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The Carriers-Redistribution Phenomenon on Short-Circuit Oscillations of IGBTs

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Introduction

In this paper, the high-frequency short-circuit oscillations of IGBT are investigated. The short-circuit phenomenons of the 1.7-kV IGBT are simulated by TCAD. It is found that the carriers-redistribution (CR) phenomenon occurs in some areas of the device during the short-circuit phase. The CR phenomenon will cause the local electric field and the local capacitance to mutate, resulting in the RLC resonance condition being satisfied, and further lead to the high-frequency short-circut oscillations of the device during the short-circuit phase.

Device Structure and Oscillation Waveforms

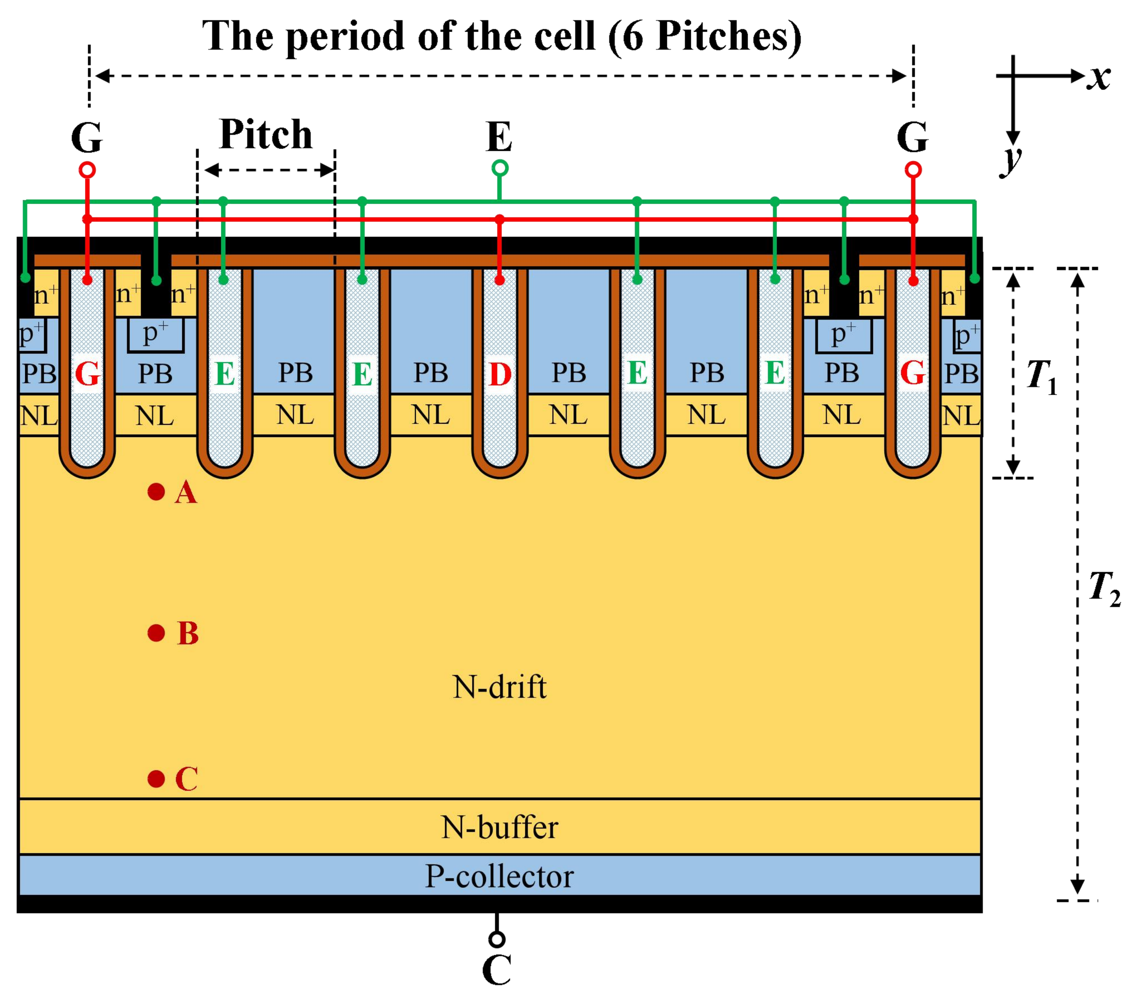

Fig. 1. Schematic diagram of 1.7-kV IGBT for the short-circuit simulations.

