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Optical triggering of 4H-SiC thyristors with a 365 nm UV LED

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Abstract. Direct light triggering of 4H-SiC thyristors with a 365 nm UV LED was demonstrated. Two different structures with etched and non etched gate were successfully tested. The current rise time was less than 100 ns and the delay time as short as 1.5 μ s. The optical energy density necessary to switch-on a thyristor has been studied for different optical power density and bus voltages. This work shows that the UV LED technology is becoming sufficiently powerful to switch-on SiC thyristors. Thus, an alternative, less expensive and more compact gate light source than UV laser is now possible. This can be of particular interest for very high voltage and pulse power electronic applications.

Introduction

The use of 4H-SiC thyristors is of specific interest in pulse power applications [1] to increase the power density and to reduce the number of devices connected in series. In such systems, the isolation of the driver and the electromagnetic interferences are serious issues. Direct light triggering of thyristors can solve these problems [2]. The switch on of SiC thyristor with a 337 nm UV laser pulse has already been shown in [3]. The development of the UV light-emitting diode (LED) technology in the past few years has resulted in the commercialization of numerous devices. 4H-SiC thyristors with a simple mesa termination were fabricated to evaluate their sensitivity to optical switch-on with UV LED.

Device Fabrication

About 50 thyristors, with an active area ranging from 0.18 to 1.5 mm², were fabricated on two 1 \times 1 cm² samples. The n-type 4H-SiC substrate covered by 4 (P/P-/N/P+) epilayers is the same as used for the thyristors presented in [4]. Fig. 1 shows the cross-section of the thyristors and indicates the epi-layer specifications as given by the material supplier. A 5.5 μ m mesa termination was first etched by a RIE process using a nickel mask. The simulated protection efficiency of this termination is rather poor (25%) but the objective was here to evaluate only the optical turn on. One of the two sample was then etched a second time (indicated by the dashed line in Fig. 1) to open the gate layer. On the second sample the top P+ layer remains unopened. Al/Ti/Ni and Ti/Ni metal layers

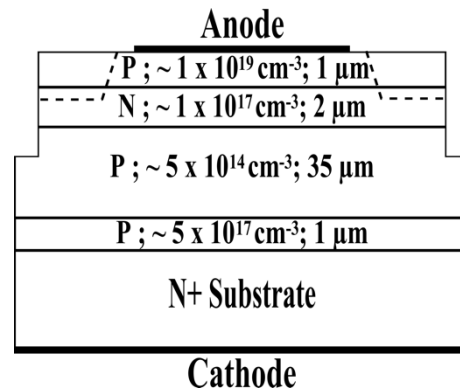


Fig. 1. Schematic cross section of the device structure. Dashed lines represent the gate etching on one of the two samples.

for the anode and the cathode were formed by lift-off and annealed at 1000°C to get ohmic contacts. A 500 nm thick overmetallization for the anode contact (Ti/Ni/Au) was finally deposited. All metallizations were realized by electron beam evaporation.

TLM measurements after the over-metallization reveal a specific resistance of the anode contact in the range of $3 - 9 \times 10^{-4} \Omega \cdot \text{cm}^2$. Forward blocking voltage for a leakage current of 1 μA was measured in vacuum. Some thyristors were able to sustain a forward voltage in excess of 1100 V. The two samples were finally attached on an alumina substrate with silver paste and bonded with 50 μm diameter gold wire.

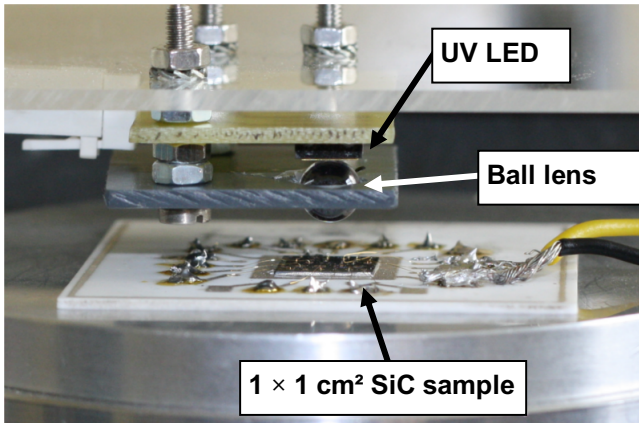


Fig. 2. Photography of the experimental set up showing the UV light source and the wire bonded thyristor devices.

