WBG Semiconductor and Capacitor Technology Evaluation for Pulsed Electroporation Applications

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***Abstract*— Electroporation is a promising technique for cancer treatment consisting on applying a high electric field in order to induce selective cell death in those tumors with difficult treatment with alternative therapies. This technique requires the application of intense electric fields, typically higher than 1000 V/cm, and currents in the range of hundreds of amperes, depending on the applications, being a chilling power electronics design.**

In order to achieve successful results, recent studies have discovered the need of high voltage and high frequency pulses to achieve the desired results without neurostimulation. This paper studies the current pulse capabilities of different semiconductor and capacitor technologies, enabling the design of an optimized high voltage generator for electroporation systems. Three different capacitor technologies, as well as Si and SiC devices are studied and compared experimentally to select the most suitable technology for high voltage generators for irreversible electroporation applications.

***Index Terms*—Electroporation, High-voltage generators, capacitors, wide bandgap semiconductor.**

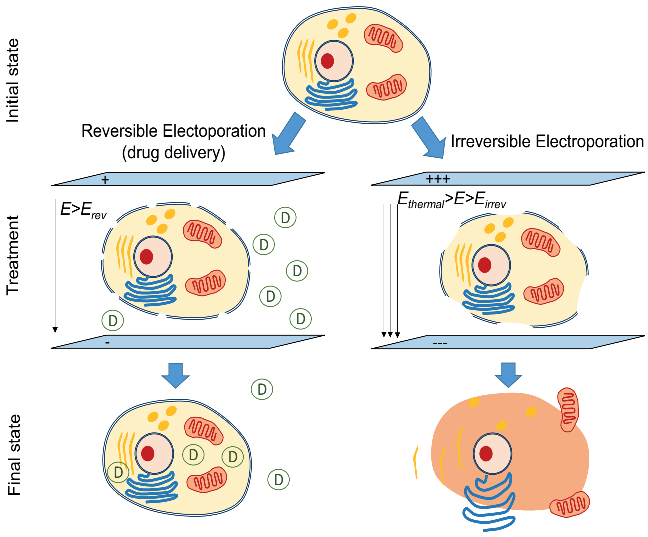


Fig. 1. Electroporation: (a) reversible and (b) irreversible phenomena.

I. INTRODUCTION

ELECTROPORATION [1, 2] consist on applying an electric field to living tissues in order to generate biological changes that may be temporary or permanent (Fig. 1). When an electric field is applied, pores appear in the cell membrane as well as the internal organelles, causing different physiological effects that can be used for a wide range of applications, including therapeutically, aesthetical or food processing, among others.

If the applied electric field is low, typically < 1kV/cm for mammalian cells, the phenomena is reversible and it can be used to improve drugs absorption or gene therapy. When the electric field is higher, >1.5 kV cm in mammalian cells [4], the process is irreversible and leads to cell apoptosis, i.e. tissue death. Both processes can be used for cancer treatment purposes, which will be the main focus of this paper. The former technique, called reversible electroporation (RE), is typically used in combination of chemotherapy to improve the treatment and reduce side effects, being called electro-chemotherapy [5]. The latter technique, called irreversible electroporation (IRE) [4, 6-9] can be used as an effective non-thermal treatment for tumors with difficult access where other therapies are not appropriate, such as liver or pancreas cancer.

Currently, research on IRE is severely limited by the limitations of commercially available generators. Besides, recent studies have highlighted the need of high-voltage and high-frequency generators in order to obtain the desired effects while avoiding undesirable neurostimulation. To enable new and promising therapies, this paper analyzes semiconductor and capacitor technologies capabilities to provide high pulse current.

The remainder of this paper is organized as follows. Section II details the proposed state-of-the-art generator previously proposed in [3], that will be the target for the semiconductor and capacitor study performed in this paper. Section III present the main implementation and experimental results, including comparison of three capacitor technologies as well as Si and SiC devices evaluation. Finally, Section IV draws the conclusions of this paper.

