Light Emitting Diode

The SPICE Model of LEDs

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SP-QR-C2-210932-2
May 13, 2022

1. Overview

Electronic devices have been becoming more and more multifunctional than ever before. As a result, the devices need to incorporate more capable and complicated circuits. Circuit simulations are an effective tool to reduce the time and cost to develop the products using these circuits; the importance of circuit simulations has been increasing for electronic device manufacturers. To meet the increasing need and requirements for circuit simulations, Nichia offers simulation models for its LEDs that can be used for SPICE simulations. SPICE is an electronic circuit simulator.
This application note provides information and precautions for use of the SPICE models Nichia offers.

2. SPICE

SPICE stands for "Simulation Program with Integrated Circuit Emphasis". This is a circuit simulator to simulate the electrical behavior of a circuit on a computer. With SPICE, electrical behavior including a basic DC analysis, AC (transient) analysis, and noise analysis can be simulated by creating a circuit model through a text command or a Graphical User Interface (GUI).
SPICE was originally developed at the University of California Berkeley (UCB). Since a free source code for SPICE is available, many companies in the IT and electronics industries develop and sell their own modified SPICE simulators. This makes SPICE the most commonly used circuit simulator among all those currently available.

3. Nichia's SPICE Models

3.1 Characteristics that can be Simulated using Nichia's SPICE Models

Nichia offers simulation models for its LEDs in a diode-model format. Figure 1 shows an example of a SPICE model Nichia offers. Among the characteristics of the LED that are provided in the FORWARD CURRENT CHARACTERISTICS/TEMPERATURE CHARACTERISTICS section in the specification, the behavior of the following two characteristics can be reproduced with a simulation that is performed using Nichia's SPICE models:

1. Forward Characteristics: Forward Voltage vs. Forward Current at the junction temperature of 25°C (see Figure 2 on the following page)
2. Temperature Characteristics: Junction temperature vs. Forward Voltage at the sorting current of the LED (see Figure 3 on the following page)

Simulations using Nichia's SPICE models do not cover other characteristics including capacitance characteristics, reverse characteristics, AC (transient) characteristics, etc.

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*All Rights Reserved Copyright (c) Nichia Corporation 2020
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.model xxxxxxxx D
+ IS=2.5939E-13
+ N=4.0113
+ RS=0.24229
+ IKF=0
+ EG=3
+ XTI=25
*$
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Figure 1. Example of a SPICE Model Nichia Offers

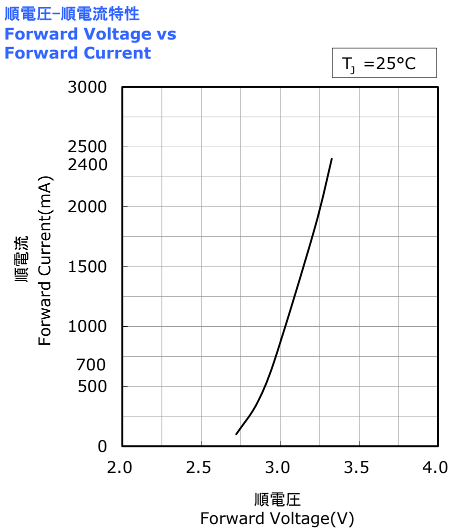

Figure 2. Example of Forward Characteristics[1]

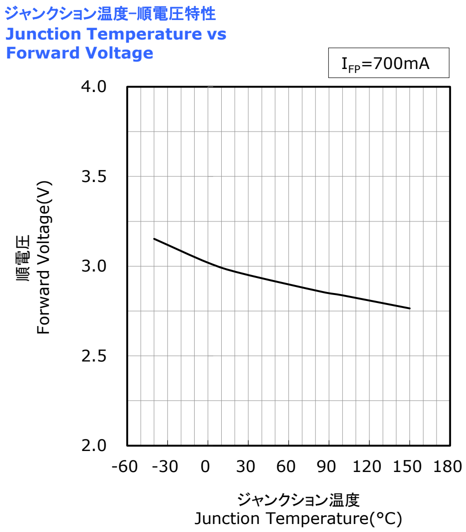

Figure 3. Example of Temperature Characteristics[1]

3.2 Verification of Nichia's SPICE Models

Nichia uses OrCAD PSPICE[2] to verify that Nichia's SPICE models are correctly implemented for the simulator. The same parameter values of the model may be used for another simulator if it is a modified version of UCB SPICE; note that the simulation results may be different depending on the simulation conditions.

