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Determination of *dV/dt* and *dI/dt* characteristics for high voltage 4H-SiC Schottky diodes with different types of metal-polymeric packages

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Abstract. The *dV*/*dt* and *dI*/*dt* characteristics for 4H-SiC Schottky type diodes with different type metal-polymeric packages have been studied experimentally. It is determined that experimental *dV*/*dt* values for 4H-SiC Schottky type diodes in large-sized and small-sized metal-polymeric packages type (TO-220, SOT-89, QFN, PQFN) are varying in interval of 753÷1087 V/ns. For the first for time 4H-SiC Schottky type diodes have been determined experimentally another important diode's characteristics *dI/dt* which are varying in interval of 1.91÷4.00 A/ns for all diodes It is established that package's size miniaturization not lead to characteristics degradation (*dV/dt* and *dI*/*dt*) during of impulse mode of operation that is positive factor for the for diode failure-free operation during of impulse mode.

1. Introduction

Recent progress in power electronics has been driven by development of the SiC-based devices, in particular, the high-voltage silicon carbide Schottky type diodes are new generation of power semiconductors, posses the maximal values of breakdown voltage and minimal leakage currents [1,2,3]. Recently it has been established that the one of the important characteristics for silicon carbide Schottky diodes during the operation of the diode in pulse mode is value of *dV/dt* when a reverse voltage pulse is applied to the diode and therefore devices with lower *dV/dt* capability are more susceptible to failure from large in-rush currents [4,5].

Thus, in our previous papers were studied 4H-SiC Schottky type diodes in respect effect of their structure on electric properties [6-9] and stability to rate of reverse voltage rise *dV/dt* [10-12]. Also it was established that in 4H-SiC Schottky diodes packaged in standard large-sized package of TO (Transistor Outline) type demonstrate the typical value of *dV/dt* ≈ 150÷200 V/ns [10-12].

On the other hand, it is known that the diode package is one of the main elements that determines the characteristics of the diode [13]. At the present time moment power electronic industry comes down to use of small-sized type of metal-polymeric package such as SOT (Small Outline Transistor), QFN (Quad Flat No-leads) and others [2,3,13].

However, effect of packaging type on *dV/dt* characteristics of 4H-SiC Schottky diodes to present are almost not studied, therefore the first goal of this work is to study *dV/dt* characteristics for Schottky diodes in different types of packages. Because of this, during the operation of the diode in pulse mode for 4H-SiC type Schottky diode is important another parameter *dI/dt* that describes stability of diodes to

current rise process during of impulse mode of reverse voltage across the diodes. Therefore, the second goal of this study is to establish stability of diodes to rate of reverse current rise *dI/dt*.

2. Materials and methods

The used experimental measuring test were described in detail earlier [10-12] and then has been modernized. In figure 1 is shown the principal electric scheme of output stage module of the modernized measuring tester for determination of *dV/dt* and *dI/dt* values across a testing silicon carbide Schottky diode. A reverse voltage pulse is formed when the transistor VT2 is turned on using a pre-charged capacitor C8. The amplitude of the voltage pulse is set by the voltage (see +UR in figure 1) in the range from 300 up to 1000 V.

