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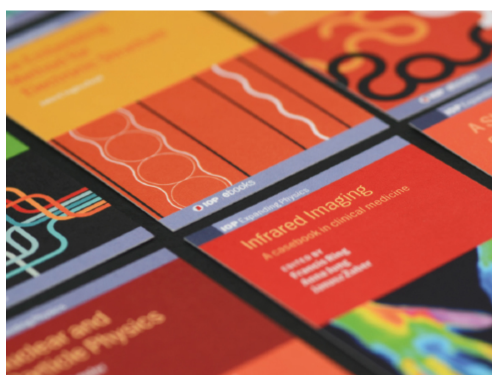

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dV/dt testing of high voltage 4H-SiC Schottky diodes with different types of metal-polymeric packages

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Abstract. The *dV/dt* values for 4H-SiC Schottky type diodes with different type packages have been determined experimentally. It is determined that experimental *dV/dt* values for 4H-SiC Schottky type diodes in metal-polymeric packages (SOT-89, QFN, PQFN, TO-220) are varying in interval of 645÷1103 V/ns. It is established that the *dV/dt* dependence on maximal amplitude of reverse voltage demonstrate nonlinear character (close to parabolic dependence) for all studied SiC Schottky type diodes in different type packages.

1. Introduction

At present the SiC-based high-voltage Schottky type diodes are based on absolutely new generation of power semiconductors, posses the maximal values of breakdown voltage and minimal leakage currents [1,2]. Earlier, in our previous studies were investigated 4H-SiC Schottky type diodes in respect of their structure [3-6] and stability to rate of reverse voltage rise *dV/dt* [7,8]. In particular, it was established that in 4H-SiC Schottky diodes packaged in standard large-sized package of TO (Transistor Outline) type demonstrate the value of *dV/dt* ≈ 150÷200 V/ns [7,8]. It is known that the diode package is one of the main elements that determines the characteristics of the diode [4]. Moreover, at present 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 [2,9]. However, effect of packaging type on *dV/dt* characteristics of 4H-SiC Schottky diodes to present are almost not studied, therefore the goal of this work is to study *dV/dt* characteristics for Schottky diodes in different types of packages.

2. Materials and methods

The used experimental measuring test (was described in detail earlier [7,8]) makes it possible to test on *dV/dt* characteristics of a SiC Schottky type diodes with varying of applied *dV/dt* values from 100 V/ns up to 1000 V/ns. In our experiments were used amplitudes of pulse of reverse voltage applied through a testing diodes in interval of 300÷1000 V. Analyses of oscillograms has been carried out with used Tektronix MDO3102 oscillograph (bandwidth 1 GHz, refresh rate 5×10^9 s^{-1}).

3. Results and discussion

To prevent experimental errors, 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, black curve which is shown in Figure 1). Then, were tested the following 4H-SiC type Schottky diodes: diode C3D06060F (CREE/Wolfspeed, US) in large-sized TO package type (TO-220-F2); diode 5DS402A (AO «GRUPPA KREMNY EL», Bryansk, Russia) in small-sized SOT package type (SOT-89); diode C3D1P7060Q (CREE/Wolfspeed, US) in small-sized QFN package type (PowerQFN) and diode FFSM0665 (ON Semiconductor, US) in large-sized QFN package type

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(PQFN). The value of *dV/dt* for diode was obtained by slope of the linear part of oscilogram for voltage waveform (for example, in Figure 1 the *dV* values for *dV/dt* calculations were obtained for *dt* time interval between 20 and 23 ns approximately).

Figure 1 shows the testing results for 4H-SiC type Schottky diodes when the maximal amplitude of impulse of reverse voltage across the diodes is equal of 800 V. For C3D06060F in large-sized TO package type (TO-220-F2) *dV/dt* value is 939 V/ns. For diode 5DS402A in small-sized SOT package type (SOT-89) obtained value of *dV/dt* value is 979 V/ns. The *dV/dt* value for diode C3D1P7060Q in small-sized QFN package type (PowerQFN) demonstrate the maximal *dV/dt*=1087 V/ns. And for diode FFSM0665 in large-sized QFN package type *dV/dt*=898 V/ns that is the minimal value for all diodes at these conditions. Because of this, package's size miniaturization not lead to *dV/dt* characteristics degradation.