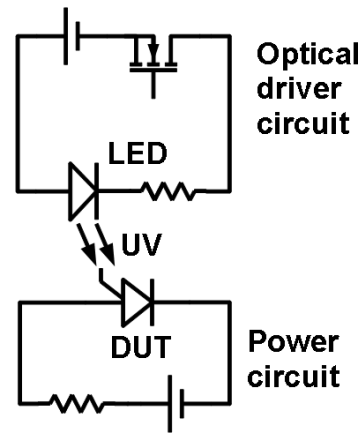


Fig. 3. Simplified circuits of the experiment.

Experimental Set-up

A 365 nm UV LED with a spectrum half width of 9 nm and a nominal optical power output of 250 mW was used to switch on the thyristors. Its wide emission angle of 120° was narrowed using a ball lens (see Fig. 2). The position of the device could be set quite precisely in the X, Y and Z directions. The optical power of this light source was measured through a 1 mm diameter hole. To perform these measurements, the hole was moved to the position of maximum power. The optical power was found to rise linearly with the LED current in the range of 0.1 A to 1 A. Over this range and for a useful lightening area corresponding to the 1 mm diameter hole, the power yield of the optical system as a whole is between 1% and 2%. The yield of an individual 365 nm LED is between 10 and 15%, according to the technical data-sheet. Before the measurements presented in the next section, the position of the SiC thyristor was adjusted to the maximum optical power point, using its photo-current as indicator. As shown on Fig. 3, the switching characteristics of the thyristors were studied with a resistive load.

Results

Switch-on behavior. Thyristors on both etched gate and non etched gate samples were able to be turned on. This is explained by the quite long penetration depth of UV light in SiC for these wavelengths. Indeed, the penetration depth is around 125 μm [5] for a wavelength of 365 nm, which is much longer than the thickness of all epi-layers of the thyristor. A light source with a shorter wavelength would have been more suitable, but the yield and the output power of such UV LEDs are quite low. The structure without gate etching will be preferred when designing new light triggered thyristors (LTT), because the process is a little simpler and the current homogeneity is supposed to be better with the P+ layer covering the entire active area.

A typical switching waveform is plotted in Fig. 3. The current of 1.3 A after turn-on corresponds to a current density of 370 $\text{A} \cdot \text{cm}^{-2}$. The switching was very fast with a rise time of about 40 ns. All

commutations on various devices show always a rise time shorter than 100 ns.

The delay time between the beginning of the current pulse in the LED and the switch-on of the thyristor was measured for several bus voltages and LED currents. The LED current pulse was 50 μs long. The shortest delay time of 1.5 μs was measured with the maximum power of our light source. The values reported in the literature for electrically triggered thyristor (ETT) are typically in the range of 0.1 μs – 2 μs [6-8].

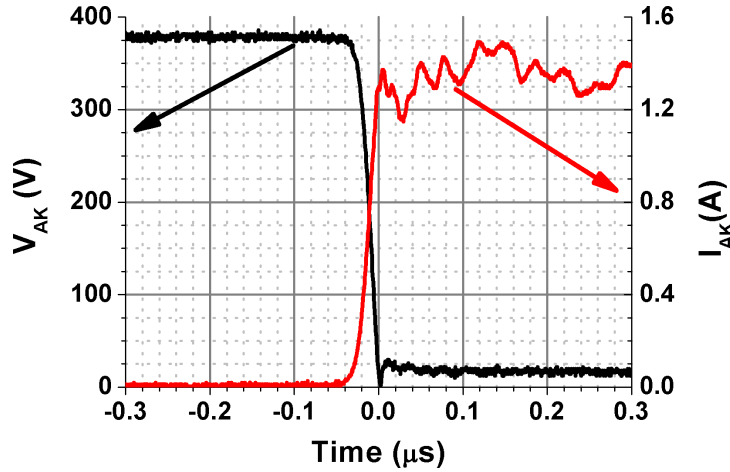


Fig. 4. Current and voltage switch-on waveforms of a 0.35 mm² thyristor. The load was a 280 Ω resistor.