The reproducibility of the characteristics verified at Nichia is only for Forward Voltage vs. Forward Current and Junction temperature vs. Forward Voltage.

[1] Excerpt from the specification for the Nichia NVSW219F LED as an example.

[2] OrCAD and PSPICE are trademarks of Cadence Design Systems, Inc. Nichia's verification is performed using OrCAD Ver. 9 or higher.

4. Parameters of a SPICE Model

Table 1 provides a list of parameters that are used for a typical diode model for a SPICE simulation. Six of these parameters (i.e. IS, N, RS, IKF, EG, and XTI) are supported by Nichia's SPICE models; with these six parameters, the forward (DC) and temperature characteristics are reproduced. The other parameters are not supported; note that they are not provided in the model file Nichia offers.
This section provides the information of the parameters and how to determine the values.

Table 1. Parameters Used for a Typical Diode Model

Characteristics	Parameter Name	Parameter	Supported by Nichia's Model
Forward (DC)	IS	Saturation Current	Supported
	N	Emission Coefficient	Supported
	RS	Parasitic Resistance (Series Resistance)	Supported
	IKF	High-injection Knee Current	Supported
Temperature	EG	Energy Gap	Supported
	XTI	"IS" Temperature Exponent	Supported
Capacitance	CJO	Zero-bias Junction Capacitance	Unsupported
	M	Junction Grading Coefficient	Unsupported
	VJ	Junction Potential	Unsupported
Reverse (DC)	ISR	Recombination Current	Unsupported
	NR	Emission Coefficient for ISR	Unsupported
	BV	Reverse Breakdown Voltage	Unsupported
	IBV	Reverse Breakdown Current	Unsupported
Reverse (AC)	TT	Transit Time	Unsupported

4.1 Parameters for the Forward (DC) Characteristics

The IS, N, RS, and IKF parameters are used to reproduce the forward characteristics of voltage vs. current. These parameters express electrical characteristics of typical diodes. For Nichia's SPICE models, Nichia determines the values of the parameters with an emphasis on how well the forward characteristics can be reproduced.

4.1.1 IS: Saturation Current

The IS is the saturation current that flows in the reverse direction (i.e. negative voltage). In a simulation with a typical diode model, the larger the IS is, the larger the current flowing in the reverse direction will be (see Figure 4). This affects the forward voltage rise (i.e. the voltage at which the current starts to flow); the larger the IS is, the lower the voltage rise will be. The same behavior is seen in the operating range of an LED (See Figure 5); the forward voltage rise is reproduced with parameter IS in a simulation.