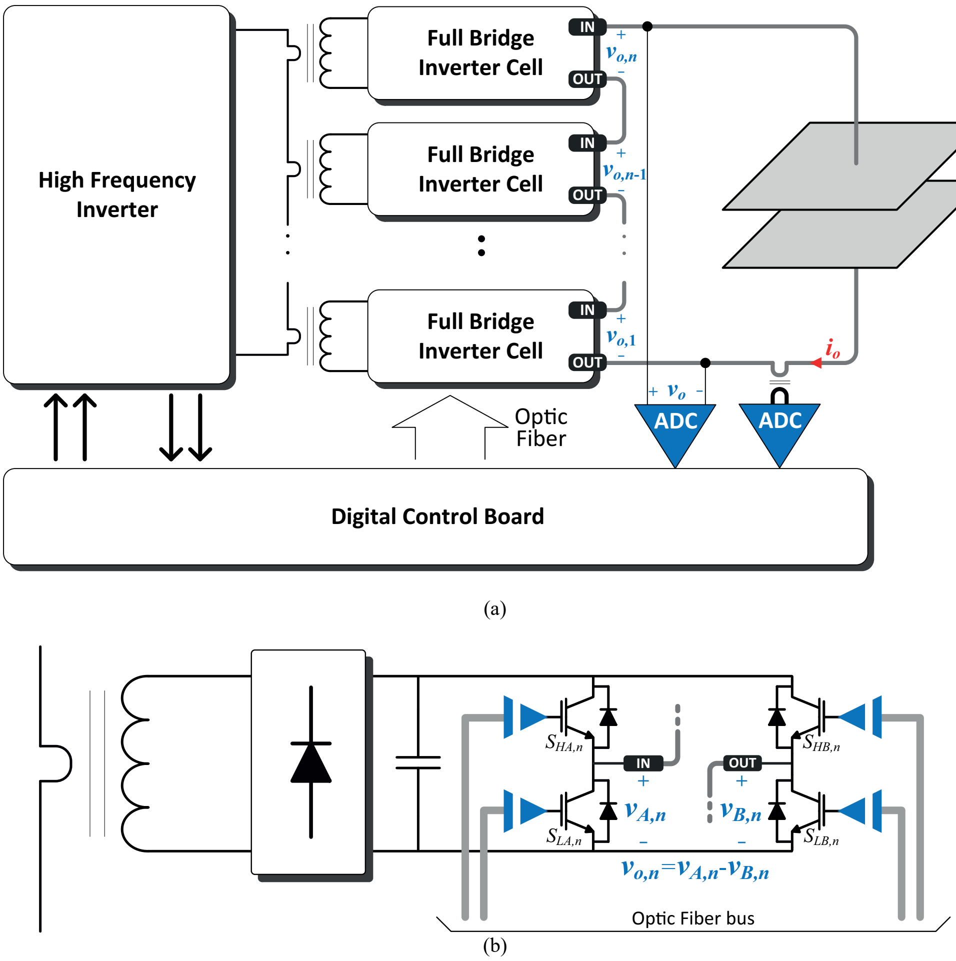


Fig. 2. Proposed power converter (a) and full-bridge inverter cell detail (b) [3].

II. HIGH-VOLTAGE ELECTROPORATION GENERATOR

Power electronics plays a major role in many biomedical applications [5] and it is essential to enable new IRE therapies. Fig. 2 (a) shows the proposed converter to achieve high-voltage high-frequency operation [3]. It is based on a high-frequency inverter to provide isolation and a number of cascaded full-bridge inverter cell to provide the required high voltage/current capabilities. Each cell relies on a capacitor to deliver the required high current pulse, being its technology selection as well as the power devices key to obtain the desired performance.