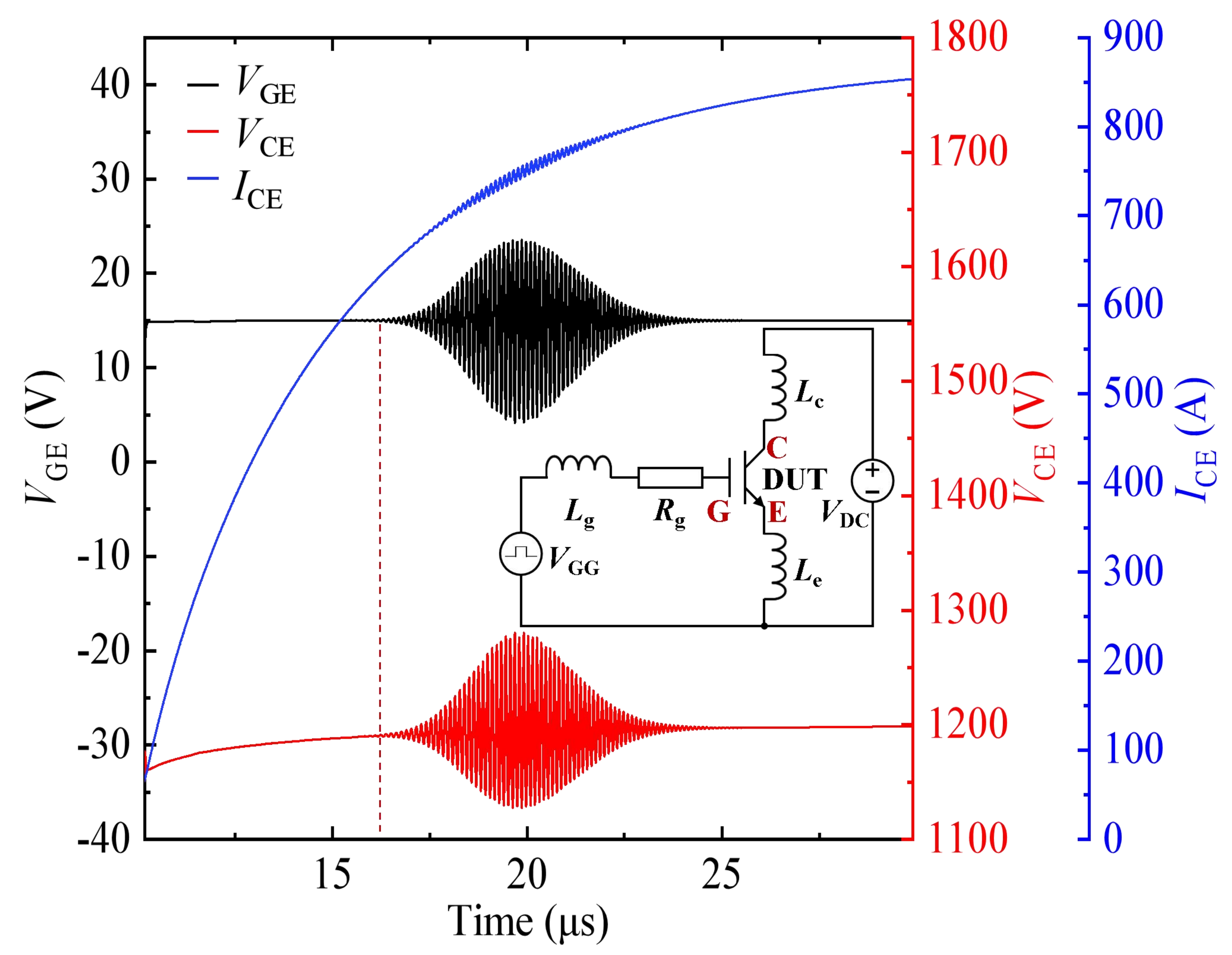

Fig. 2. Short-circuit simulation of the 1.7-kV IGBT at V_{DC} = 1200 V.