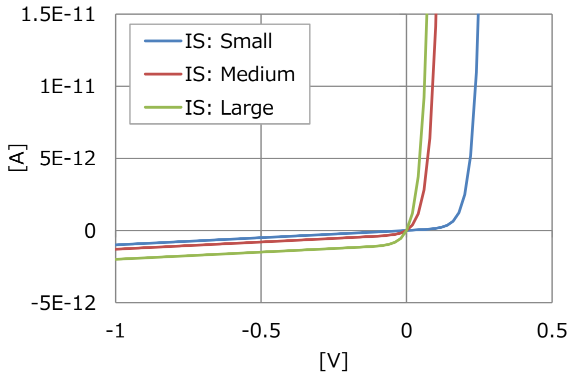

Figure 4. Examples of the Characteristics of a diode

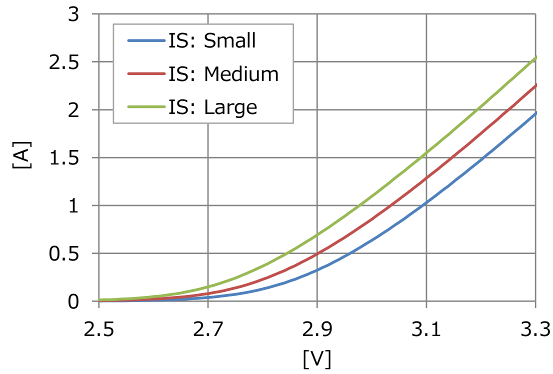

Figure 5. Examples of the Characteristics of an LED

4.1.2 N: Emission Coefficient

The N represents how many injected carriers recombine. For a SPICE model for a typical diode, the value of parameter N is between 1 and 2. If the value is close to 1, that means the amount of recombination is small; the closer the N is to 1, the more ideal the diode is, regarding the electrical characteristics. Figure 6 shows that the larger the N is, the larger the forward voltage will be. This behavior is also seen for LEDs; the value of parameter N affects the forward voltage (see Figure 7). Since the forward voltage of an LED is higher than that of a typical diode, the value of the N may be larger than 2 for an LED model.

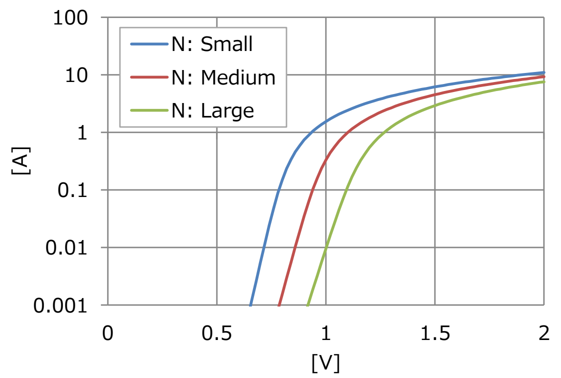

Figure 6. Examples of the Characteristics of a diode

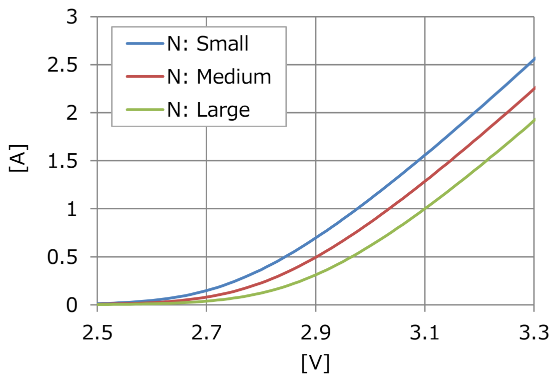

Figure 7. Examples of the Characteristics of an LED

4.1.3 RS: Parasitic Resistance (Series Resistance)

The RS is the resistive component connected to a diode (e.g. LED) in series. For a typical LED, the bonding materials, and other connecting components (e.g. wire) are components that would be considered the resistive component. The larger the RS is, the less current will flow through the LED (See Figures 8 and 9); the slopes in the high current regions change depending on the value of parameter RS.