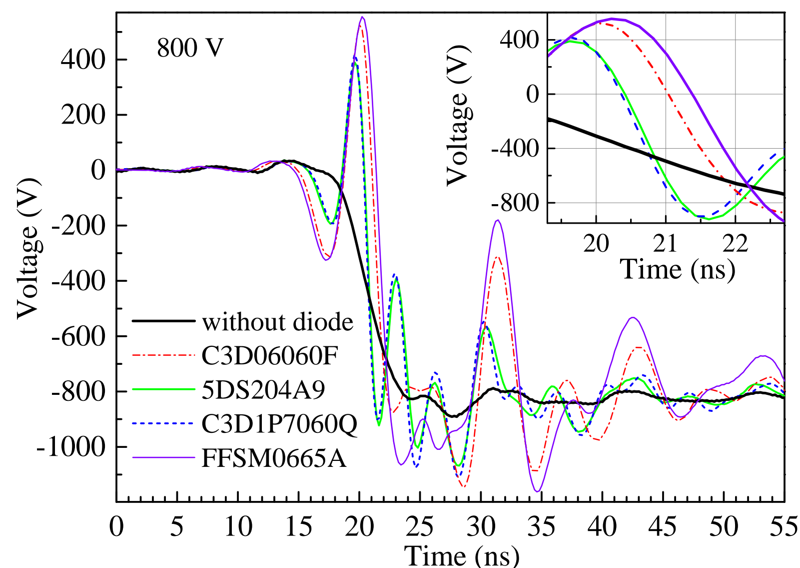

Figure 1. The reverse voltage waveform with pulse amplitude of 800 V (type of voltage waveform without diode - black curve) for 4H-SiC type Schottky diodes with different package types: C3D06060F (TO-220-F2, Cree), 5DS402A (SOT-89, «GRUPPA KREMNY EL»), C3D1P7060Q (QFN 3.3, Cree), FFSM0665A (PQFN, ON Semiconductor).

In our previous work [7,8] for the first time was established that *dV/dt* value increase with increase of impulse of reverse voltage applied across the diode and therefore in present study all diodes were tested by analogues approach.

In Figure 2 are shown testing results for following 4H-SiC type Schottky diodes: C3D06060F diode in large-sized TO package type (TO-220-F2), 5DS402A diode in small-sized SOT package type (SOT-89), diode C3D1P7060Q in small-sized QFN package type and diode FFSM0665 in large-sized QFN package type (PowerQFN). As can be seen from Figure 2 increasing of maximal amplitude of impulse of reverse voltage lead to increase of *dV/dt* value for all investigated diodes. For C3D06060F diode *dV/dt* value varying from 823 up to 958 V/ns with increase of maximal pulse amplitude of reverse voltage from 300 up to 1000 V. In case of 5DS402A diode *dV/dt* value varying from 863 up to 992 V/ns (maximal pulse amplitude is 300-1000 V). The *dV/dt* value for C3D1P7060Q diode varying from 972 up to 1103 V/ns (maximal pulse amplitude is 300-1000 V). For FFSM0665 diode *dV/dt* value varying from 766 up to 879 V/ns with increase of maximal pulse amplitude of reverse voltage from 300 up to 800 V.