Mechanism Analysis

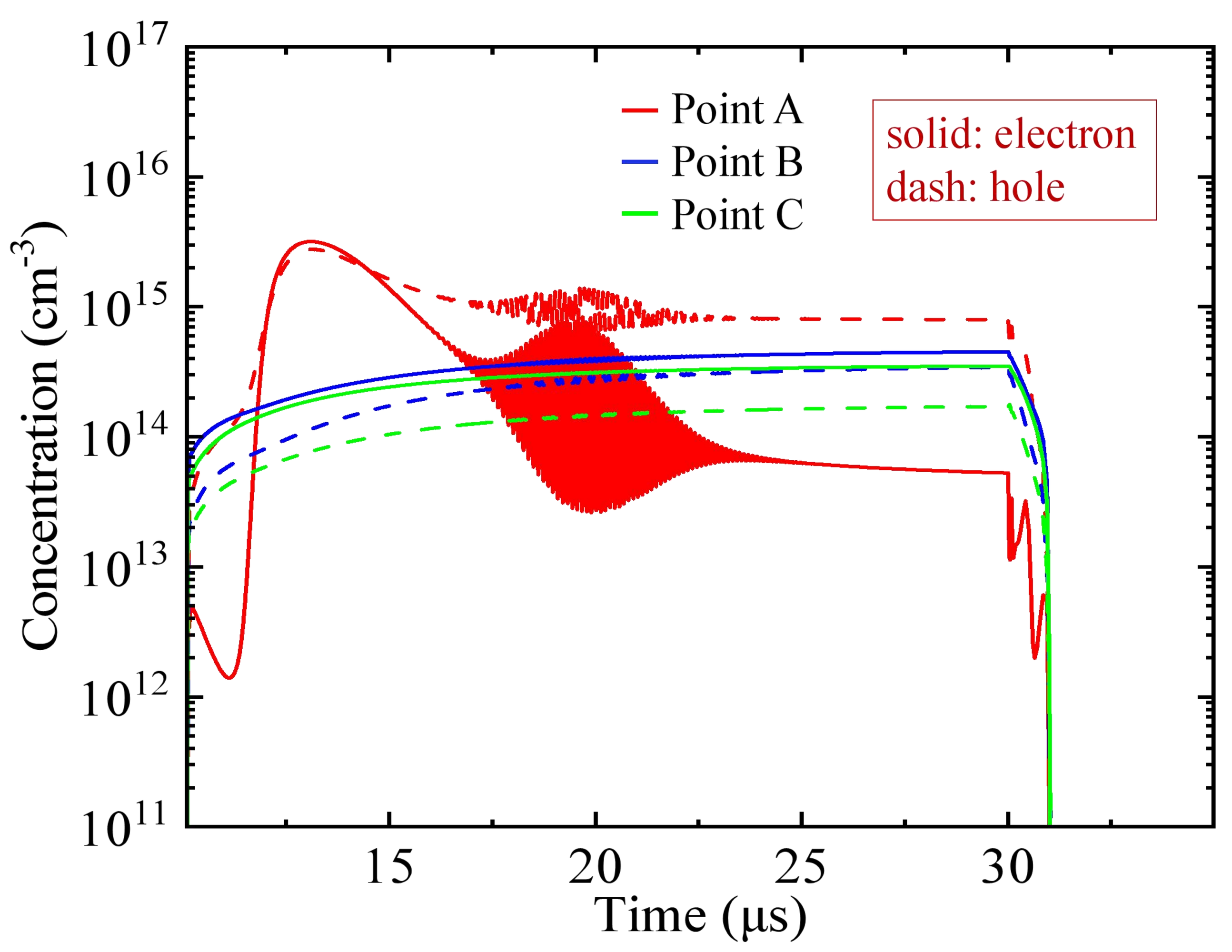

Fig. 3. The carrier concentrations at points A, B, and C during the short-circuit phase.

