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ULTRA-FAST GENERATOR FOR IMPACT IONIZATION TRIGGERING*

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Abstract

Impact ionization triggering can be successfully applied to standard thyristors, thus boosting their dI/dt capability by up to 1000x. This ground-breaking triggering requires applying significant overvoltage on the anode-cathode of a thyristor with a slew rate > 1 kV/ns. Compact pulse generators based on commercial off-the-shelf (COTS) components would allow the spread of this technology into numerous applications, including fast kicker generators for particle accelerators.

In our approach, the beginning of the triggering chain is an HV SiC MOS with an ultra-fast super-boosting gate driver. The super boosting of a 1.7 kV rated SiC MOS allows to reduce the MOS rise time by a factor of > 26 (datasheet tr = 20 ns vs. measured tr < 800 ps), resulting in an output voltage slew rate > 1 kV/ns and an amplitude > 1 kV.

Additional boosting is obtained by a Marx generator with GaAs diodes, reaching an output voltage slew rate > 11 kV/ns. The final stage will be a Marx generator with medium size thyristors triggered in impact ionization mode with sufficient voltage and current rating necessary for the triggering of a high power thyristor.

This paper presents the impact ionization triggering of a small size thyristor.

INTRODUCTION

In beam transfer facilities for particle accelerators, magnets generally require multi kV/kA pulse generators. Presently this is achieved using thyratrons. However, these devices present several disadvantages such as erratic firing, their need of complex triggering and biasing electronics, their rarity, approaching obsolescence and high cost. These factors are driving their replacement by semiconductor switches.

Recent investigations have shown that switching semiconductors using impact ionization mode is a viable option to replace thyratrons. Impact ionization is achieved when a high dU/dt creates an ionization wavefront in the semiconductor structure. This ultra fast switching technique is even feasible in cheap commercially available thyristors [1]. Thyristors are cheaper and faster than thyratrons (when triggered in impact ionization mode), and offer a higher current density compared to thyratrons.

The following conditions are necessary to achieve impact ionisation on a thyristor:

- A voltage applied by the triggering circuit on the anode-cathode of the thyristor more than double the static breakdown voltage
- Said triggering voltage requires a slew rate of >1 kV/ns in order to create the right conditions in the semiconductor structure
- All this while providing enough current to charge the parasitic capacitance of the thyristor with the required dU/dt.

In this paper, we present a Marx generator based topology that achieves impact ionization triggering in a small size (D2PAK) thyristor.

METHODOLOGY

Traditionally, as seen in [2], the triggering generators for impact ionization used drift step recovery diodes (DSRD) and semiconductor opening switch (SOS) diodes. Generators based on both of these components are bulky, require relatively long pre-charging and more importantly, DSRD and SOS themselves are not commercially available. This is why we propose an alternative approach, based on three main stages.

The first stage has been described in [3] and [4]: ultra-fast MOSFET triggering based on the upgraded gate boosting technique outlined by M. Hochberg *et al*. [5]. M. Azizi *et al* presented in [6] a gate-boosting driving method optimized for a SiC MOSFET to reduce its turn-on time. Our SiC MOSFETs were more aggressively gate-boosted, resulting in an acceleration of their rise time by a factor of >26, depending on the device.

In order to more aggressively boost the MOS device, as per the depicted method in [4], we developed a driver that can deliver 430 V/ns onto a 50 Ω load, with a maximum output voltage >300 V. The resulting output voltage is presented in Fig. 1, indicated by the blue lines.

This SiC MOSFET, the second stage of the series, was tested onto a 50 Ω load (by mistake up to 2.1 kV, and survived) at the nominal voltage of 1.3 kV and it produced a 1.2 kV/ns slew rate, as seen in Fig. 2. Once these parameters are achieved, we can use this pulse generator for impact ionization triggering in the third stage.

The third stage is an ultra-fast Marx generator with GaAs diodes switched in impact ionization mode acting as switches. As seen in Fig. 3, this generator is made up of multiple stages of 900 V rated GaAs diodes [7]; their number depends on the required output voltage amplitude. The triggering of this Marx generator is conducted by a super-boosted SiC MOSFET (Infineon IMBF170R450M1), thanks

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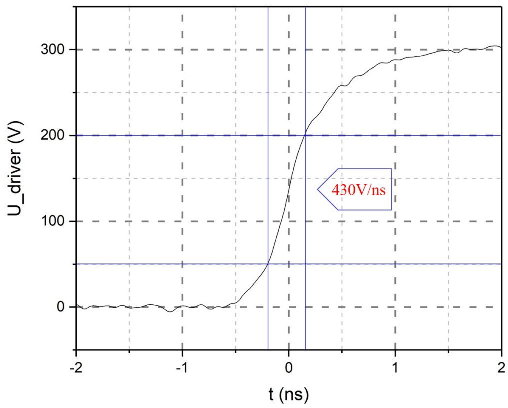

Figure 1: Output voltage of our MOS driver.

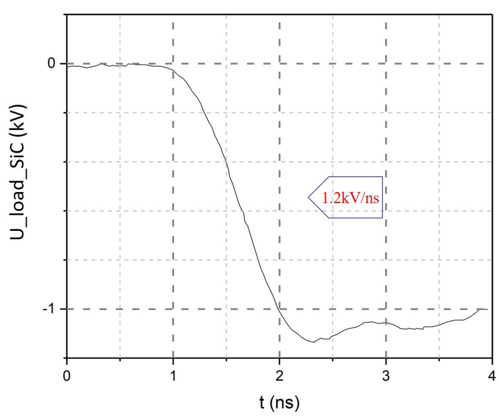

Figure 2: SiC MOSFET voltage output on 50 Ω load.

to the method that has been described above. The negative voltage generated by the MOSFET is applied on the anode of the GaAs diodes.