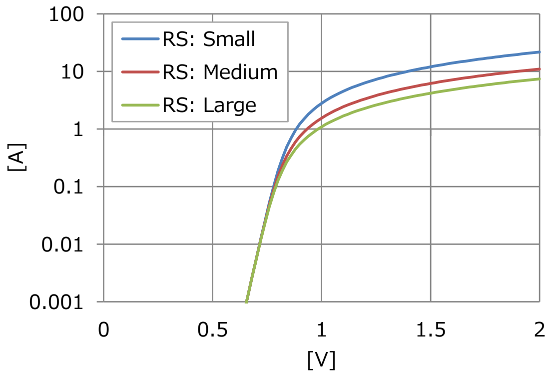

Figure 8. Examples of the Characteristics of a diode

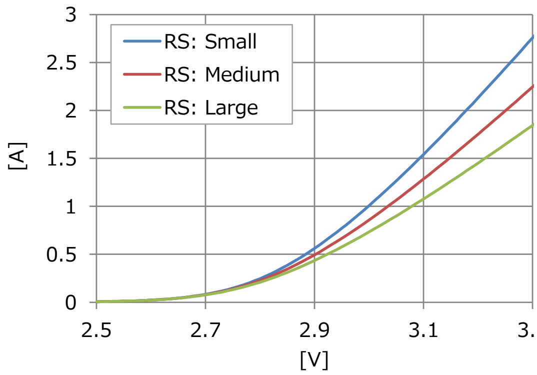

Figure 9. Examples of the Characteristics of an LED

4.1.4 IKF: High-injection Knee Current

The IKF is the knee current when the current flowing into a diode is large. The IKF is used for common SPICE simulators including PSPICE, though it is not included in UCB's diode model. This parameter is used to change the slope of the forward characteristics at a certain point; the larger the IKF is, the higher the current at which the slope changes will be (see Figures 10 and 11).

In the current range that is specified for the actual use of a diode, the characteristics will be close to those at IKF=0 since the slope changes at a higher current as the IKF becomes larger.

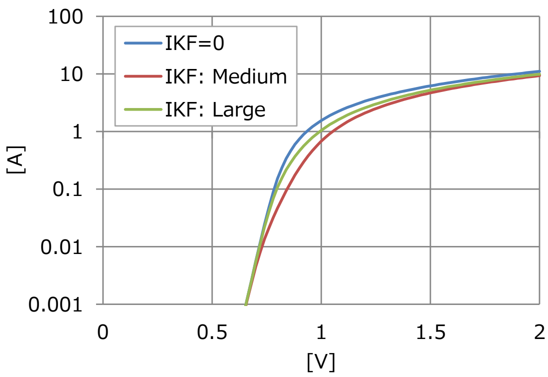

Figure 10. Examples of the Characteristics of a diode

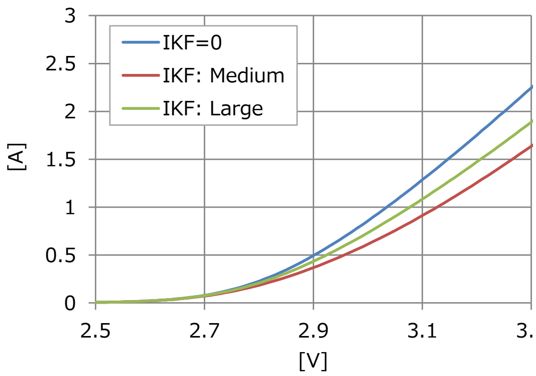

Figure 11. Examples of the Characteristics of an LED

4.2 Parameters for the Temperature Characteristics

The EG and XTI parameters are used to reproduce the temperature characteristics of the junction temperature vs. voltage. Nichia determines the values of the parameters assuming the junction temperature of the LED will be ≥25˚C during operation; there may be a large error in the reproducibility of the characteristics when the junction temperature is much lower than 25˚C.

4.2.1 EG: Energy Gap

The EG parameter is the energy gap in the band structure of a typical semiconductor (i.e. band gap). Each material within a semiconductor has its own value for this parameter (e.g. Si=1.11eV); usually, this value is used for a SPICE simulation. Nichia determines the value of parameter EG with an emphasis on how well the temperature characteristics can be reproduced.

4.2.2 XTI: IS Temperature Exponent

The Parameter XTI is the temperature exponent of parameter IS; the value of the IS is determined in order to reproduce the forward characteristics. The XTI affects how much the IS changes when the junction temperature changes; the larger the XTI is, the smaller the slope of the temperature characteristics will be (i.e. the graph will have a downward slope. See Figure 12). Since Nichia's SPICE models are created using a reference junction temperature of 25˚C, the base point where the slope will change is 25˚C. The base point for voltage differs depending on the values of parameters IS, N, RS, and IKF.

