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Static and Transient Performance Comparisons between Diamond p+/p- Diode and m-i-p+ (Metal-Intrinsic-p+) Diode

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Abstract

This paper presents the static and transient performance comparisons of 2 types of experimental diamond Schottky diodes, i.e. p+/p- and m-i-p+ diodes. Analysis based on numerical simulations and experiment data shows that although diamond m-i-p+ diode has high conduction loss, it has very small peak reverse current during turn-off transient.

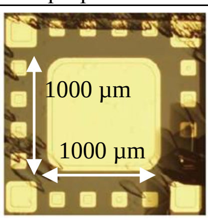
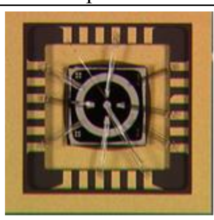
1. Introduction

Diamond is very attractive for high voltage, high power, high frequency, and high temperature power electronic devices due to its superior properties: high maximum electric field (10 MV/cm), high carrier mobility (1600 $cm^2.V^{-1}.s^{-1}$ at RT for hole), and high thermal conductivity (20 W/cm.K). However, due to the vastly different properties of diamond compared to silicon, design of diamond power devices requires different approaches from that for conventional silicon based devices. One of such approaches is the diamond m-i-p+ diode that employs intrinsic drift layer (which has high carrier mobility and high reverse voltage blocking capability), instead of lowly doped layer in the p+/p- diode [1]. In this study, we investigated and compared performances of unipolar diamond p+/p- and m-i-p+ diode with vertical structure by means of experimental data and TCAD numerical simulations. Analysis of diodes' switching characteristics using the double pulse test circuit is presented.

2. Devices under Investigations

The p+/p- and m-i-p+ diodes under investigations were fabricated by Microwave Plasma Chemical Vapour Deposition (MPCVD) method with Schottky contact on Oxygen terminated diamond surface (yielding electron affinity ~1.3 eV) as specified in Table I [1, 2].

Table I: Specifications of the Investigated Diamond Diodes

	p+/p- diode	m-i-p+ diode
Top View		
Drift layer	12 µm thick, Boron doping of 10^{16} cm^{-3}	10 µm thick, ideally intrinsic
p+ layer	Boron doping of~ $3x10^{20}$ cm^{-3}	Boron doping of~ $2x10^{19}$ cm^{-3}
Ohmic contact	Ti (30 nm)/Pt (30 nm)/Au (100 nm)	Ti/Al
Schottky contact	Mo (30 nm)/Au (200 nm)	Al or Au

Modelling and simulations of the diodes were carried out in two-dimensional physics-based TCAD Sentaurus Device software. Various physics-based models and parameters were implemented, such as doping concentration-dependent and temperature-dependent mobility model and incomplete ionization model for Boron acceptor [3].

3. Results and Discussions

Static Characteristics

Fig. 1 (a) and (b) compare the static forward *I-V* characteristics of the investigated diodes. In contrast with p+/p- diode, the diamond m-i-p+ diode shows low current density and positive temperature coefficient of resistance (on-resistance increases with increasing temperature) due to the nature of its intrinsic drift region. When temperature increases, the mobility drops while there is no addition to the number of carriers. Good matching of simulations and experimental results verifies the applied models and parameters. The forward voltage-drop of diamond p+/p- and m-i-p+ diode with active area of 0.0097 cm^2 at 0.5 A forward current is 3 V and 8.5 V respectively.

Transient Characteristics

The turn-off characteristics of the diodes were investigated by using double pulse test method with schematics shown in Fig. 2. Analysis by transient simulations was conducted in TCAD Sentaurus Device software in mixed-mode environment to include single-device simulator (for the diode) and circuit simulator. SPICE model of power NMOS [4] and circuit parasitic components were incorporated to increase accuracy.

Fig. 3 (a) shows the simulations results in comparison with measurements data [2] for diamond p+/p- diode with 0.5 A forward current, 100 V reverse voltage, and *di/dt*~ 30 A/µs at 298 K. Good correlation is achieved by adjusting the circuit parameters like LPar and RG (refer to Fig. 2).