Current and voltage requirements are defined by the area of parallel plates and the distance between them, respectively. Nowadays, current treatments are severely limited by the capability of current generators. However, future developments will require to push voltage and current limits up to 1000 A with an electric field of, at least, 2.5 kV/cm (Fig. 3). In order to ensure a voltage drop less than 10%, this will

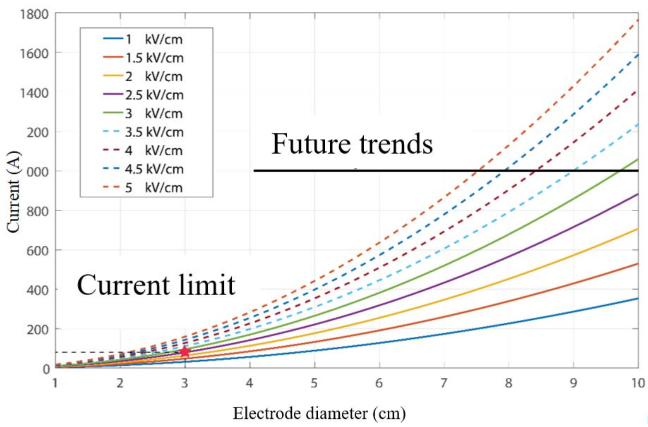
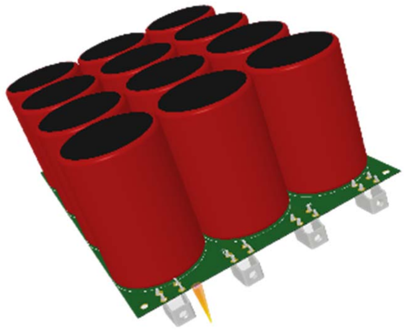
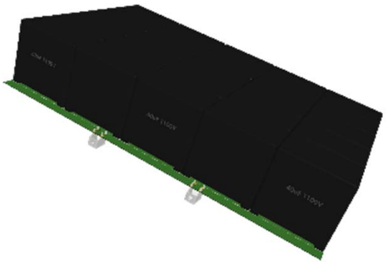


Fig. 3. Current and voltage curves for different electrode diameter sizes.



(a)

(b)



(c)

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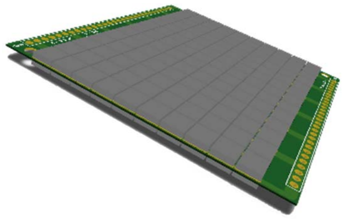

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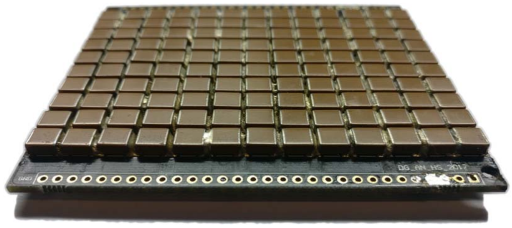
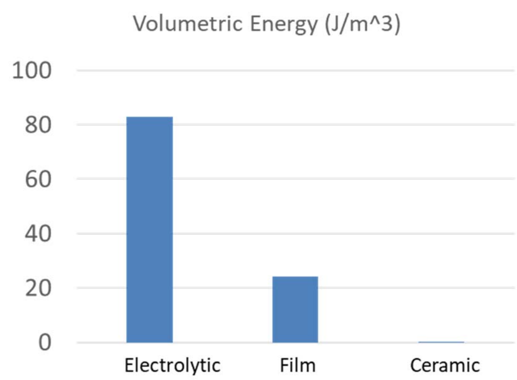
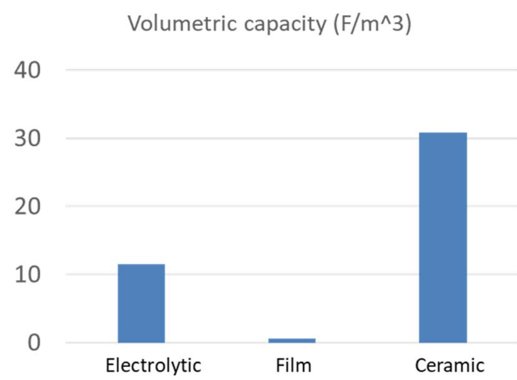


(f)

Fig. 4. Bus capacitor technologies: render (left) and implemented board (right).