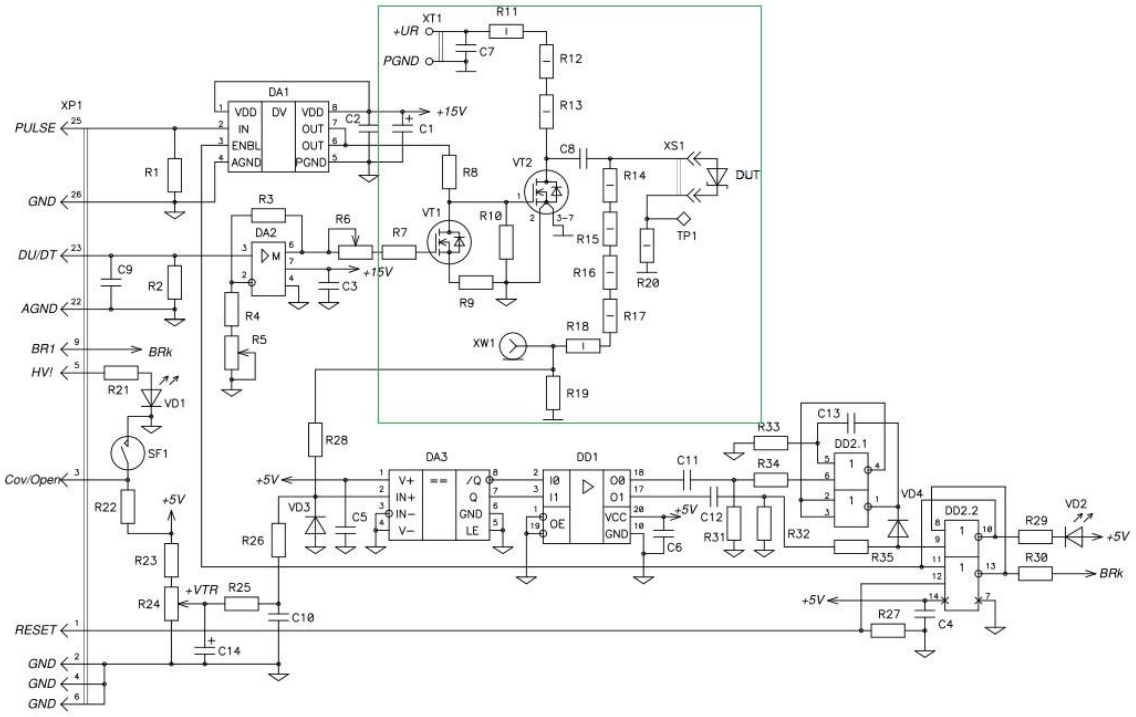

Figure 1. The principal electric scheme of output stage module of the measuring tester for determination of *dV/dt* and *dI/dt* values across a testing silicon carbide Schottky diode.

A high voltage rise rate (more than 250 V/ns) is provided by the DA1 driver microcircuit with an output current of up to 9 A. Then, control of the rate of rise of the reverse voltage is provided with the help of an additional transistor VT1, shunting the gate circuit of the transistor VT2. For recording of voltage and current signals was used the Tektronix MDO3102 oscillograph (bandwidth 1 GHz, refresh rate 5 GS/s). In particular, the voltage measurement was performed using the Tektronix MDO3102 oscillograph connected to R19 resistor (XW1 in figure 1) and current measurement was performed using the oscillograph connected to R20=1 Ω resistor (XW1 in figure 1) in series with the testing diode. The reverse voltage front across to tested diode is formed switching on VT2 silicon carbide transistor. Small acceleration time has been provided by charge of input capacitance of the VT2 transistor with using of avalanche breakdown current of the VT1 transistor. Regulation process of dV/dt parameter has been realized by the R21 resistor. The tested Schottky diodes (DUT) were connected to connectors marked as XS1 in figure 1.

3. Results and discussion

At first in order to prevent experimental error, in all cases the equipment was initially calibrated with a control signal from the equipment by applied amplitude of pulse of reverse voltage (voltage amplitude of 800 V) without diode (for instance, blue dash-dotted curve which is shown in figure 2a). Further, the value of *dV/dt* and *dI/dt* for diode was obtained by slope of the linear part of oscilogram for voltage and current waveform (for instance, in figure 2a the *dV* and *dI* values for *dV/dt* and *dI/dt* calculations were obtained for *dt* time interval between 14.5 and 15.5 ns approximately).

