ANALYTICAL MODEL FOR CAPACITANCE-VOLTAGE CHARACTERISTICS OF ION-IMPLANTED 4H SILICON CARBIDE SCHOTTKY BARRIER DIODES

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In order to undertake theory analysis in the application area of switching, frequency and power devices, an analytical model for capacitance-voltage (C-V) characteristics of ion-implanted 4H silicon carbide (SiC) Schottky barrier diodes (SBDs) was investigated. This model was established by considering the effects of incomplete ionization of nitrogen in 4H-SiC, the Poole-Frenkel on the ionization energy, and the ion-implanted nitrogen donor profiles. An agreement between the modeled C-V curves and the measured results for two ion-implanted 4H-SiC SBDs fabricated was shown.

The structure of ion-implanted 4H-SiC SBDs was shown in Fig. 1, in which the channel region N-well was fabricated by multiple nitrogen ion-implantations. N-wells of two samples were formed by three and four fold multiple nitrogen ion-implantations, while N^+ regions for ohmic contacts were formed by a high-dose nitrogen ion-implantation. High-dose nitrogen ion-implantation in ohmic contact region was at energy and dose of 30 keV 3.54×10^{14}cm^{-2}. Ohmic contact metals were Ni/Cr alloy, Schottky contact metals were Ti/Pt with the metal Ti as first layer, and metal Au were pads outside.

Fig. 2 gave the output current-voltage (I-V) characteristics of two samples (sample A for three fold and sample B for four fold) ion-implanted 4H-SiC MESFETs with the pinch-off voltage -0.3 and -9.0V respectively. From the output power, the characteristics of Sample B were better than that of Sample A.

The lowering of the ionization energies for the donor nitrogen from the enhancement of the carrier emission rate by the electric field was called the Poole-Frenkel effect [1] as shown in Fig.3. The change for the donor ionization energy by the Poole-Frenkel effect can be

$$\Delta E_D = q\sqrt{\frac{qE}{\pi\varepsilon_s}} \qquad (1).$$

The capacitance of SBDs was

$$C = \frac{\varepsilon_s}{W} \qquad (2).$$

W is the depletion layer thickness of the SBDs (μ m), The voltage applied of SBDs was [2]

$$\begin{aligned} V = \frac{\Delta E_F}{q} - \psi(0)\Big|_{h=a} &= \sum_{i=1}^{n}\{\frac{q\beta Q_i R_{pi}}{2\varepsilon_s}[erf(\frac{h_0 - R_{pi}}{\sqrt{2}\sigma_i}) - erf(\frac{a - R_{pi}}{\sqrt{2}\sigma_i})] \\ &+ \frac{q\beta Q_i \sigma_i}{\sqrt{2\pi}\,\varepsilon_s}\exp[-(\frac{a - R_{pi}}{\sqrt{2}\sigma_i})^2] - \exp[-(\frac{h_0 - R_{pi}}{\sqrt{2}\sigma_i})^2]\} + \frac{qN_A}{2\varepsilon_s}(a^2 - h_0^2) \end{aligned} \qquad (3)$$

where the location of peak concentration R_p (R_{pi}) and the longitudinal straggling σ (σ_i) of implanted ions can be calculated with the Monte Carlo simulator TRIM.

C-V simulation lines of ion-implanted 4H-SiC SBDs fabricated by three and four fold multiple ion-implantations in the experiment were shown in Fig. 4(a) and Fig. 4(b) respectively. The activation rates of implanted ions for simulation calculation are 0.02, 0.04, 0.06, and 0.08. The measurements of small signal alternating current capacitances at 1MHz for three and four fold ion-implanted 4H-SiC SBDs were carried out and were also given in Fig. 4(a) and Fig. 4(b). The experiment lines of the SBDs are close to the simulation results with the activation rates of 0.02 and 0.04 for three and four fold ion-implantation lines respectively.

Minimum capacitances exist for all activation rates when the depletion layer thickness was equal to the channel depth. The capacitances for all activation rates almost come from a same point, at which the depletion layer thickness was nearly zero when the voltage was forward applied. This capacitance model has the potential to be used to simulate and design ion-implanted SiC devices concerned in the future.

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References

[1] L. Pelaz, J. L. Orantes, and J. Vincente, " The Poole-Frenkel effect in 6H-SiC diode characteristics," *IEEE Trans. Electron. Dev.*, vol.41, no.4, pp.587-591, April 1994.

