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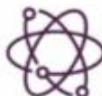


**Determination of dV/dt and dI/dt characteristics for high voltage 4H-SiC
Schottky diodes with different types of metal-polymeric packages**

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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, possess the maximal values of breakdown voltage and minimal leakage currents [*Baliga B J 2019 Wide Bandgap Semiconductor Power Devices: Materials, Physics, Design, and Applications (Cambridge: Woodhead Publishing–Elsevier)*]. 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 [*Barbieri T 2015 Assessing next-generation discretes: Measuring SiC Schottky diode ruggedness with a high voltage pulse generator Power Systems Design Wolfspeed, A Cree Company*].

Thus, in our previous papers were studied 4H-SiC Schottky type diodes in respect effect of their structure on electric properties [*Knyagin D A, Rybalka S B, Drakin A Yu and Demidov A A 2019 J. Phys.: Conf. Ser. 914140 012196*] and stability to rate of reverse voltage rise dV/dt [*Sedykh S V, Rybalka S B, Drakin A Yu, Demidov A A and Kulchenkov E A 2019 J. Phys.: Conf. Ser. 1410 012195*]. 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 $dV/dt \approx 150\div 200$ V/ns [*Rybalka S B, Demidov A A, Kulchenkov E A and Drakin A Yu 2018 Belgorod State University Scientific Bulletin: Mathematics & Physics. 50(4) 460*].

On the other hand, it is known that the diode package is one of the main elements that determines the characteristics of the diode [*Lu D, Wong C P 2017 Materials for advanced packaging (Cham: Springer International Publishing)*]. 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 [*Kimoto T, Cooper J A 2014 Fundamentals of Silicon Carbide Technology. Growth, Characterization, Devices, and Applications (New York: Wiley–IEEE Press)*].

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 .

Materials and methods

The method of measuring of dV/dt value is implemented by the experimental tester which scheme is presented below in Fig. 1 [Sedykh S V, Rybalka S B, Drakin A Yu, Demidov A A and Kulchenkov E A 2019 J. Phys.: Conf. Ser. 1410 012195].

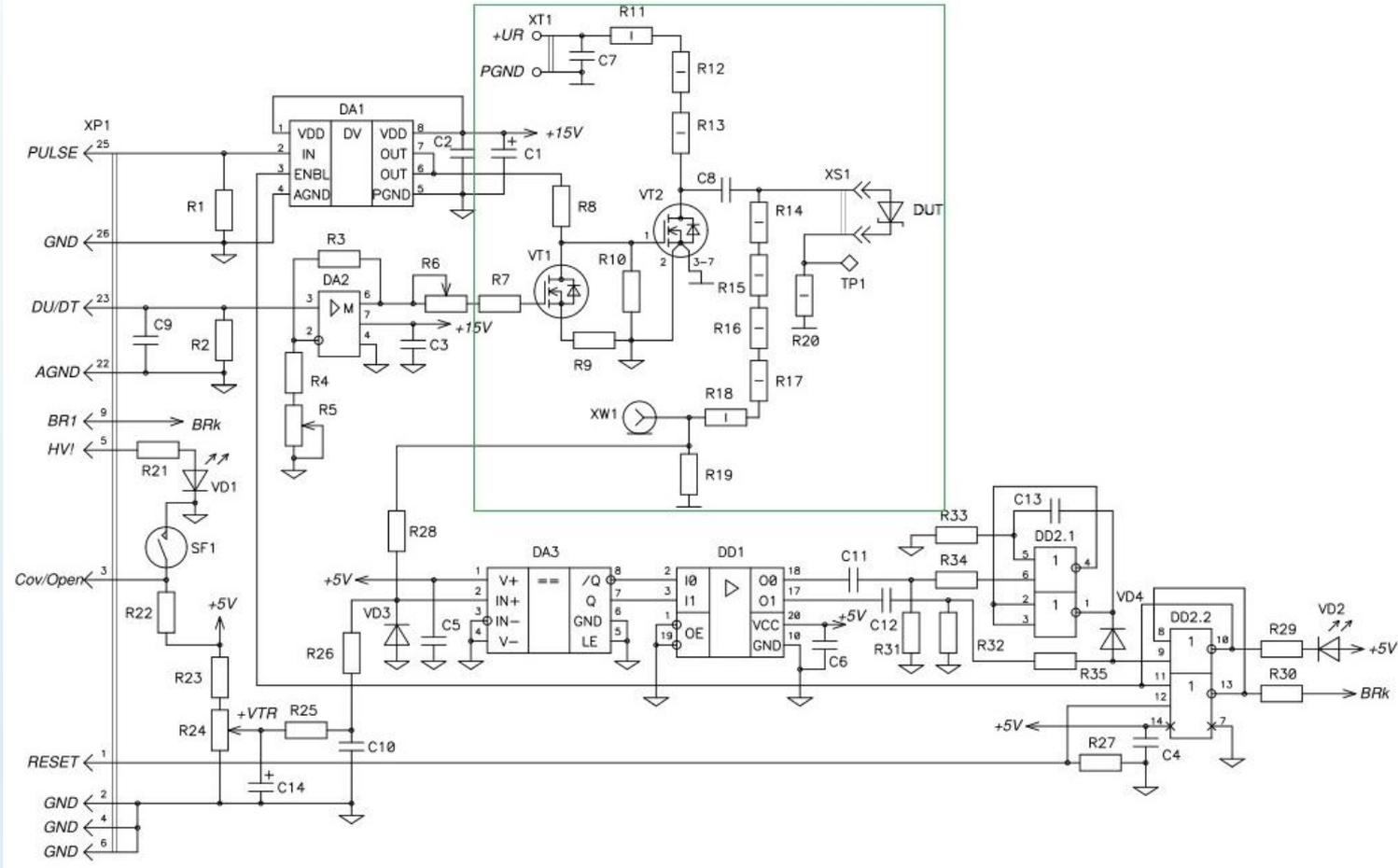


Figure 1. The principal electric scheme of output stage module of the measuring tester for determination of dV/dt and dI/dt values across a testing silicon carbide Schottky diode.