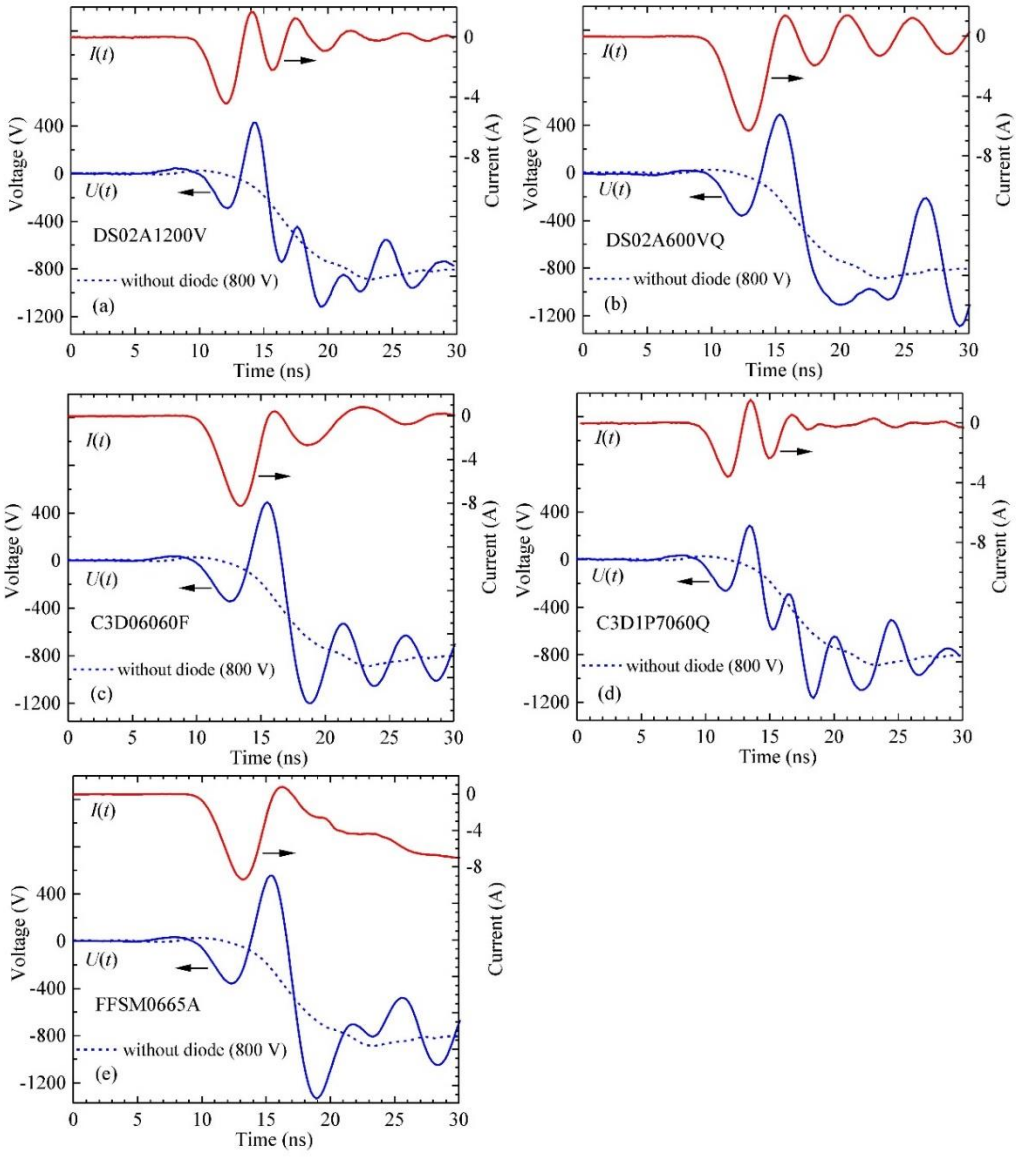

Figure 2. The reverse voltage and current waveform with maximal pulse amplitude 800 V for 4H-SiC type Schottky diodes with different package types: (a) DS02A1200V (SOT-89, «GRUPPA KREMNY EL»); (b) DS02A600VQ (QFN-8, «GRUPPA KREMNY EL»); (c) C3D06060F (TO-220-F2, Cree); (d) C3D1P7060Q (QFN 3.3, Cree); (e) FFSM0665A (PQFN, ON Semiconductor).