[2] S. G. Wang, and Z. Y. Zhang, "Analytical Model for ion-implanted 4H Silicon Carbide Metal-Semiconductor Field-Effect Transistors," International Semiconductor Device Research Symposium (ISDRS), December 7-9, 2011.

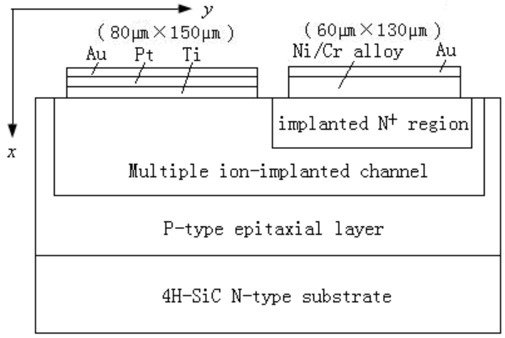

Fig. 1 Schematic cross section of ion-implanted 4H-SiC SBDs and the direction for theory analysis.

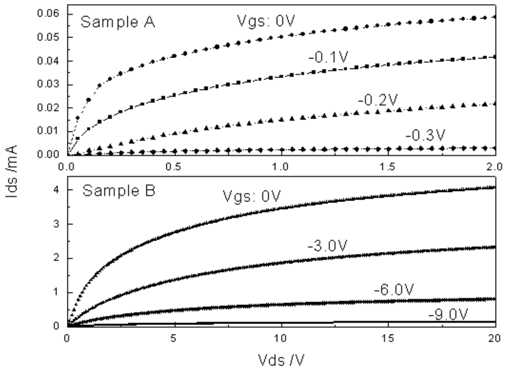

Fig. 2 Output current-voltage characteristics of two Samples ion-implanted 4H-SiC MESFETs.

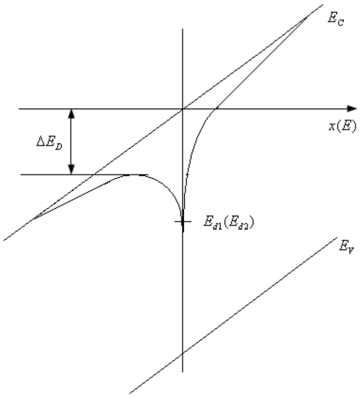

Fig. 3 Changes for the donor ionization energy and energy band by the effect of the electric field.

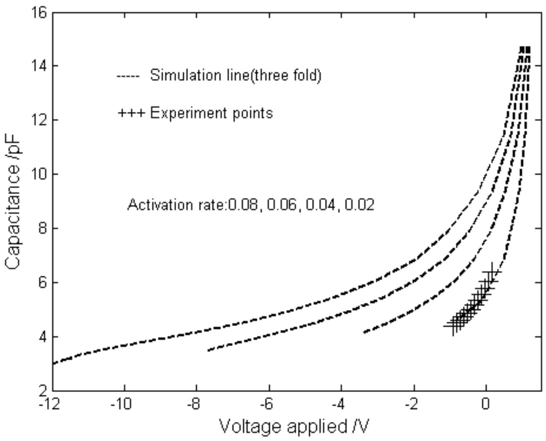

Fig. 4(a) Simulation line and experiment results of the C-V characteristics for three fold multiple ion-implanted SBDs.

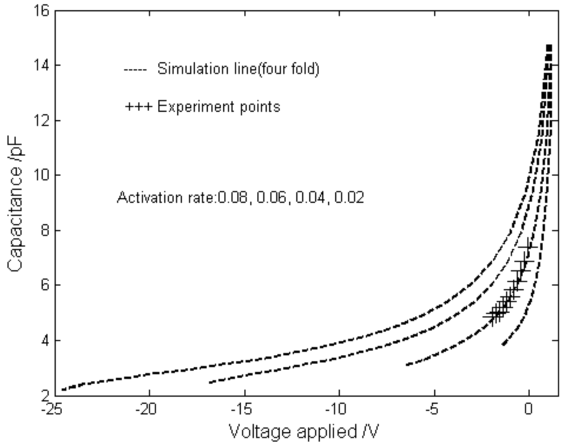

Fig. 4(b) Simulation line and experiment results of the C-V characteristics for four fold multiple ion-implanted SBDs.