

Structural Simulation of a 4H-SiC Based Optically Controlled Thyristor using a GaAs based Optically Triggered Power Transistor and its Application to DC-DC Boost Converter

Srikanta Bose, and S.K. Mazumder

Abstract—In the present simulation work, an attempt is made to study the switching dynamics of an optically controlled 4H-SiC thyristor power semiconductor device with the use of GaAs optically triggered power transistor. The half-cell thyristor has the forward breakdown of 200 V and reverse breakdown of more than 1000 V. The optically controlled thyristor has a rise time of 0.14 μ s and fall time of 0.065 μ s. The turn-on and turn-off delays are 0.1 μ s and 0.06 μ s, respectively. In addition, this optically controlled thyristor is used as a control switch for the DC-DC Boost converter. The *pn*-diode used for the converter has the forward drop of 2.8 V and reverse breakdown of around 400 V.

Keywords—4H-SiC, Boost converter, Optical triggering, Power semiconductor device, thyristor.

I. INTRODUCTION

IN an environment where the external radio-frequency (RF) signals can interact with power electronics electromagnetic interference (EMI) is a critical issue from system reliability, survivability, and stealth point of views. Employing photonic technology to design power-electronic systems, which are unaffected by EMI and hence, enable high-frequency operation leading to higher power densities, can provide a lightweight and reliable EMI-resistant system. On a system level, optically-triggered devices (OTDs) offer further significant advantages over conventional electrically-triggered device (ETD). First, there is a complete isolation between the gate driver and the device (and hence, the power stage). As such, very high di/dt and dv/dt , which cause significant reliability problems in an ETD, have no impact on an OTD. Second, for multilevel electrically triggered (ET) switching converters, different designs of low- and high-side drivers are required; the latter is especially difficult to design for high and medium-power applications. For an OTD-based converter, the designs of high- and low-side drivers remain the same, leading to simplicity of overall design, enhanced reliability of the system and enhanced reliability of the system and monolithic integration. Third, as the switching frequency of an ETD increases, parasitic oscillations may be induced in

the driver circuit owing to the coupling effects between the device capacitance and the parasitic inductance of the gate connection and also due to transmission-line effects; this may lead to failure of the gate driver. With an OTD, such possibilities do not arise. Fourth, an OTD-based converter does not suffer from gate-driver failure due to short-circuiting. Fifth, optical switching enhances the possibility of system integration by reducing the problems associated with EMI effects. However, the key challenge to realizing such systems is designing a suitable device structure, which can address the multi-faced performance demands posed by a typical power semiconductor device including large voltage and current handling capabilities, high-temperature sustenance, high device gain (which translates to lower optical power requirements and optical source volume and weight), fast turn-on and turn-off times, latch-free switching action, and low on-state resistance and yet, at the same time, integrating the optical controllability and optical gain into the structure. Since many years, the thyristor semiconductor device [1], has been a choice by power engineers because of its high current handling capability in the on-state and very large voltage blocking capacity in the off-state. However, the main drawback of this device is to latching into on-state, during conductive mode. To overcome this problem, the thyristor structures like Gate Turn-off (GTO) and Emitter Turn-off (ETO), have been proposed in the literatures [2-4]. In the former structure (GTO), though the device gets turned-off by controlling the gate-terminal, but it is associated with large turn-off delay whereas in the later structure (ETO), the device is forced to turn-off by cutting down the main supply voltage from anode to cathode with use of an additional switch resulting into quite less turn-off delay. More details about the principle of operation for ETO can be found in [4]. However, in both the electrical structures (GTO, and ETO), there is a strong presence of EMI. In conventional ETO, two auxiliary switches and two biases are used. To avoid any EMI and to get rid of dual bias features as in conventional ETO, in the present work, a simulation study is conducted to study the switching dynamics of an optically controlled thyristor by using GaAs based optically triggered power transistor (OTPT) [5], and thus, using only one main supply voltage from anode to cathode. Furthermore, this optically controlled thyristor is used as the control switch for the system level DC-DC Boost

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converter. The simulation study is made using 4H-SiC as the semiconductor material because of its high critical field strength and high thermal conductivity [6]. ATLAS semiconductor device simulation software package from Silvaco Inc. [7] is used for the above purpose.