Then, were tested the following 4H-SiC type Schottky diodes: experimental diode DS02A1200V (JSC «GRUPPA KREMNY EL», Bryansk, Russia) in small-sized SOT package type (SOT-89);

experimental diode DS02A600VQ (JSC «GRUPPA KREMNY EL», Bryansk, Russia) in small-sized QFN package type (QFN-8); diode C3D06060F [14] (CREE/Wolfspeed, US) in large-sized TO package type (TO-220-F2); diode C3D1P7060Q [15] (CREE/Wolfspeed, US) in small-sized QFN package type (QFN-3.3) and diode FFSM0665A [16] (ON Semiconductor, US) in large-sized QFN package type (PQFN/ Power QFN).

The testing *dV/dt* results for 4H-SiC type Schottky diodes are shown in figure 2 for case when the maximal amplitude of impulse of reverse voltage across the diodes is equal of 800 V.

As follows from figure 2a, for experimental diode DS02A1200V in small-sized SOT package type (SOT-89) obtained value of *dV/dt* value is 940 V/ns.

Further, as can be seen from figure 2b for experimental diode DS02A600VQ in small-sized QFN package type (QFN-8) the obtained value of *dV/dt* value is 753 V/ns.

For C3D06060F diode (figure 2c) in large-sized TO package type (TO-220-F2) *dV/dt* value is 939 V/ns.

Figure 2d displays oscilograms for diode C3D1P7060Q in small-sized QFN package type (QFN 3.3). In this case have been obtained the maximal values *dV/dt* in experiments where *dV/dt*=1087 V/ns.

Finally, for diode FFSM0665 in large-sized QFN package type (PowerQFN) *dV/dt* value obtained is 879 V/ns (figure 2e).

By comparing obtained *dV/dt* results for experimentally developed diodes (DS02A600VQ and DS02A600VQ) in small-sized packages with *dV/dt* results for similar small-sized packages diodes (C3D1P7060Q and FFSM0665A) it can be concluded that the *dV/dt* data are approximately equal.

The obtained results for *dV/dt* characteristics for all type investigated diodes (at constant impulse of reverse voltage applied across the diodes of 800 V) with different types package are generalized below in table 1.

Table 1. *dV/dt* and *dI/dt* results for testing of 4H-SiC Schottky diodes with different packages type (at constant impulse of reverse voltage applied across the diodes of 800 V).

Package type	TO-220-F2	SOT-89	QFN-8	QFN 3.3	PQFN
Diode's type	C3D06060F	DS02A1200V	DS02A600VQ	C3D1P7060Q	FFSM0665A
Package dimensions (mm)	10.3×16.07	4.6×2.6	3.3×3.3	3.3×3.3	8×8
dV/dt (V/ns)	939	940	753	1087	879
dI/dt (A/ns)	2.11	3.85	2.35	4.00	1.91

In our previous paper [12] was studied previous generation of 4H-SiC type Schottky diode 5DS402A produced by JSC «GRUPPA KREMNY EL» where at the same small-sized package (SOT-89) and experiment conditions was obtained *dV/dt*=670 V/ns that less then for new generation DS02A1200V diode type (*dV/dt*=940 V/ns).

It should also be noted that for all diodes type in different packages type were fixed very essential values of maximal amplitude of reverse voltage varying from 1116 up to 1287 V that exceed the typical limit for non-pulsed mode (600-1200 V).

At the same time for SiC type of Schottky diodes the typical *dV/dt* values are ~200 V/ns [4,5,15,17] and can reach up to 650-800 V/ns [18,19]. Hence, *dV/dt* values (753-940 V/ns) obtained for experimental 4H-SiC commercial diode (DS02A600VQ and DS02A600VQ) in small-sized packages demonstrate that more then typical for these type devices and therefore can stably work without failures in electric circuits.

Because of this, it can be noticed that package's size miniaturization not lead to *dV/dt* characteristics degradation, for instance, *dV/dt* value for small-sized package (940 V/ns – SOT-89/DS02A120V) is approximately equal for *dV/dt* value for large-sized package (939 V/ns – TO-220-F2/C3D06060F).

On the other hand, because of *dV/dt* parameter during the operation of the diode in pulse mode for 4H-SiC type Schottky diode it is important also another parameter *dI/dt* that describes stability of diodes to current rise process during of impulse mode of reverse voltage across the diodes.

