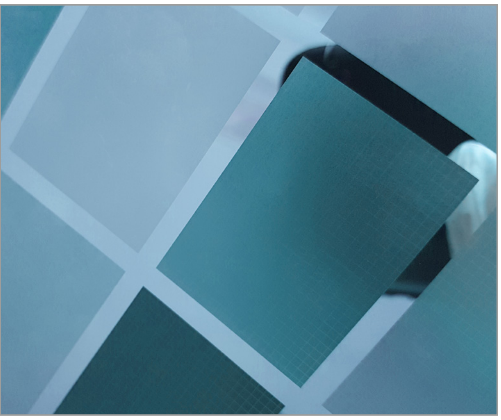
Ohmic Contact Formation

Comparative Study on the Influence of Laser Ohmic Contact Formation on the Electrical Characteristics of SiC-Ni Interfaces*



Introduction

4H-SiC power semiconductor devices such as diodes, MOSFETs and JFETs, are vertical devices with structures at the chip front side and a metallization stack at the chip backside. The current flow of this type of device is vertical between the front and the backside. By thinning the chips, the resistance can be reduced [1]. To produce these power devices, the front side of the silicon carbide (SiC) wafer is processed first. Next, the SiC wafer is thinned from the backside using a grinding process. After the grinding step, the metallization stack is produced on the backside of the wafer.

Typically, nickel (Ni) is used as a first metallization layer. However, combinations of titanium (Ti) and silicon (Si) can also be realized [2]. Directly after metal deposition, the electrical characteristics of the metal SiC interface correlate with a Schottky characteristic curve. The Ohmic Contact Formation (OCF) process is performed after the first metallization layer is deposited. This process applies heat to the backside of the wafer to convert the Schottky contact into an ohmic contact. More metal layers are applied to finish the backside processing in additional process steps. For standard thick SiC wafers without backside grinding (e.g., 350 µm thickness), flash lamps were used to perform the OCF process. This annealing cannot be performed with thinner wafers due to the high heat load generated at the front side of the wafers. That is why, with thinner wafers down to 80 µm thickness and below, nanosecond (ns) laser systems are used to perform the OCF process.

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After applying the first metallization layer at the backside of power semiconductor wafers, an ohmic contact must be formed between the semiconductor and the metallization. For SiC power semiconductors, Ni or Ti layers with 40 to 100 nm thickness are typically used. To form an ohmic contact with oven annealing, a heat treatment of approx. 900 - 1000°C at the wafer backside is necessary [3, 4]. While applying the heat, the backside metal and the silicon from the SiC form a metal silicide, e.g., a nickel silicide (Ni_xSi_y). The residual carbon produces carbon clusters at the interface of SiC and Ni_xSi_y [4, 5]. For thin wafers, laser annealing with short-pulsed lasers has significant benefits, such as it doesn't influence the front side of the SiC wafers since the heat treatment is performed on the backside.

Experimental setup

Laser systems

We compared the process results of two different laser systems. Both laser systems are production systems equipped with a solid-state ns laser with a 355 nm wavelength.

The laser source of system 1 has a Gaussian beam profile with TEM_{00} characteristics at the laser interaction zone. The pulse length of the single laser pulses is between 100-300 ns. The process runs under oxygen reduced atmosphere.

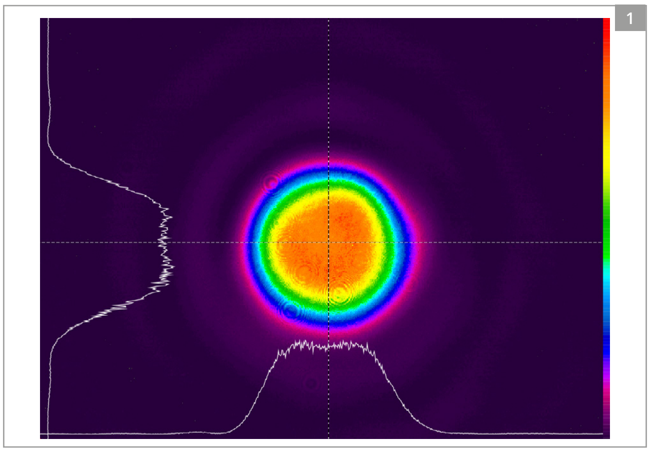

Fig. 1: Flat top of laser spot.