Optical power density. From the LED current measurements one can deduce the optical power density at the thyristor surface using the previous characterization of the diode (section “Experimental Set-up”). The optical energy density necessary to turn-on the thyristor can then be estimated by multiplying the power density by the delay time. The dependence of this energy density on the power density at the surface of the thyristor is shown in Fig. 5.

Over the power range covered by the light source, the energy density E_{on} required to switch on the device decrease with the optical power density. The lowest optical energy density used to turn-on this device was $1.1 \times 10^{-5} \text{ J.cm}^{-2}$. This value is close to the value of $1.0 \times 10^{-5} \text{ J.cm}^{-2}$ from [3], which was measured using a 337 nm, 7 ns laser pulse. E_{on} for an electrical triggering of SiC-thyristors fabricated on the same material is around $8 \times 10^{-6} \text{ J.cm}^{-2}$. This value has been obtained with the data given in [4] and assuming an anode gate voltage of 3 V. Thus, the energy density necessary to turn on the thyristor is approximately the same for optical and electrical triggering. Nevertheless, considering the efficiency of the optical system used, light triggering of SiC-thyristors still requires approximately 2 orders of magnitude more energy than electrical triggering. However, this energy is still low compared to the energy that the thyristor can handle.

Furthermore, Fig. 5 shows that E_{on} and consequently the delay time decrease with an increasing bus voltage. This is to be explained by the space charge region expanding with the bus voltage which means that the amount of optically generated carriers that are separated by the electric field increases. Therefore, the equivalent gate current becomes higher. Moreover, as the space charge expands, the drift layer length on which the carrier have to diffuse becomes shorter. This accelerates the transport of the carriers through the drift layer, and thus the turn-on process. On the other hand, figure 5 shows that E_{on} does not decrease significantly when the bus voltage moves from 400 V to 500 V. A possible explanation is that the drift layer was already fully depleted at 400 V. Considering the epi-layer specifications given in the Fig.1, an anode cathode voltage of 400 V should theoretically result in a depletion layer width of about 30 μm . This is in contradiction with the previous supposition. So, C/V measurement between the anode and the cathode were performed, revealing that the capacitance reaches its minimum at about 360 V and keeps the same value for higher voltage. This implies a full depletion of the drift layer at 360 V. This is in accordance with

our delay time measurements. As a result, the real drift-layer seems to be much thinner than the specification.

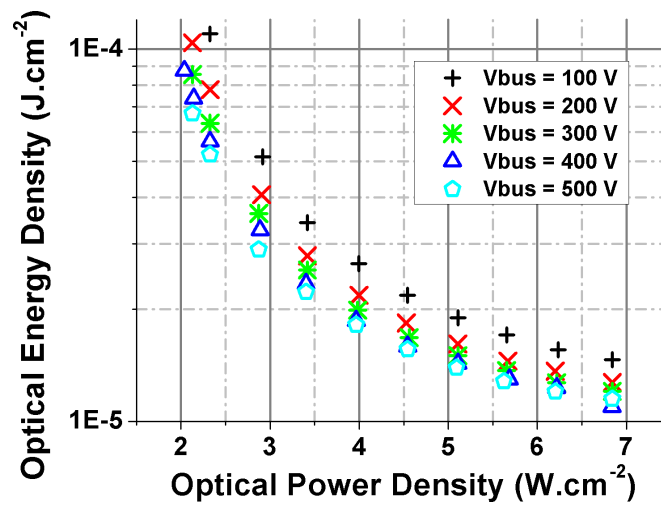


Fig. 5. Optical energy density E_{on} required to switch on a 0.35 mm^2 thyristor versus the optical power density P_{on} for different bus voltages V_{bus} . E_{on} is estimated by multiplying P_{on} by the delay time.

Conclusion

4H-SiC thyristors were successfully triggered with a 365 nm UV light-emitting diode. The delay time and the rise time are comparable with those of electrically triggered thyristors. However, due to the losses in the optical system (LED and lens), the energy required to turn-on the thyristor is much higher for optical triggering than for electrical triggering. Moreover, the wavelength of the UV LED is not optimal because the penetration depth is much longer than the epi-layers thickness, but commercially available LEDs with shorter wavelengths are less efficient and less powerful. The near UV-light allows also the use of optical fibre with low attenuation. Based on the results attained, a second generation of LTT is under development to evaluate the pulse current capabilities of such devices.

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