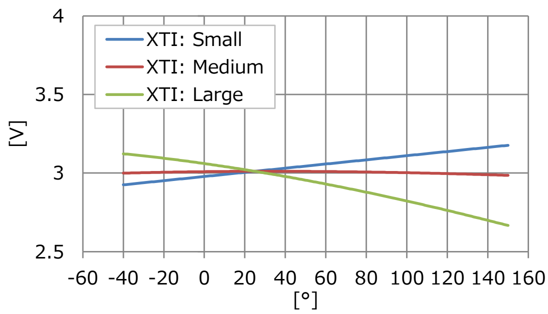

Figure 12. Examples of the Characteristics of an LED

4.3 Parameters for the Capacitance Characteristics

Diodes (e.g. LED) have capacitive components that act as capacitors. Unlike common capacitors, the capacitance value of a capacitive component changes depending on the value of the voltage that is applied to the diode. To reproduce those voltage-capacitance characteristics, parameters CJO, M, and VJ are used.

4.3.1 CJO: Zero-bias Junction Capacitance

The CJO is the value of the junction capacitance at zero-bias (i.e. where voltage is not applied to the diode and there is no current flowing through the diode).

4.3.2 M: Junction Grading Coefficient

The M parameter is the junction grading coefficient. If the impurity concentration in the depletion layer changes abruptly at the p-n junction, the junction is called a step-graded junction; if the change is gradual, the junction is called a linearly-graded junction. The slope of the voltage-capacitance characteristics can be changed by changing the value of parameter M. Usually, the value of the M is determined to be between the step-graded junction (M=1/2) and the linearly-graded junction (M=1/3).

4.3.3 VJ: Junction Potential

The VJ parameter is the junction potential. This is the potential difference in the depletion layer when voltage is not applied to the diode. Usually, the value of parameter VJ is determined depending on the material within a semiconductor.

4.4 Parameters for the Reverse (DC) Characteristics

The ISR, NR, BV, and IBV parameters are used to reproduce the DC characteristics in the reverse direction including the reverse leakage current and breakdown phenomenon (i.e. a phenomenon where the reverse current starts to flow rapidly at a certain voltage when a high voltage is applied in the reverse direction). If a protection device (e.g. Zener diode) is incorporated in an LED, the reverse characteristics of the LED are affected by the forward characteristics of the protection device (see Figure 13); the reverse characteristics of LEDs with a protection device may be greatly different from those of LEDs without a protection device.

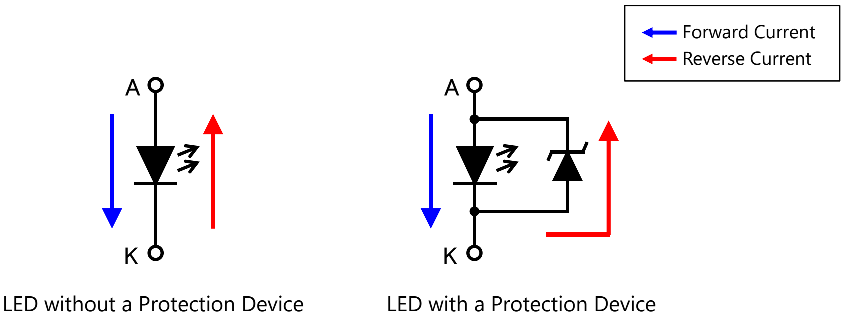

Figure 13. Reverse Characteristics of an LED

4.4.1 ISR: Recombination Current

The ISR is the recombination current. With this parameter, the reverse leak current can be reproduced. The value of parameter ISR needs to be determined at the same time as the value of parameter IS since the forward characteristics are greatly affected by the recombination current when the current is low.

4.4.2 NR: Emission coefficient for ISR

The NR is the coefficient that is used to change the effect of parameter ISR.

4.4.3 BV: Reverse Breakdown Voltage

The BV is the value of the voltage at which the breakdown phenomenon occurs. For LEDs that have an incorporated protection device, the reverse current starts to flow at a lower voltage compared to a typical breakdown phenomenon since the reverse breakdown voltage is dependent on the forward characteristics of the protection device.