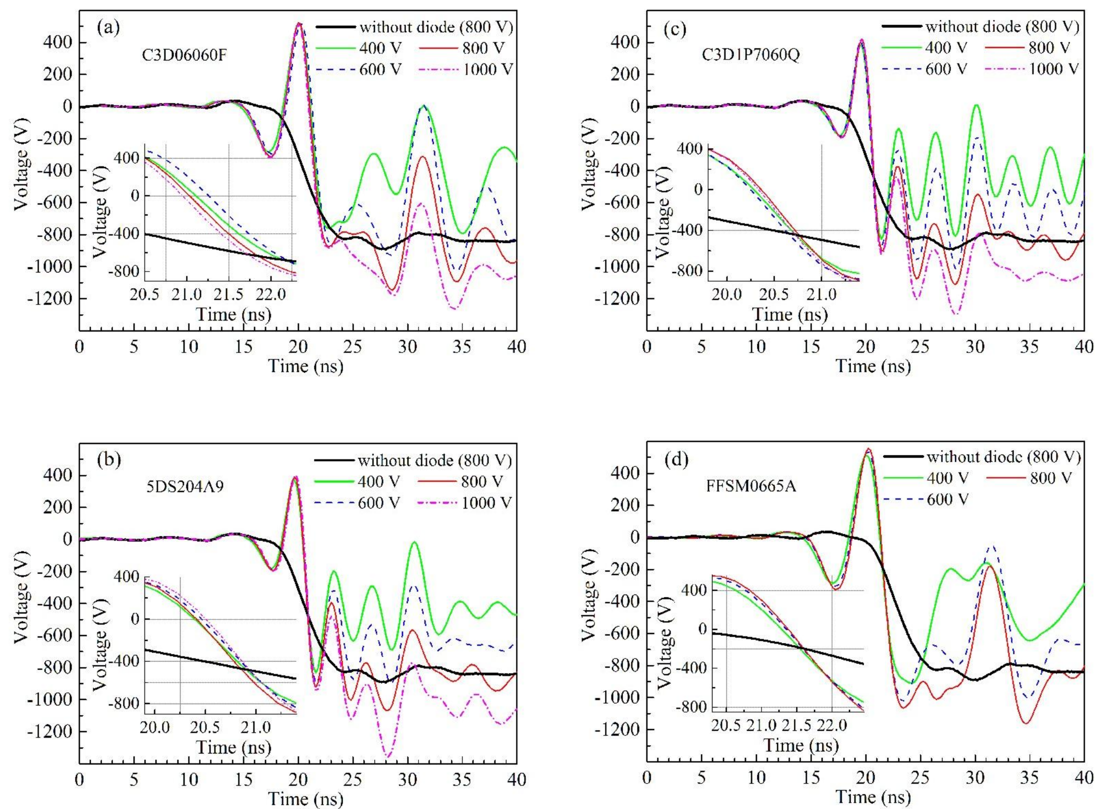

Figure 2. The reverse voltage waveform with different maximal pulse amplitude (from 400 V up to 1000 V) for 4H-SiC type Schottky diodes with different package types: (a) C3D06060F (TO-220-F2, Cree); (b) 5DS402A (SOT-89, «GRUPPA KREMNY EL»); (c) C3D1P7060Q (QFN 3.3, Cree); (d) FFSM0665A (PQFN, ON Semiconductor).

The obtained results for *dV/dt* dependence on impulse of reverse voltage applied across the diodes with different types package then were generalized below in Table 1.

Table 1. *dV/dt* results for testing of 4H-SiC Schottky diodes with different packages type.

Package type		TO-220-F2	SOT-89	QFN 3.3	PQFN
Diode's type		C3D06060F	5DS402A	C3D1P7060Q	FFSM0665A
Package dimensions (mm)		10.3×16.07	4.6×2.6	3.3×3.3	8x8
	300 V	704	801	908	645
	400 V	823	863	972	766
	500 V	871	905	1020	811
	600 V	903	931	1044	841
dV/dt (V/ns)	700 V	925	954	1072	860
	800 V	939	979	1087	879
	900 V	948	989	1092	
	1000 V	958	992	1103	

As follows from Table 1, with increase of maximal amplitude of impulse of reverse voltage applied across the diodes with different types package the *dV/dt* values increase too. Further, all obtained results from Table 1 then were presented in graphics mode for referencing in Figure 3.

As can be seen from Figure 3 the *dV/dt* dependence on maximal amplitude of reverse voltage demonstrate similar nonlinear character (close to parabolic dependence) for all type of investigated SiC Schottky diodes in different package types.

Therefore, it should be made conclusion that the above-established nonlinear features of *dV/dt* dependency from maximal impulse amplitude is similar for all diodes type and *dV/dt* not depends on diode's type or packages.

Thus, on the basis of this fact it can be assumed that in this case takes place some general *dV/dt* dependency for all type of the 4H-SiC Schottky diodes.

The mechanism of this phenomenon is not clear but it can believed that the main cause is some similar physical processes that occur in diodes when maximal amplitude of impulse of reverse voltage increase. In general case when maximal amplitude increase it lead to increase of electric field rate within diode volume and steady-state electric field will be result of interaction of applied external and induced internal non-stationary fields.

