impulse magnetron sputtering (HiPIMS) plasma source is considered including a *low-cost* ultra-fast arcing quenching circuit allowing detection and suppression of arcs in few microseconds. In this regard, two arc handling strategies are considered: (i) the arc is detected by a sudden increase of the voltage across the high-power transistor above a certain threshold and (ii) a fast current sensor is used, which gives an arc signal once the discharge current grows above a defined level. In this work, the first strategy is considered.

Experimental setup

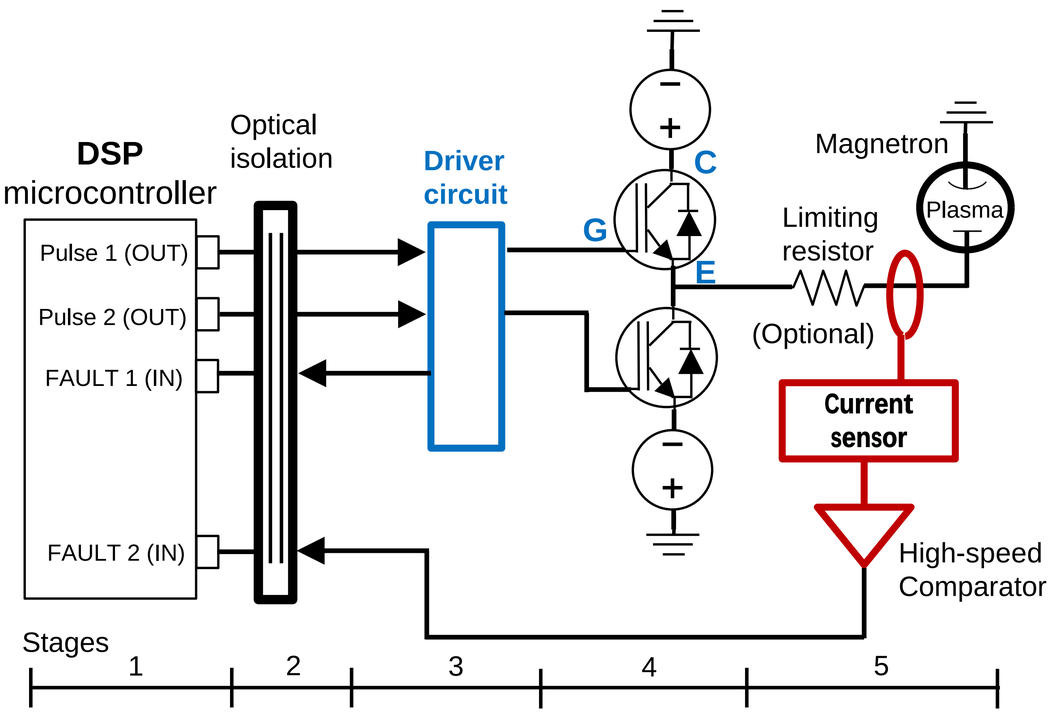
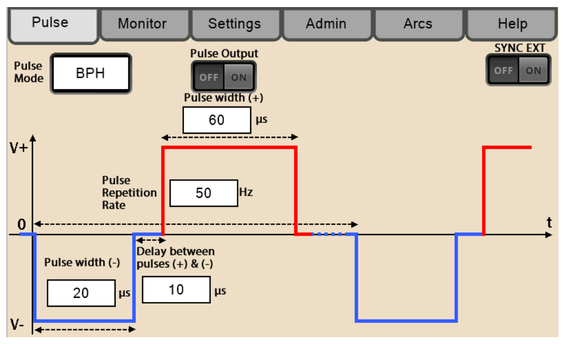


Fig. 1: A typical half-bridge topology for generating bipolar pulsed discharges.

Our BPH plasma source

(a)

(b)

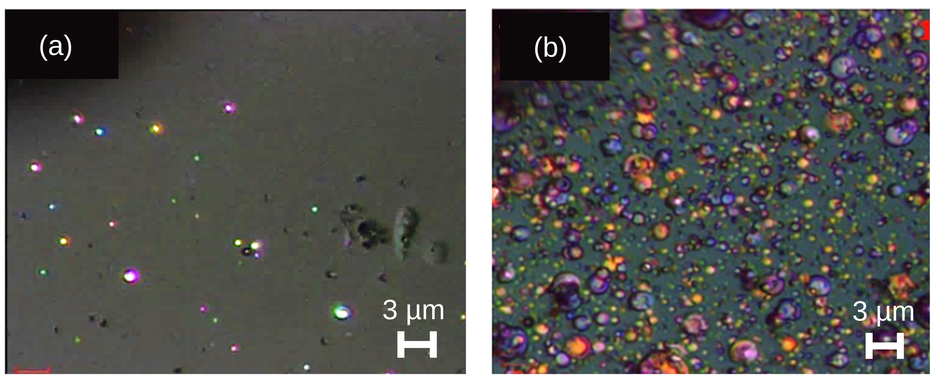


(c)