The second system was the new microPRO XS OCF built by 3D-Micromac. This system has an integrated 25 W ns laser with a pulse length between 50 and 100 ns and a flat top profile with a diameter of 80 µm (Fig. 1). The benefit of a flat top profile compared to a Gaussian beam is the homogenous energy distribution over the wafer. Furthermore, a larger laser spot size leads to an increase in throughput. A galvo scanner system guides the laser over the surface of the wafer. The process chamber is purged with N_2 to reduce the oxygen level to <300 ppm.

Material

We used fully processed power electronic 4H-SiC wafers. The diameter of the wafers was 150 mm. The material thickness was between 80 µm and 175 µm. For wafer thinning, two different grinding processes (A and B) were used to check if there is an influence on forward resistance. A 75 nm thick nickel layer was sputtered at the wafers' backside. After the laser-based ohmic contact formation, the wafers were cleaned, and the backside metallization stack was finished with a 4 µm to 5 µm thick aluminum layer. After that, the forward resistance was measured for each device at the wafer level.

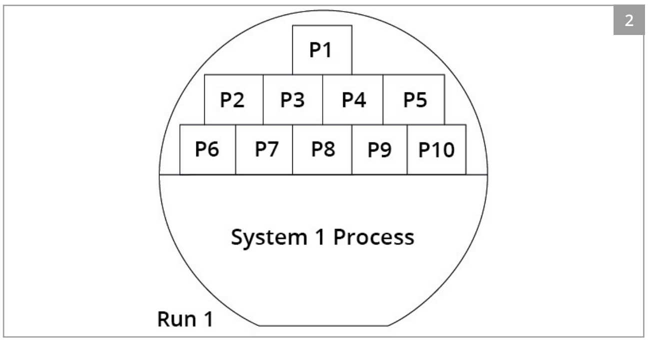

Fig. 2: Overview of parameter field for run 1.

Parameter #	Pulse energy density [%]	Pulse overlap	Beam profile
P0	System 1	System 1	Gaussian
P1	78	Max	Top hat
P2	78	Middle	Top hat
P3	85	Max	Top hat
P4	85	Middle	Top hat
P5	93	Max	Top hat
P6	93	Middle	Top hat
P7	93	Min	Top hat
P8	93	Min	Top hat
P9	100	Max	Top hat
P10	100	Middle	Top hat

Table 1. Run 1: Process parameter fields per each wafer

Test procedure

Two wafer runs were performed. The first run was with six wafers with vertical resistor structures.

The wafers had a thickness of 80 and 175 µm. For this evaluation, low forward resistance was the main quality criterion. With system 1, only one OCF parameter set was used. For the 3D-Micromac process, a parameter sweep was performed (Fig. 2). With this, the pulse energy density and the pulse overlap were varied (Table 1).

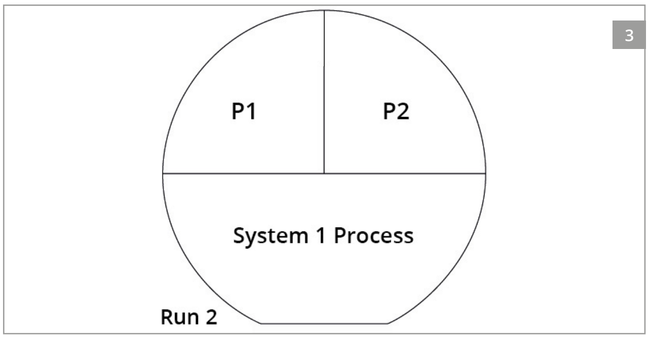

Fig. 3: Overview of parameter field run 2 (wafer 1 and 4).