(a)

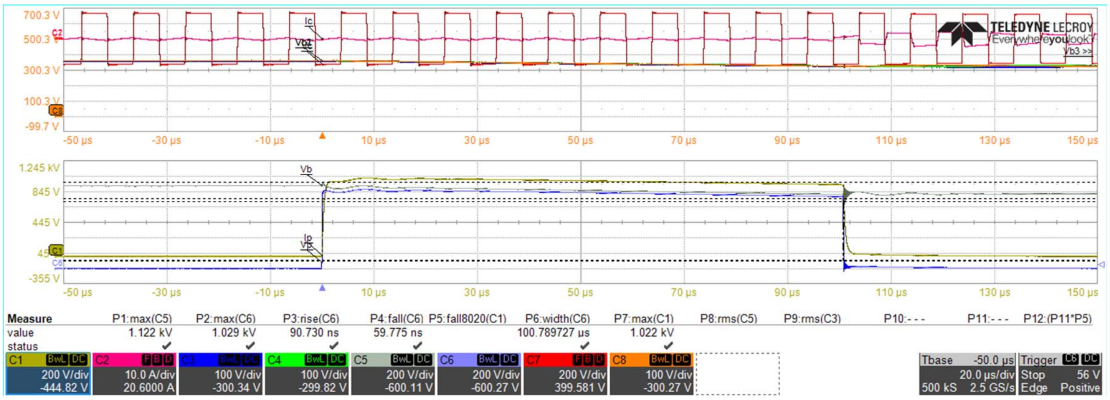


(b)

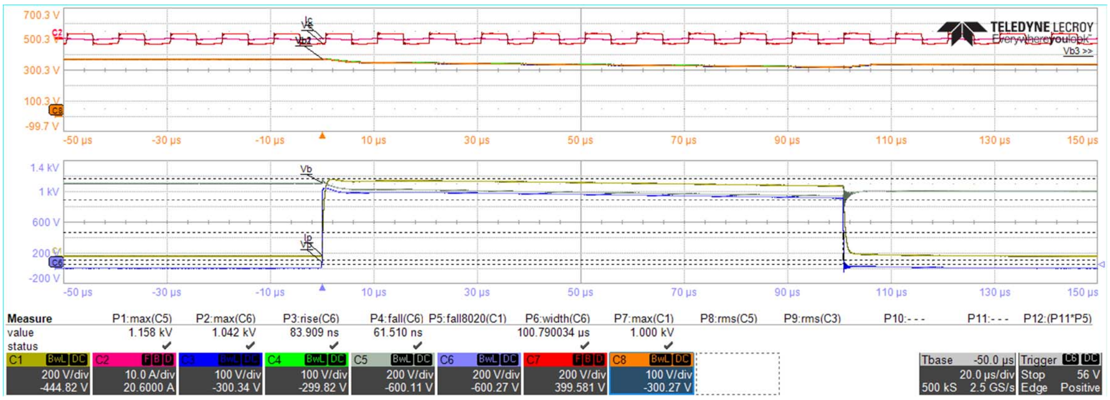
Fig. 5. Main experimental results using electrodes in an electroporation experiment with plant cells and single pulse.

imply the design of capacitor tanks of up to 1000 V and 1000 µF, and the capability of delivering pulses of few µs. To explore these limits in capacitor technology [7, 8], this paper presents several tests and experimental results leading to an optimum technology selection.

Current and voltage requirements are defined by the area of parallel plates and the distance between them, respectively. Nowadays, current treatments are severely limited by the capability of current generators. However, future developments will require to push voltage and current limits



(a)



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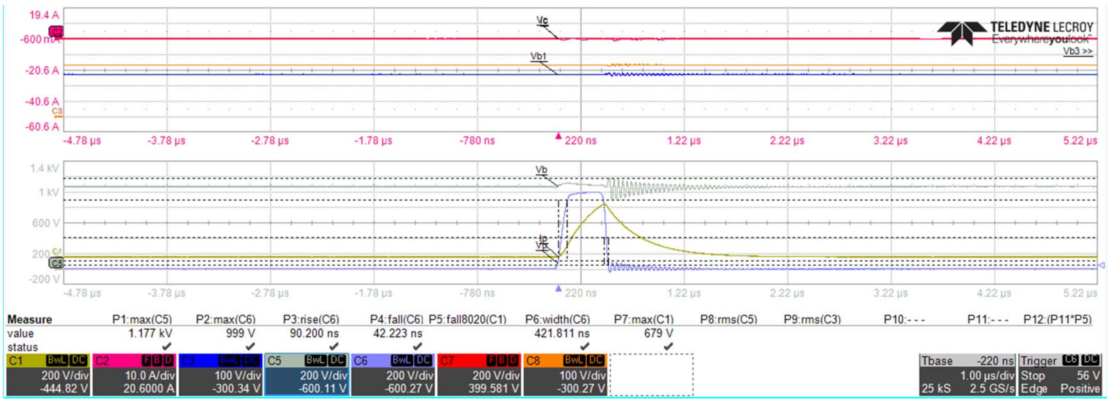