4.4.4 IBV: Reverse Breakdown Current

The IBV is the value of the reverse current that flows at the reverse breakdown voltage (i.e. BV).

4.5 Parameters for the Reverse (AC) Characteristics

The parameter TT is used to reproduce the AC (transient) characteristics in the reverse direction. As with the reverse (DC) characteristics, the reverse (AC) characteristics are affected by an incorporated protection device.

4.5.1 TT: Transit Time

The TT is the transient time. When the operating direction is switched from forward to the reverse direction, the accumulated carriers are transferred (diffused) to the reverse direction and the current flows in the reverse direction. The current flow stops when the carrier concentration decreases. See Figure 14. Parameter TT indicates the amount of time from the moment of switching to the reverse direction until the stop of the reverse current flow. The shorter the transient time is, the better the response characteristics of the diode is.

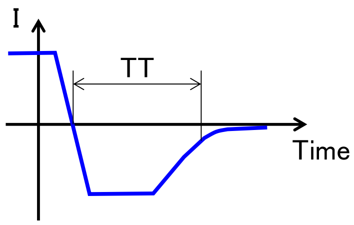

Figure 14. Example Current Waveform of Transit Time

5. Precautions When Using Nichia's LED Models

- The SPICE models Nichia offers are not guaranteed to reproduce the characteristics of the LED when it is used in the chosen application. Also, note that the characteristics may not be reproduced perfectly and there may be errors between the characteristics reproduced and the characteristics seen during actual use. Use the simulation results only as reference; sufficient verification must be done to ensure there are no issues for the chosen application.

- Nichia's models are to reproduce only the forward characteristics (Forward Current vs. Forward Voltage) and temperature characteristics (Junction Temperature vs. Forward Voltage). The other characteristics including capacitance characteristics, reverse characteristics, transient characteristics are not supported.

- The characteristics that are reproduced with Nichia's models are the typical characteristics that are provided in the Initial Electrical/Optical Characteristics section of the specification of the LED; variations of each individual LED, characteristics ranks, etc. are not considered.

- Nichia's models are created assuming the LEDs are used at the junction temperature of ≥25˚C; there may be a large error in the reproducibility of the characteristics when the simulation is performed at a lower junction temperature.

- The junction temperature of an LED depends on the heat dissipation design and/or the operating conditions of the chosen application. Regarding how to measure the junction temperature, refer to the applicable specification and application notes.

- When the simulation is performed at a low current, the reproduced characteristics tend to be greatly different from those during actual use; Nichia recommends performing a simulation at a current that is ≥10% of the sorting current.

- For some parameters, a specific value is given to each material and/or the structure of the diode for a SPICE simulation. Nichia's models are created with an emphasis on how well the characteristics can be reproduced; the parameter values used for Nichia's models may be different from the typical value for each material/structure.

- Nichia has verified that Nichia's SPICE models work properly with the OrCAD PSPICE simulator; Nichia does not perform verifications with other simulators.

- Nichia provides a parameter file only; a symbol file for a circuit diagram is not included. Create a symbol file for the LED that is suitable for the simulator being used.

- Nichia provides the parameter files in text format (.txt). Convert them to a file format that is accepted by the simulator being used or feed the simulator with another diode model and then overwrite the data with Nichia's parameters if necessary.

- In the parameter file Nichia offers (see Figure 1), the lines starting with an asterisk (*) are for information Nichia uses to control the file; these lines are not used for the simulations.

6. Summary

Nichia's SPICE models may not perfectly reproduce the characteristics of the LED and may include errors. In addition, there may be variations for each individual LED and/or the measurement repeatability /reproducibility and if these errors and variations affect the simulation, it may lead to a large difference between the characteristics measured in the chosen application and the characteristics reproduced during the simulation. Use the simulation results only as reference; perform a verification with the chosen application to ensure that the designed performance is achieved.

Light Emitting Diode

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