Parameter	Value
Output	
Maximum Voltage	1200 V
Maximum peak current	500 A
Maximum power	500 W
Output	
Pulse repetition rate	5 Hz – 10.000 Hz
Negative pulse width, τ_-	1 µs to 60 ms
Positive pulse width, τ_+	1 µs to 60 ms
Delay, $\tau_\pm$	0 µs to 199 ms
Pulsed waveforms	Unipolar or bipolar HiPIMS
Input	
Mains supply	1 AC 230 V, 50/60 Hz
Others	
Cooling	Air cooling
Construction	Rack 19" – 3U
Display	5" colored touch screen

Fig. 2: (a) Front panel of our pulsed power module, (b) human-machine interface allowing switching parameters to be modified and (c) main specifications.

2. What about the morphology of the film surface ?



→ Arcing (or the use of a very high target current density) often results in droplets or macroparticles ejection.

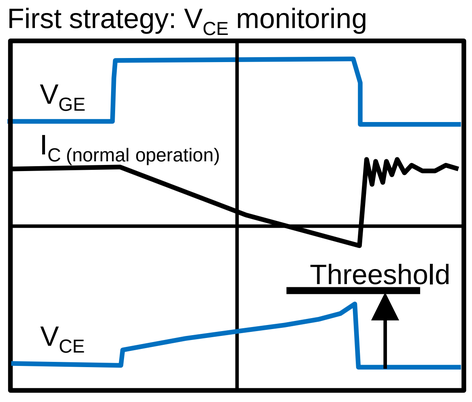
→ The importance of controlling the target current peak is shown here [1].

Fig. 5: Optical micrographs of SiO_2 thin films deposited by reactive HiPIMS for two pulse durations (3 and 10 µs). Reprinted from [1]. In this work, short pulses are used as a strategy for stabilizing arcing.

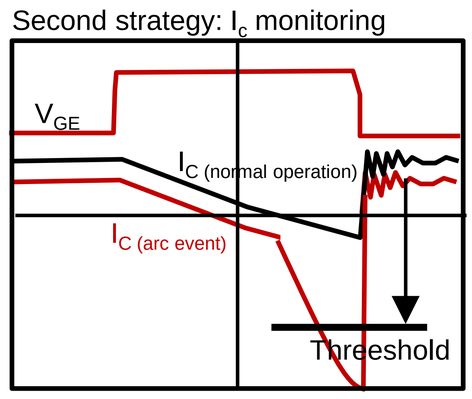
[1] Tiron, V et al., Ultra-Short Pulse HiPIMS: A Strategy to Suppress Arcing during Reactive Deposition of SiO2 Thin Films with Enhanced Mechanical and Optical Properties. Coatings 2020, 10, 633.

Research Strategy

First strategy: V_{CE} monitoring



Second strategy: I_c monitoring

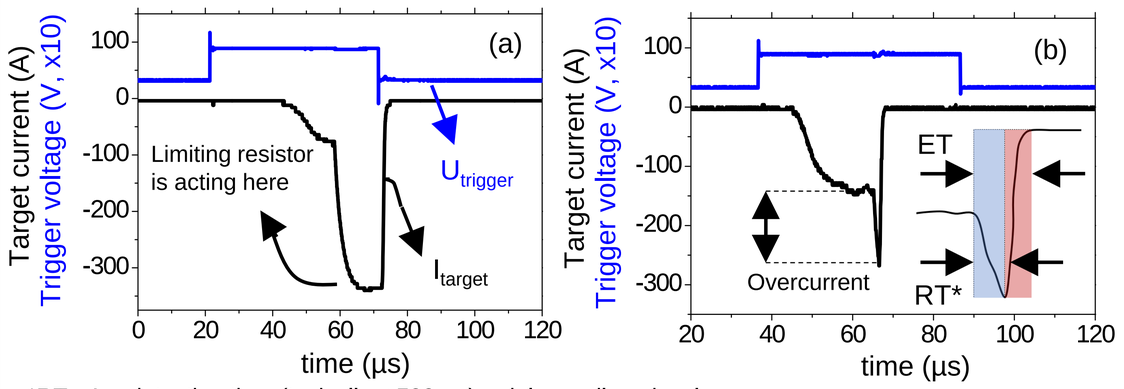


Main objective: minimizing the arc extinction time

- Development of a high-power plasma source (based on solid-state switches)
- Minimize the propagation delay and switching time of each electronic component for each stage (1-5) of the power supply module
- Generate the plasma phase under various discharge conditions
- Study the arc handling performances using V_{CE} monitoring
- Study the arc handling performances using I_C monitoring
- Voltage/current waveforms monitoring during an arc event using a digital oscilloscope