Therefore, in figure 2 are presented the testing *dI/dt* results for 4H-SiC type Schottky diodes (when the maximal amplitude of impulse of reverse voltage across the diodes is equal of 800 V).

As can be seen from figure 2a, for experimental diode DS02A1200V in small-sized SOT package type (SOT-89) obtained value of *dI/dt* is 3.85 A/ns. Then, as can be seen from figure 2b for experimental diode DS02A600VQ in small-sized QFN package type (QFN-8) the obtained value of *dI/dt* value is 2.35 A/ns. For C3D06060F diode (figure 2c) in large-sized TO package type (TO-220-F2) *dI/dt* value is 2.11 A/ns. Figure 2d displays oscilograms for diode C3D1P7060Q in small-sized QFN package type (QFN 3.3). In this case have been obtained the maximal *dI/dt* values in experiments, i.e. *dI/dt*=4.00 A/ns. Finally, for diode FFSM0665 in large-sized QFN package type (PowerQFN) *dI/dt* value obtained is is 1.91 A/ns that is the minimal *dI/dt* value for all diodes at these conditions. The obtained results for *dI/dt* characteristics for all investigated diodes (at constant impulse of reverse voltage applied across the diodes of 800 V) with different types package are generalized in table 1.

Thus, for the first time on the basis of carried out experiments were established *dI/dt* value for SiC type Schottky diodes in different type packages that varying from 1.91 A/ns up to 4.00 A/ns.

Because of this, it can be noticed that package's size miniaturization not lead to *dI/dt* characteristics degradation, i.e. *dI/dt* value for small-sized package (3.85 A/ns – SOT-89/DS02A1200V) is larger then *dI/dt* value for large-sized package (4.00 A/ns – TO-220-F2/C3D06060F).

Also for all diodes type in different packages type have been fixed very essential values of maximal amplitude of reverse current varying from 3.6 up to 9.35 A that exceed the typical current limit for non-pulsed reverse mode (15-200 μA [14-16]).

Thus, it is evident from experimental data that 4H-SiC type Schottky diode new generation produced by JSC «GRUPPA KREMNY EL» in small-sized package have demonstrated very good *dV/dt* and *dI/dt* characteristics are comparable to diodes from leading manufacturers and package's size miniaturization not lead to characteristics degradation that lead to very stably work in electric circuits without failures.

4. Conclusions

In summary, *dV/dt* and *dI/dt* characteristics during of impulse mode of operation have been investigated for 4H-SiC type Schottky diodes in large-sized and small-sized metal-polymeric packages type (TO-220, SOT-89, QFN, PQFN). It is shown that for all packages type obtained *dV/dt* values varying from 753 up to 1187 V/ns.

It is established that *dV/dt* values (753-940 V/ns) for experimental 4H-SiC type Schottky diodes new generation produced by JSC «GRUPPA KREMNY EL» in small-sized metal-polymeric packages are approximately equal to diodes produced by leading firms (879-1087 V/ns). In addition, it is shown that package's size miniaturization not lead to *dV/dt* characteristics degradation.

For the first time it is established stability of Schottky diodes to rate of reverse current rise *dI/dt.* In particular, it is determined that the *dI/dt* values varying from 1.91 up to 4.00 A/ns for all diodes.

Because of this, it is obtained that *dI/dt* value for small-sized package of experimental 4H-SiC type Schottky diodes new generation produced by JSC «GRUPPA KREMNY EL» are comparable with diodes from leading firms and package's size miniaturization not lead to characteristics degradation.

In addition, for the first time was established that for all diodes type in different packages type have been fixed very essential values of maximal amplitude of reverse current varying from 3.6 up to 9.35 A that exceed the typical current limit for non-pulsed reverse mode (15-200 μA).

Therefore, it is shown that experimental 4H-SiC type Schottky diodes new generation produced by JSC «GRUPPA KREMNY EL» in small-sized metal-polymeric packages type (SOT-89, QFN-8) can stably work without failures during of impulse mode of operation.

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