Results and discussions

The testing results for 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 (CREE/Wolfspeed, US) in large-sized TO package type (TO-220-F2); diode C3D1P7060Q (CREE/Wolfspeed, US) in small-sized QFN package type (QFN-3.3) and diode FFSM0665 (ON Semiconductor, US) in large-sized QFN package type (PQFN/ Power QFN) are presented below in [Figure 2](#) and [Table 1](#).

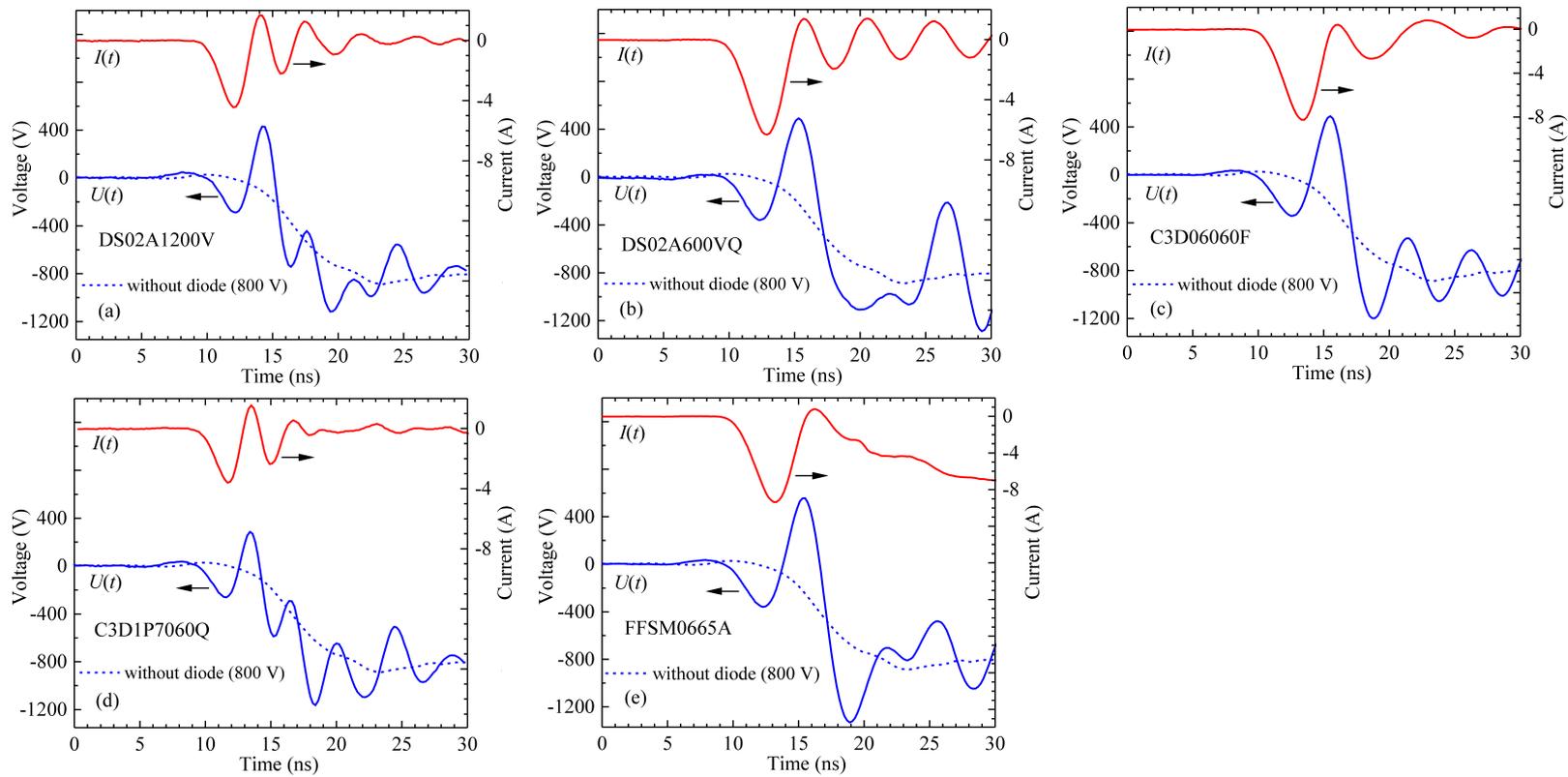
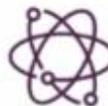


Figure 2. The reverse voltage and current waveform with maximal pulse amplitude 800 V for 4H-SiC type Schottky diodes with different package types: (a) DS02A1200V (SOT-89, «GRUPPA KREMNY EL»); (b) DS02A600VQ (QFN-8, «GRUPPA KREMNY EL»); (c) C3D06060F (TO-220-F2, Cree); (d) C3D1P7060Q (QFN 3.3, Cree);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

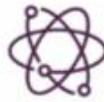


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Table 1. dV/dt and dI/dt results for testing of 4H-SiC Schottky diodes with different packages type (at constant impulse of reverse voltage applied across the diodes of 800 V).

Package type	TO-220-F2	SOT-89	QFN-8	QFN 3.3	PQFN
Diode's type	C3D06060F	DS02A1200V	DS02A600VQ	C3D1P7060Q	FF5M0665A
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



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 μ A). 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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