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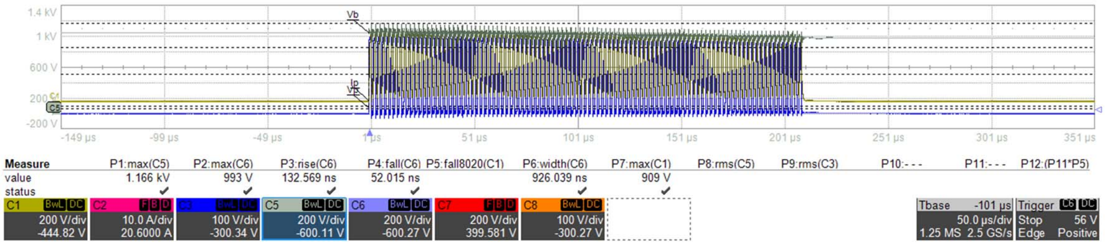

(d)

Fig. 6. Main experimental results using the SiC full-bridge inverter: 100-µs pulse with electrolytic (a) and film capacitors (b); 500-ns pulse with electrolytic capacitor (c) and burst mode with 100 x 1 µs pulses using electrolytic capacitors (d).

up to 1000 A with an electric field of, at least, 2.5 kV/cm (Fig. 3). In order to ensure a voltage drop less than 10%, this will imply the design of capacitor tanks of up to 1000 V and 1000 μF, and the capability of delivering pulses of few μs. To explore these limits in capacitor technology [7, 8], this paper presents several tests and experimental results leading to an optimum technology selection.

III. Implementation and Experimental Results

After a detailed literature and commercial component research, electrolytic capacitors of 450 V and 820 μF have been selected to build a 4x3 equivalent tank of 1093 μF and 1350 V with independent charge network to ensure balanced charge (Fig. 5 (a,b)). Also, film capacitors of 1100 V and 40 μF following a parallel network to achieve 1000 μF and 1100 V were chosen (Fig. 5c,d)). Finally, 260 parallel-connected 2.2-μF 450-V ceramic capacitors were considered and implemented (Fig. 5 (e,f)). Electrolytic capacitors achieve the highest volumetric energy, although ceramic technology achieves the highest volumetric capacity. The former technology, together with film technology, will be tested to analyze their pulsed current capabilities, whereas the latter technology was discarded due to cost and maximum ratings limitation.

The experimental evaluation included IGBT technology to test its pulse capabilities and SiC devices. Thus, full-bridge inverters were implemented using 1700-V Si IGBTs (FF300R17KE3) and 1700-V SiC MOSFETs (CAS300M17BM2) to take the most of WBG technology [10, 11]. Fig. 6 shows a summary of the main experimental results, including electrolytic (a) and film capacitors (b). Despite the voltage drop in latter due to stray inductance, electrolytic technology performed well in electroporation pulsed application. Moreover, Fig. 6 (c) and (d) show a high-frequency pulse and burst-mode operation, proving the proper operation of electrolytic technology combined with SiC devices.

IV. Conclusions

Electroporation is a promising cancer treatment technique. This paper has studied capacitor and semiconductor technology to provide the required high-voltage pulses. As a conclusion of the detailed experimental study, electrolytic capacitors combined with high-voltage SiC devices are proposed. This will enable the research and development of new ablation and cancer treatment techniques taking advantage of the latest advances in power electronics applied to electroporation.

Acknowledgement

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