Laser processing for bevel termination of high voltage pn junction in SiC

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Abstract. Proper edge termination of the p-n junction in silicon carbide is a key requirement in the fabrication of discrete devices able to withstand high voltages in reverse polarization. Due to the hardness of SiC the creation of the bevel termination remains difficult using mechanical machining. The use of laser beam sources with medium wavelength (532 nm) gives new possibilities in the machining of the silicon carbide. The paper presents the fabrication of the bevel termination structure in SiC using a green DPSS laser equipped with scanner and dedicated rotating sample holder. Characterization of the resulting structures proves the high potential of the proposed approach.

1. Introduction

Silicon carbide (SiC) is a wide-bandgap semiconductor that offers many advantages over common silicon for power devices, as it can be doped to higher levels than silicon to achieve a given blocking voltage. High voltage devices require a proper edge termination to eliminate early breakdown caused by the edge electric field intensification. For SiC devices the critical electric field is about one order of magnitude higher than of silicon, therefore the stress on the passivating dielectric can be much higher for SiC devices at breakdown than that for Si devices. Moreover, the high temperature capability is one of the advantages of SiC over other semiconductors. To take advantage of this, fabrication technology of SiC high-field devices capable of operating at much higher temperatures than Si devices must be developed. Since the reliability of any dielectric degrades when the temperature increases, reducing of the surface and edge electric field becomes critical for SiC high-field devices. This problem may be addressed by the edge termination technique, which can substantially reduce the electric field at the edges of the high voltage SiC device and thus improve its reverse characteristic.

1.1. Bevel termination of p-n junction

The process of bevelling consists of removal of semiconductor material at the edges of device at a precisely defined angle. The bevelling of the edges has been demonstrated to enhance the breakdown...
voltage by reducing the electric field at the edges as compared to cut orthogonal to the surface [1]. An example of the power devices with bevel edge termination at the upper high voltage junction is presented in figure 1. Mechanical grinding or abrasive powder bombardment are used for bevelling in silicon devices, but for silicon carbide those techniques are not successful.

![Figure 1](image)

**Figure 1.** Cross section of the bevelled power devices: rectifier (a) and thyristor (b) [1].

### 1.2. Laser machining for bevelled SiC structures

Due to its hardness and smaller chips as compared to silicon ones, silicon carbide remains one of the most difficult material for mechanical treatment and thus fabrication of the bevelled surface by means of grinding may cause many troubles [2]. On the other hand, techniques based on the selective ICP etching of bevelled structures are quite complicated (multistep masking) and results in rough SiC surfaces [3]. Nowadays, the new possibility opens for maskless, non-contact bevel termination fabrication for SiC devices due to the laser technology development [4]. UV (335 nm) and green (532 nm) lasers are interesting for the ablation cutting of wide bandgap materials that have a low absorption coefficient or are nearly transparent at NIR (including 1064 nm) wavelengths, such as GaAs, sapphire or glass [5,6]. The high photon energy of UV and green lasers plays also a significant role in laser machining of polymer materials such as polyimide. In addition to the absorption coefficient different ablation results are expected for ultraviolet, green and infrared lasers. In many cases, the heat diffusion length should not exceed the optical penetration depth, in order to obtain high quality microstructures with clean edges and smooth surfaces which are required for junction termination.

As a result, many laser parameters, such as the frequency and duration of the laser pulses as well as scanning parameters needed to be considered too [7].

### 2. Experiment and results

Pure 4H-SiC substrate cut to 5x5 mm samples were used for laser machining. The green laser (532 nm, 6 W power output, output power variation <1%) equipped with beam scanner and dedicated rotating sample holder were employed to fabricate the bevelled structures. In the experiment the bevel angle adjusted by the holder position was set to 10°, 20°, 30° and 40° (±2°).

The images of the structures obtained by Zeiss Evo25 SEM are presented in figure 2. It can be seen that the bevelled surface remains well shaped and recurrent for all samples. However, for smaller laser beam angle (10°) it is difficult to keep the top surface undamaged and the interface between the bevelled and top surfaces become rounded (figure 2d). This effect is caused by insufficient precision in the available sample holder combined with the need of manual adjustment of the rotating sample according to laser beam focus position.

For the decreasing incident beam angle, the top surface of the device is also decreasing, but this effect is caused mainly due to the limited dimensions of the samples. To keep the active area of devices equal regardless of the bevelling angle, the samples would need to be bigger when smaller bevel angles are to be fabricated.
In some circumstances the surface of the device may be accidentally damaged by the laser beam, as it can be seen in figure 2a. Therefore the additional protective layer covering the top surface of the structure would be beneficial. In case of complete device (e.g. diode), a rounded aluminium or nickel contact layer would act as a good protective layer since metals reflect laser beam nearly completely. Due to very short laser pulses used during the machining process (35 ns) and low pulse repetition (31 kHz) straight lines caused by the passing light beam are visible on each processed surface. Those lines give raise to the bevelled surface roughness and make it wrinkled, as presented in figure 3. The wrinkles are especially intensive close to the top surface of the sample, where laser beam remains well collimated.

**Figure 2.** SEM images of the SiC laser cut structure with bevel angle 40° (a), 30° (b), 20° (c) and 10° (d).

**Figure 3.** SEM image of laser bevelled surface (30°).
During the laser machining, locally heated SiC reacts with oxygen from the atmosphere leading to formation of CO\(_2\) (volatile) and SiO\(_2\) (solid), which can be seen in figure 2c. An accumulation of silicon oxide grains may interfere with SiC laser processing making it less controllable and inaccurate.

3. Conclusions
In the paper the new approach for bevel termination fabrication for SiC high-voltage devices is presented. The green laser equipped with beam scanner and dedicated rotating sample holder has been employed to verify the results of silicon carbide laser machining. The structures obtained were characterised using electron microscopy. Observed results proved that it is possible to create a bevelled surface at the edges of the round silicon carbide device and therefore the presented method may be useful for termination of the device’s junction. At present the process remains immature and results with rough and uneven surface, but since the surface quality is strongly dependant on the laser beam and sample holder parameters many ways of improvement are possible and will be examined.

4. References
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