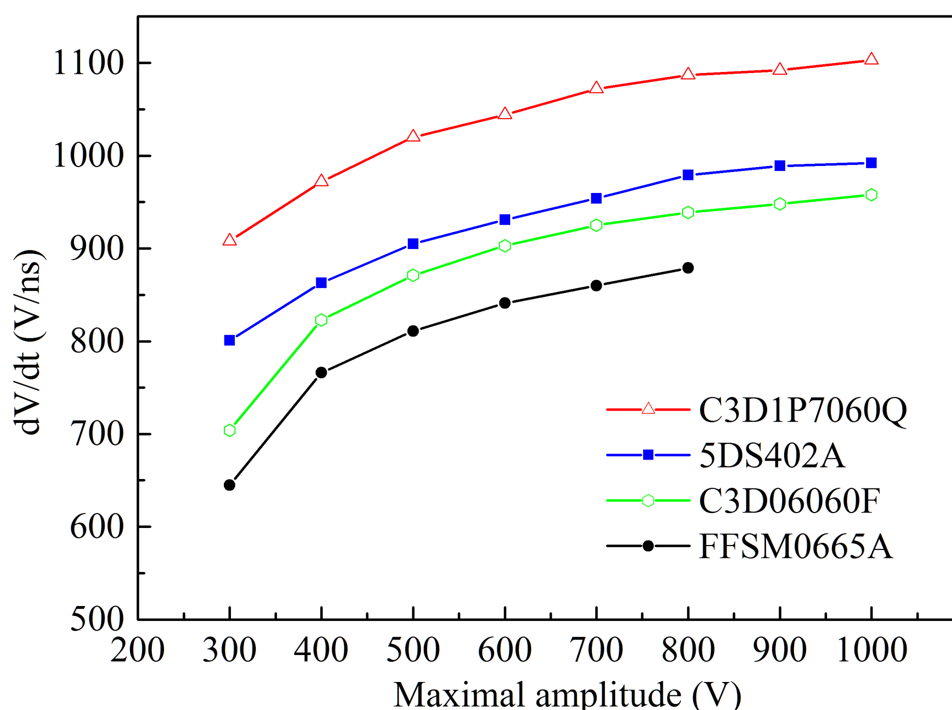

Figure 3. *dV/dt* dependence on maximal amplitude of impulse of reverse voltage applied across the 4H-SiC type Schottky diodes with different package types: C3D06060F (TO-220-F2, Cree), 5DS402A (SOT-89, «GRUPPA KREMNY EL»), C3D1P7060Q (QFN 3.3, Cree), FFSM0665A (PQFN, ON Semiconductor).

In comparison, study of the Infineon SiC diodes it is shown that *dV/dt* value equals 90-120 V/ns, for C3D03060A type Wolfspeed diode value of *dV/dt*=295 V/ns and for C4D10120A diode *dV/dt*=495 V/ns [10-12]. Because of this, recently it is shown that the silicon carbide Schottky diodes of new generation of the Wolfspeed firm can stably work without failures under high values of *dV/dt* up to 400 V/ns and at increase of *dV/dt* up to 650-800 V/ns [13,14].

At the same time for SiC type of Schottky diodes the typical *dV/dt* values are ~200 V/ns [10,15].

Thus, obtained *dV/dt* values (704-1103 V/ns) for 4H-SiC commercial diode demonstrate that more then typical for these type devices and therefore can stably work without failures in electric circuits.

4. Conclusions

It is established that for all packages type (SOT-89, QFN, PQFN, TO-220) obtained *dV/dt* values varying from 645 up to 1103 V/ns. As results *dV/dt* values for all type of 4H-SiC Schottky commercial diodes are more then typical for these type devices (~200 V/ns) and therefore can stably work without failures in electric circuits.

For the first time, it is found that the *dV/dt* dependence on maximal amplitude of reverse voltage demonstrate nonlinear character (close to parabolic dependence) for SiC Schottky diodes.

In addition, the obtained results indicated that the package's size miniaturization not lead to *dV/dt* characteristics degradation and *dV/dt* values for small-sized metal-polymeric packages type (SOT-89, QFN) not only are comparable with large-sized TO-220 package type, but in case of QFN package type the *dV/dt* results are greater than in case of the large-sized (TO-220, PQFN) package.

Acknowledgements

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