Population estimation of characteristic variation and its application to circuit simulation for power transistors

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Background

From the perspective of design quality assurance, it is crucial to estimate the impact of variations in electronic device characteristics on circuit operation as early as possible in the device development process. For such estimations, it is effective to use models built with machine learning. However, it requires a large amount of data, and only limited data are available while developing. Traditional statistical estimation can be used under the strong constraint of assuming a normally distributed population, but it is not always clear whether the data collected during the development phase follow a normally distributed population or not . Therefore, alternative methods must be considered [1].

Summary

Herein, we propose a highly accurate method for estimating population distribution using Bayes' theorem. SiC MOSFETs (metal-oxide-semiconductor field-effect transistors) were chosen as the research subject. The drain current (I_d) and drain-source voltage (V_{ds}) were measured at various gate-source voltages (V_{gs}) for 300 SiC MOSFETs [2]. This data set is regarded as the population, S_m, in this research.

We randomly sampled from S_m and estimated the population, S_e, by using the machine-learning model detailed in the next section. I_d–V_{ds} data were virtually generated according to S_e and S_e reflects well the measurement results. Then we derived the two sets of the circuit model parameters of the transistors in the way described in the next section. Finally, the circuit simulation results were compared to show the superiority of our proposed method.

Technique

Our proposed strategy is to use the gamma generalized linear model (Gamma GLM) [3], which is a generalized linear model using the Bayes' theorem. This was applied to estimate the population by using 30 randomly selected samples of I_d–V_{ds} data among the 300 SiC MOSFETs as shown in Figure 1. This estimated population is S_e.

The I_d–V_{ds} data were randomly generated so that they followed S_e, and the circuit model parameters that reproduced these generated properties were extracted by simulated annealing [4] using the model equation [5] for I_d. The procedure was repeated to produce 300 circuit model parameters.

Circuit simulations were performed using the double-pulse circuit shown in Figure 2 for all combinations of two samples out of 300, and the switching waveforms were obtained. Each of the combinations was connected in parallel in the test circuit. The circuit simulator SIMetrix (Version: 9.10d(x64), Maker: SIMetrix Technologies Ltd.) was used.

For comparison, the other 300 circuit model parameters were also randomly generated so that they followed the population S_n created under the assumption that each of the circuit model parameters derived from S_m independently follows a normal distribution. Then the switching waveforms were simulated in the same manner as mentioned above.

Result

Figure 3 shows the 30 I_d–V_{ds} data picked up from S_m denoted by blue dots, and the range representing S_e denoted by the pale red shade area. As clearly shown, S_e follows the sampled data very well.

Figure 4 shows the results of the circuit simulations based on S_m, S_e, and S_n to display the largest difference in I_d. We compared the difference in peak I_d as the index to judge which model is good, because the peak I_d symbolizes the current imbalance between devices and is one of the most important factors causing thermal breakdown. The maximum difference in the peak I_d's based on S_m is 2.80A, while it is 3.22 A for S_e and 7.62 A for S_n, respectively. S_e-based prediction provides the better prediction of peak I_d than S_n-based one. This clearly shows the effectiveness of our proposed method based on Gamma GLM.

References

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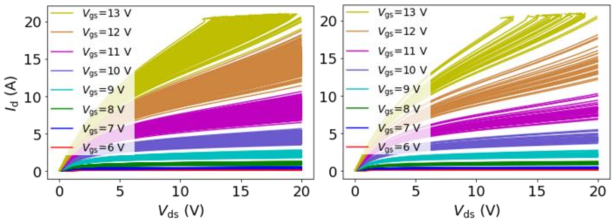
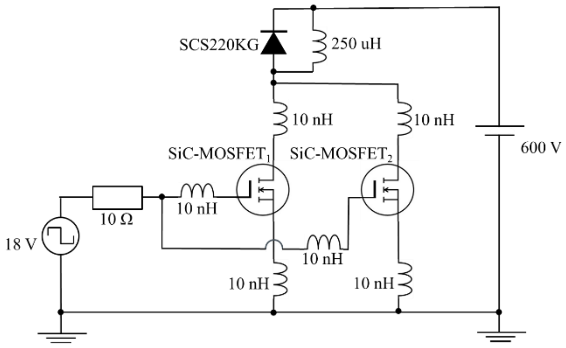


300 SiC-MOSFETs assumed as population.
(a)

30 SiC-MOSFETs used for estimation.
(b)

Figure 1: (a) Measured I_d–V_{ds} characteristic data of 300 SiC-MOSFETs (S_m) and (b) the 30 sampled I_d–V_{ds} data used for obtaining S_e.



Parallel circuit diagram.

Figure 2： Double-pulse circuit with two parallel-connected SiC-MOSFETs as the switch section.

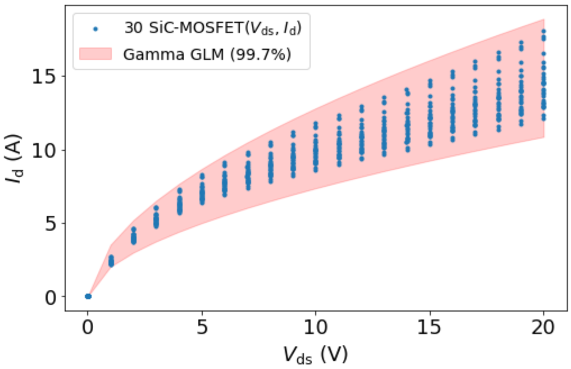
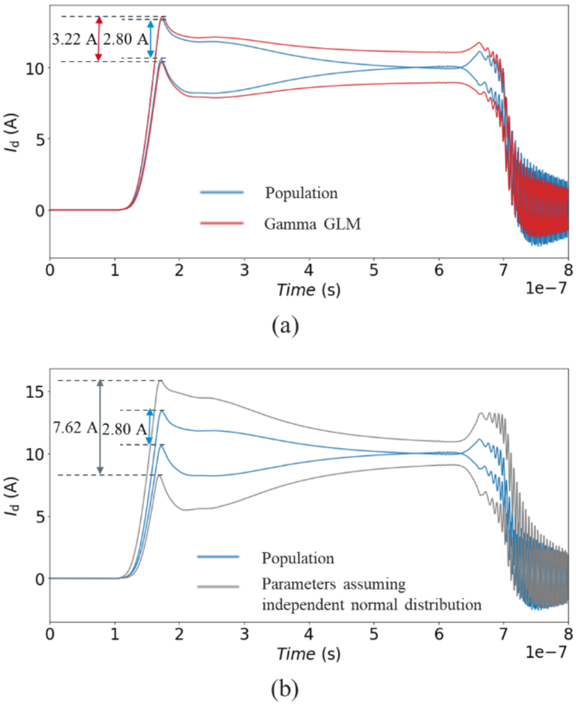


Figure 3: The blue dots represent the I_d–V_{ds} data at V_{gs}=12 V (the orange lines in Figure 1). The pale red shade area indicates the range of estimated population S_e by gamma GLM.



(a)

(b)

Parallel circuit simulation results.

Figure 4: The simulated switching waveforms of I_d are drawn with the maximum and minimum peak I_d. The blue line indicates the results simulated based on S_m. (a) The red lines indicate the result based on S_e, while (b) the gray lines based on S_n.