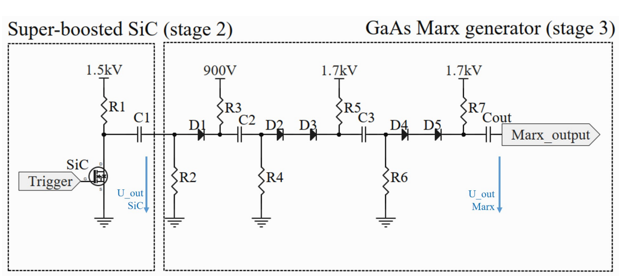

Figure 3: Schematic of stages 2 and 3.

The best results were obtained using GaAs diodes switched in impact ionization mode from the wavefront initiated by the SiC MOSFET (Fig. 2). However, the same principle can be applied to small thyristors.

With the pulse generated at the output of the three series stages of the Marx generator, a negatively biased thyristor is triggered. The chosen component is VS-16TTS12S-M3 from Vishay, a 1.2 kV rated device. The configuration is shown on Fig. 4.

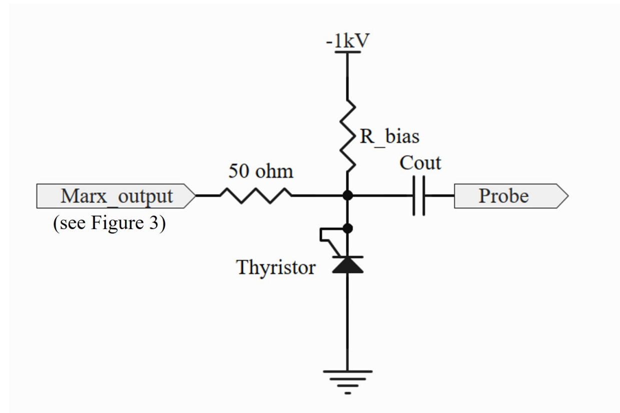

Figure 4: Schematic of Marx generator triggering a thyristor.

RESULTS

The different tests have been done using a 6 GHz oscilloscope with a series of 10-18 GHz, 50 Ω attenuators used as output loads.

Figure 5 shows the output voltage of the Marx generator. The maximum voltage reached is 4.1 kV (negative) and the slew rate, more than 11 kV/ns on a 50 Ω resistive load.

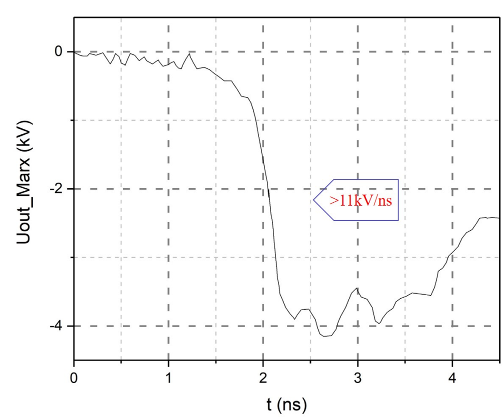

Figure 5: Output waveform of the three stage Marx generator on 50 Ω load.

It can be expected that the magnitudes and output pulse will diminish when triggering a capacitive load, which is what a thyristor represents to the generator. However, it is considered that for a 1.2 kV rated thyristor, the generator output is high enough to ensure that impact ionization will also occur on this thyristor.

As represented on Fig. 6, this assumption is correct. The phenomenon of impact ionization happening on the thyristor is clearly seen, in blue in Fig. 6, with an ultra-fast thyristor commutation of ≈ 200 ps, this being on the limit of resolution of our instrumentation.

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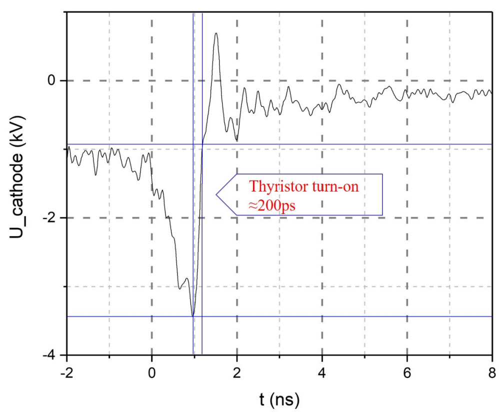

Figure 6: Impact ionization triggering of a thyristor in our laboratory.

To summarise, an innovative Marx generator is presented in this publication. With three stages of GaAs diodes, a slew rate of 11 kV/ns, and a peak output voltage on a resistive load of 4.1 kV are reached thanks to the applied ultra-fast impact ionization process.

Therefore, this Marx generator is considered to be sufficiently fast to also trigger a small-sized thyristor in impact ionization mode.

Consequently, a 1.2 kV rated, D2PAK thyristor was connected at the output of the Marx generator; with a biasing of 1 kV. The output voltage reaches an ultra-fast commutation slew rate higher than 17 kV/ns and a commutation rise time < 200 ps.

CONCLUSION

Impact ionization was achieved, proving the feasibility of this triggering method for thyristors. Furthermore, this triggering technology enables the use of conventional thyristor switches for the construction of a fast HV pulse generator – again in a Marx architecture.

With this research, we lay the foundations for a future fast multi-stage thyristor Marx generator needed to achieve the high voltage and current necessary to trigger larger thyristor stacks in impact ionisation mode. Finally, this could replace thyratrons in beam transfer facilities for particle accelerators.

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