II. DEVICE STRUCTURE WITH RESULTS AND DISCUSSIONS

The simulated structure for 4H-SiC half-cell thyristor is shown in Fig. 1 (a). The device dimensions and doping densities for the thyristor structure are also shown. The Z-dimension for the thyristor structure is kept at $1 \times 10^5 \mu\text{m}$. The incident light with the wavelength of 350 nm (30 W/cm^2) for 4H-SiC thyristor falls through an optical window of $3.0 \mu\text{m}$. So, the electrical gate contact is optional. The incident light of wavelength 808nm falls on the GaAs OTPT whose structure is shown in Fig. 1(b) and the details of which can be found in [5]. The schematic of the simulated switching circuit for optically controlled thyristor is shown in Fig. 1(c). The MOSFET used for this is a Si based N-channel vertical powerMOS. Fig. 1(d) shows the simulated DC-DC boost converter topology which uses a *pn*-diode.

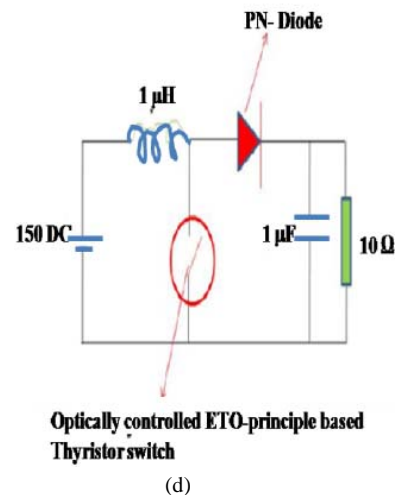
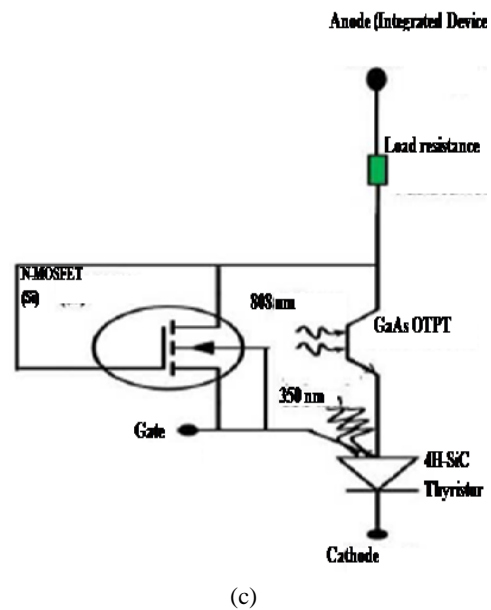
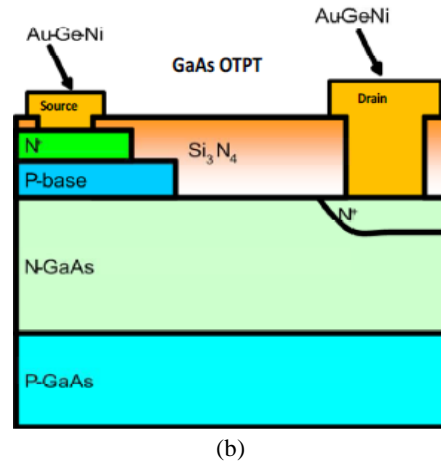
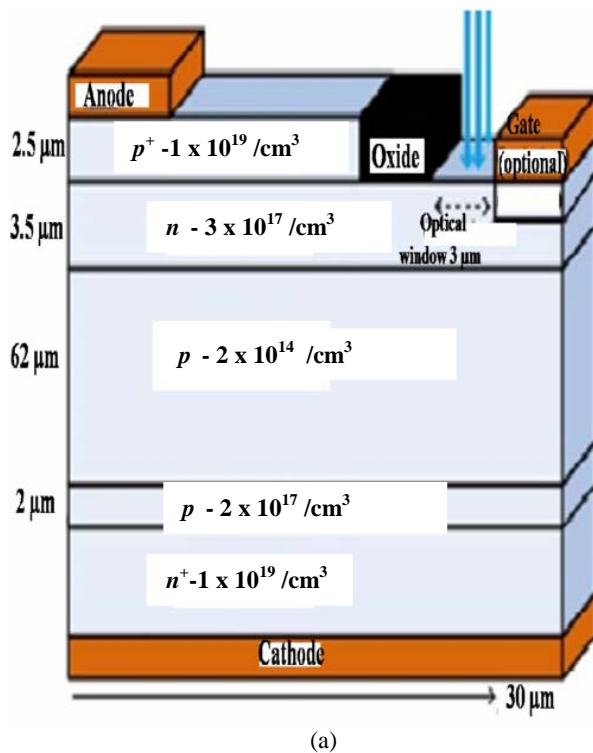


Fig. 1 Schematics of the simulated (a) 4H-SiC half-cell thyristor, and (b) OTPT (c) The schematic of the simulated switching circuit for optically controlled thyristor, and (d) the simulated DC-DC boost converter topology which uses a *pn*-diode