Results

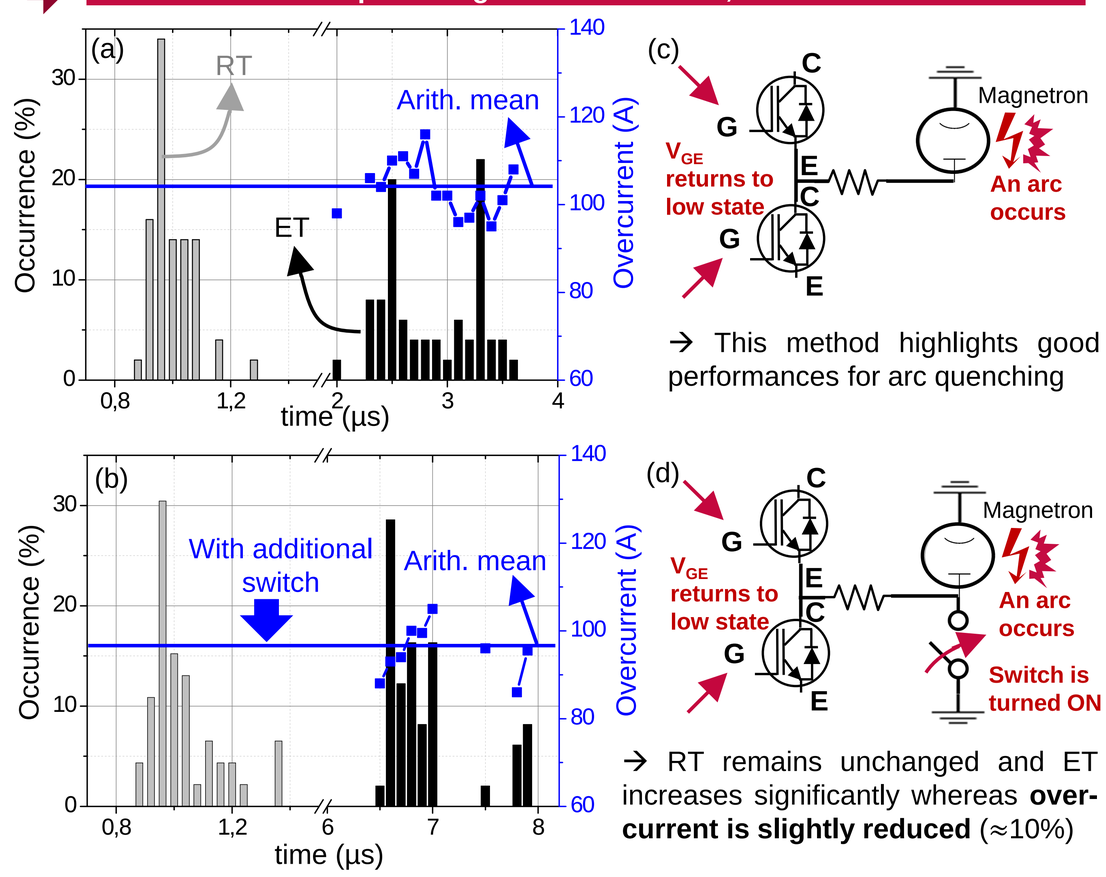
1. Reaction time (RT), extinction time (ET) and overcurrent



*RT= Arc detection time (typically **< 500 ns**) + delay until peak value

Fig. 3: Typical target current waveforms obtained at 7.5 mTorr by sputtering a Ti target in Ar/O_2 atmosphere without (a) and with (b) arc management. ET and RT are defined in (b).

How does the arc quenching method affect RT, ET and the overcurrent?



→ This method highlights good performances for arc quenching

→ RT remains unchanged and ET increases significantly whereas **over-current is slightly reduced** (≈10%)

Fig. 4: Occurrence (on 50 samples) of both RT and ET (a,b) as well as overcurrent values for the corresponding arc quenching methods (c,d). Mind the X-scale for (a) and (b)

Conclusions

- **An arc quenching circuit based on V_{CE} monitoring has been successfully implemented in a (bipolar) HiPIMS plasma source.**
- **Other (low-cost) arc handling strategies are still under consideration to reduce the time required to detect and suppress arcs.**

FÉDÉRATION WALLONIE-BRUXELLES

Wallonie – Bruxelles International.be