Parameter #	Wafer #	Pulse energy density [%]	Pulse overlap	Beam profile
P0	1,2,3,4,5,6	System 1	System 1e	Gaussian
P1	1, 4	100	Min	Top hat
P2	1, 4	100	Max	Top hat
P3	2, 5	90	Min	Top hat
P4	2, 5	90	Max	Top hat
P5	3, 6	78	Min	Top hat
P6	3, 6	78	Max	Top hat

Table 2. Run 2: Process parameter fields for each wafer

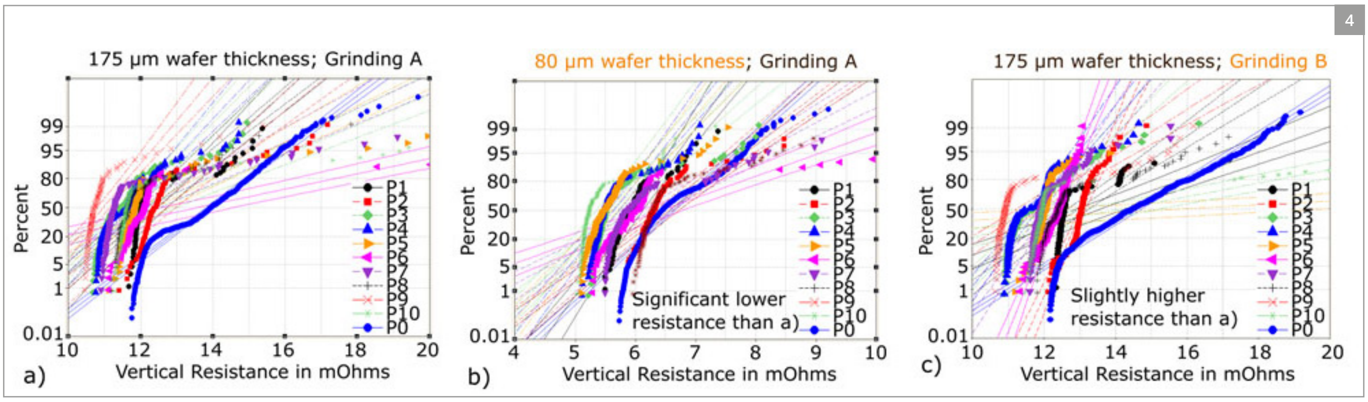

Fig. 4. Distributions of forward resistance measurement on three wafer types. a) Grinding A with 175 µm thickness, b) Grinding A with 80 µm thickness, c) Grinding B with 175 µm thickness. The aim is to reduce vertical resistance. The top hat process shows lower vertical resistance than the Gaussian beam process.

The second run was performed on 110 µm and 150 µm thick wafers with SiC JBS diodes to analyze the influence of the backside heat load generated by the OCF laser process on the front side structures. If the heat load at the front side is too high, it influences the electrical characteristic. This test is to prove the usability of the process for production. Again, only one OCF parameter set was used in system 1. In the 3D-Micromac process, a parameter sweep was performed by varying energy density and pulse overlap (Fig. 3 and Table 2).

Results

In Fig. 4, exemplary electrical results are shown. It could be demonstrated that the results of the top hat profile have a comparable or lower forward resistance compared to a Gaussian energy profile. In fact, all results generated by 3D-Micromac's OCF process are similar to or better than the OCF process with system 1. Furthermore, an optimum forward resistance can be achieved by tuning the pulse to pulse overlap and the pulse energy density. A higher energy density or pulse overlap results in lower forward resistance. Nevertheless, an increase in throughput can be achieved by reducing the overlap.

By reading the results, one must consider that the wafer raw material also has an influence of on the electrical results. This is due to inhomogeneous dopant concentration in the wafer material. The effect can be seen in Fig 5.