Fig. 2 shows the switching characteristics of the optically controlled thyristor. We see that with the application of 30 W/cm^2 , the thyristor produces current of 38A and has rise time of $0.14 \mu\text{s}$ and fall time of $0.065 \mu\text{s}$. The turn-on and turn-off delays are $0.1 \mu\text{s}$ and $0.06 \mu\text{s}$, respectively. When the light falls through the optical window, the photogeneration happens because of the photoconductivity principle [1]. Even though, 4H-SiC is indirect bandgap, its fundamental optical absorption and hence the penetration depth is more pronounced at 350 nm [8, 9], resulting into more number of photogenerated extra carriers, giving rise to better current. In addition, the carrier life in 4H-SiC is comparatively better [10]. This half-cell thyristor has a forward breakdown of 200 V and reverse breakdown of more than 1000 V. The *pn*-diode used in the converter circuit has forward drop of 2.8 V and reverse breakdown of around 400 V. Fig. 3 shows the performance of DC-DC boost converter for various duty cycles. As we see, with the increase of duty cycle, the output voltage is increasing according to the expression ($V_{\text{out}} = V_{\text{in}}/(1-D)$, where $V_{\text{in,out}}$ is the input (output) voltage and D is the duty cycle). The ripples observed in this simulation study can be avoided by using high inductance value and the simulation of which is not carried out because the results presented here are of the concept level, obtained by not using any dedicated circuit simulator but a physics based simulator ATLAS and also to avoid heavy computational time.

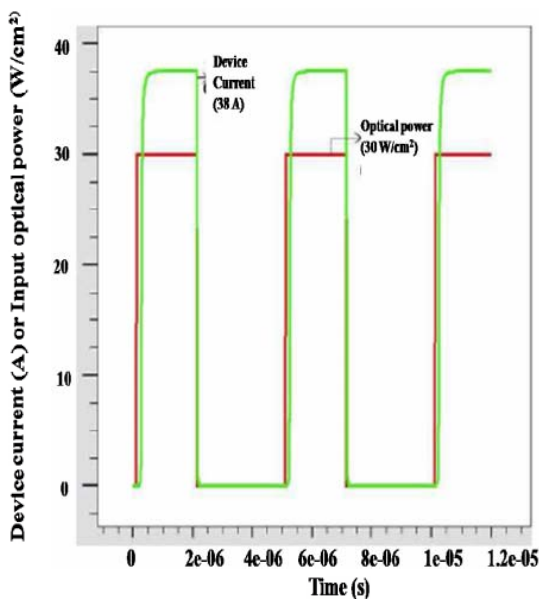


Fig. 2 Switching characteristics of the optically controlled thyristor

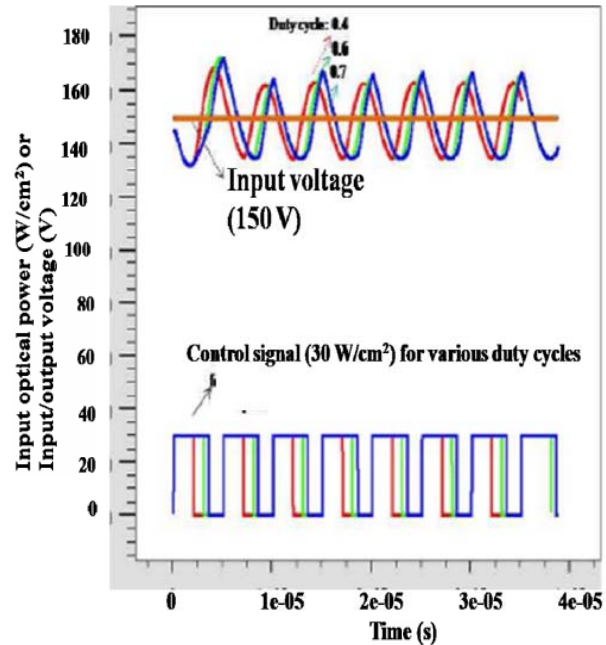


Fig. 3 The performance of DC-DC boost converter for various duty cycles

III. CONCLUSION

In this work, a simulation study for the DC-DC boost converter is presented in which an optically triggered thyristor is used as a switch. The material used for the above study is 4H-SiC because of its high bandgap, high critical field strength and adequate carrier mobility. It is observed that the optically controlled 4H-SiC converter is feasible because of the fact that 4H-SiC material has good fundamental optical absorption and penetration depth at 350 nm of wavelength and comparatively better carrier life time.

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