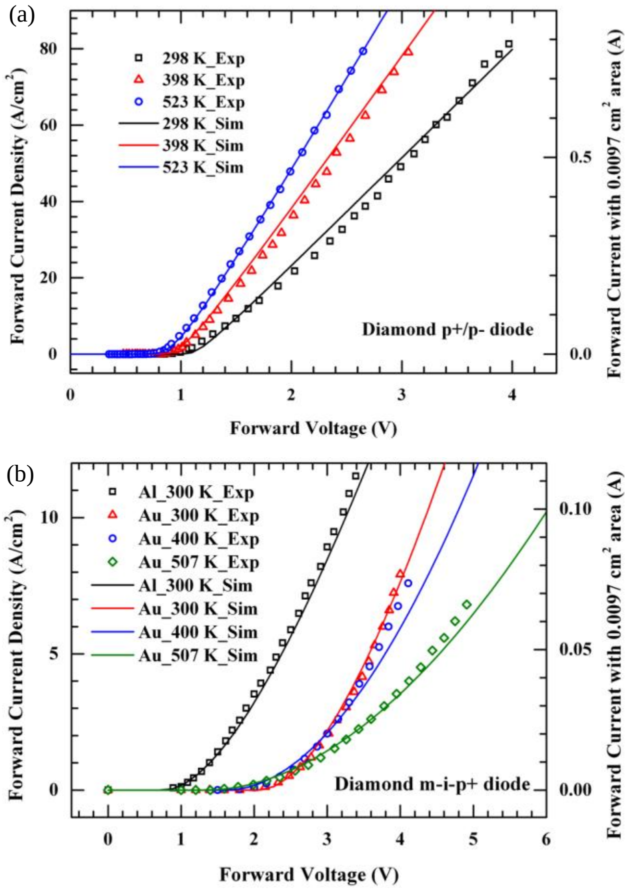


Fig. 1: Experimental data [1, 2] and simulation results of static forward *I-V* characteristics of the investigated diamond p+/p- diode (a) and m-i-p+ diode (b) at different temperatures.

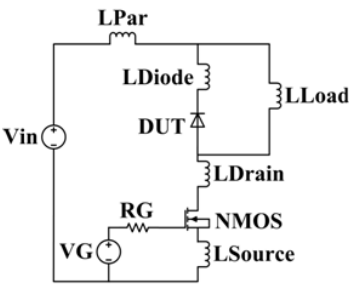


Fig. 2: Double-pulse test circuit with power NMOS switch and circuit parasitic components.

While there are few measurements on the transient characteristics of diamond p+/p- diode reported in the literature [2], there is none for diamond m-i-p+ diode up to this date. In this study, the transient characteristics of diamond m-i-p+ diode are evaluated by means of TCAD simulations in double pulse test circuit. The results are shown in Fig. 3 (b) under similar test conditions and circuit parameters as those for p+/p- simulations. Very small peak reverse current is observed due to the low holes concentration in the intrinsic drift region. Thus, although diamond m-i-p+ diode shows high on-state losses, it has very low switching losses which makes it more suitable for high switching frequency applications.

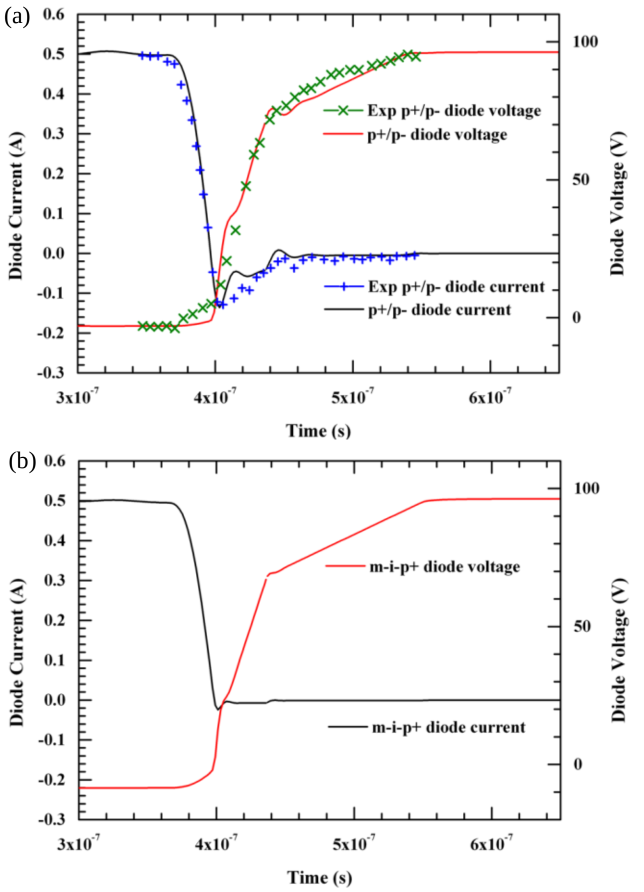


Fig. 3: Turn-off transient characteristics of the investigated diamond diodes: (a) p+/p- diode and (b) m-i-p+ diode at RT with 0.5 A forward current, 100 V reverse voltage, and *di/dt*= 30 A/µs.

4. Conclusions

This paper presents the comparisons of static and turn-off transient characteristics of experimental diamond p+/p- and m-i-p+ diodes. Experiments data and detailed analysis using TCAD numerical simulations show that although diamond m-i-p+ diode has high on-resistance, it has very low switching loss. The study also reveals different temperature coefficient of resistance for both diamond diodes. Therefore, the doping concentration in the drift region of diamond Schottky diode should be designed and optimized based on the intended applications for minimal losses. Furthermore, this study shows that combination of accurate numerical simulations and experimental results can provides cheap and fast way to assess the performances of different diamond diode designs.

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