Since vertical devices are used, the forward resistance will be reduced by lowering the wafer thickness. The wafer thickness has a much stronger influence on the forward resistance than the laser parameters (see Fig. 4a and 4b). Nevertheless, as wafer thickness is reduced, the impact of the laser parameters will be increasingly important.

The grinding process also influences the forward resistance values. The influence of the grinding process is comparable with the impact of the laser parameters (see Fig. 4a and 4c).

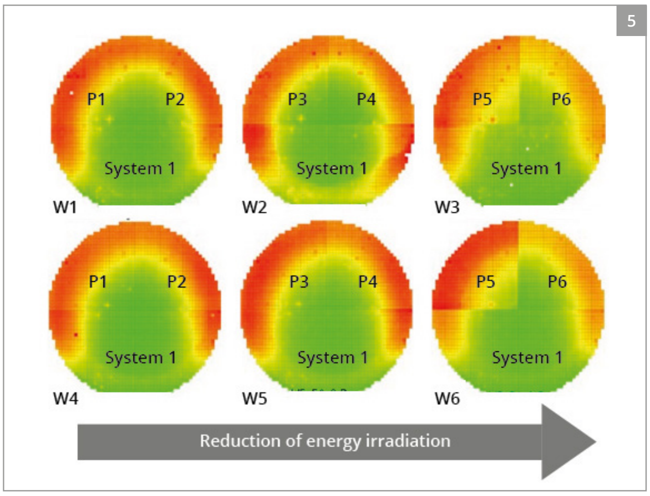

Fig. 5: Forward Voltage: Colors green to red correspond to a minimum to a maximum per wafer. Wafers 1 to 3 are 150 µm thick. Wafers 4 to 6 are 110 µm thick. For parameters, see Table 2. From left to right, the energy irradiation is increased from minimum to maximum. It can be seen that minimum energy irradiation increases forward voltage due to not entirely performed ohmic contact formation. An increase in maximum energy irradiation does not change the forward voltage. Higher forward voltage at the wafer edge region results from inhomogeneous dopant distribution in wafer material.

In Fig 5., the results of the second wafer run are shown. Only at the parameter with the lowest energy irradiation (P5 at wafers 3 and 6) is a change of the parameter fields visible. The laser energy irradiation at these fields was insufficient to form a proper ohmic contact. Hence, the resistance is higher. By analyzing all other parameter fields, it can be seen that the resistance does not significantly change with increasing the energy irradiation. That proves that higher energy irradiation does not affect the electrical characteristic of the wafers' front side for 150 and 110 µm thick wafers.

Conclusion

We evaluated the influence of the process parameters on laser-based ohmic contact formation and compared that with the influence of the wafer parameters, such as wafer thickness and the grinding process. With this knowledge, it's easy to adjust the optimal laser process management. In an additional wafer run, we could show that thermal laser annealing for ohmic contact formation does not affect the surface structures even with higher laser energy and 110 µm thin wafers.

References

* This whitepaper was written based on 3D-Micromac's and XFAB's paper at the ECSCRM 2020/2021 conference.

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microPRO™ XS for OCF

Selective Laser Annealing for Ohmic Contact Formation (OCF)

The microPRO XS system provides laser annealing with high repeatability and throughput in a versatile system. Combining a state-of-the-art laser optic module with 3D-Micromac's modular processing platform, the microPRO XS is ideally suited for OCF in silicon carbide (SiC) power devices. The microPRO XS for OCF features a UV-wavelength diode-pumped solid-state (DPSS) laser source with nanosecond pulses and spot scanning to process the entire metalized backside of SiC wafers. It forms ohmic interfaces and cures grinding defects while preventing the generation of large carbon clusters and heat-related damage to the front side of the wafer.

Fig. 6: 3D-Micromacs microPRO XS OCF selective laser annealing system for ohmic contact formation. The system has an integrated 25 W ns laser with a pulse length between 50 and 100 ns and a flat top profile. The microPRO XS OCF offers high throughput with 150-mm wafers processed in a single step.