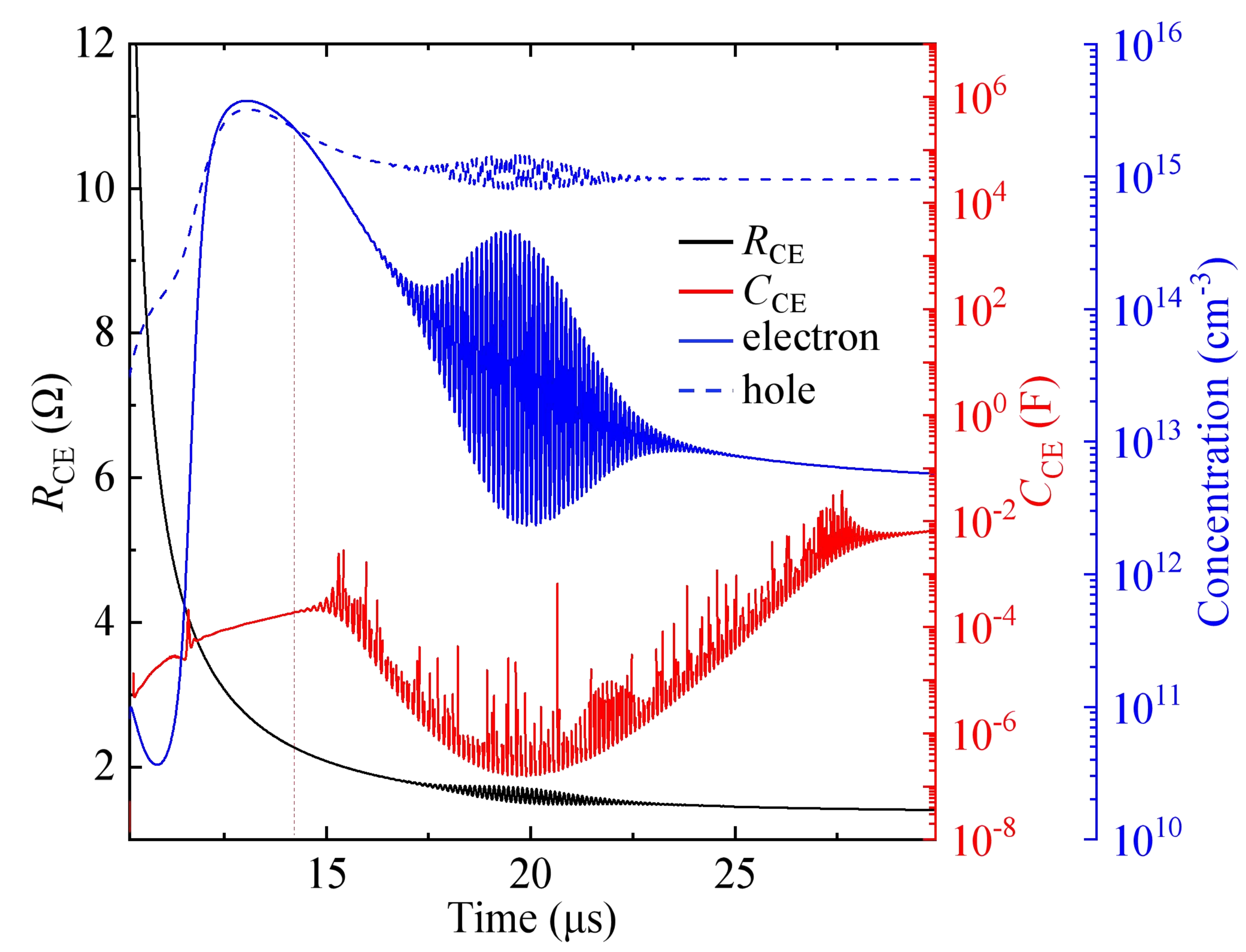

Fig. 4. Collector-emitter resistance (R_{CE}) and capacitance (C_{CE}) and the carrier concentrations at the point A during the short-circuit phase.

Formula Derivation

$$R_{CE} = \frac{V_{CE}}{I_{CE}} \quad (1\text{-}1)$$

$$\frac{dE}{dx} = \frac{q}{\varepsilon}\cdot(p_{PA} - n_{PA} + N_D - N_A) \quad (1\text{-}3)$$

$$C_{CE} = \frac{dQ_{CE}}{dV_{CE}} = \frac{dQ_{CE}/dt}{dV_{CE}/dt} = \frac{I_{CE}}{dV_{CE}/dt} \quad (1\text{-}2)$$

$$\lambda = \frac{R_{CE}}{2}\cdot\sqrt{\frac{C_{CE}}{L_C}} \quad (1\text{-}4)$$

Simulation Results of Different D_{pc}

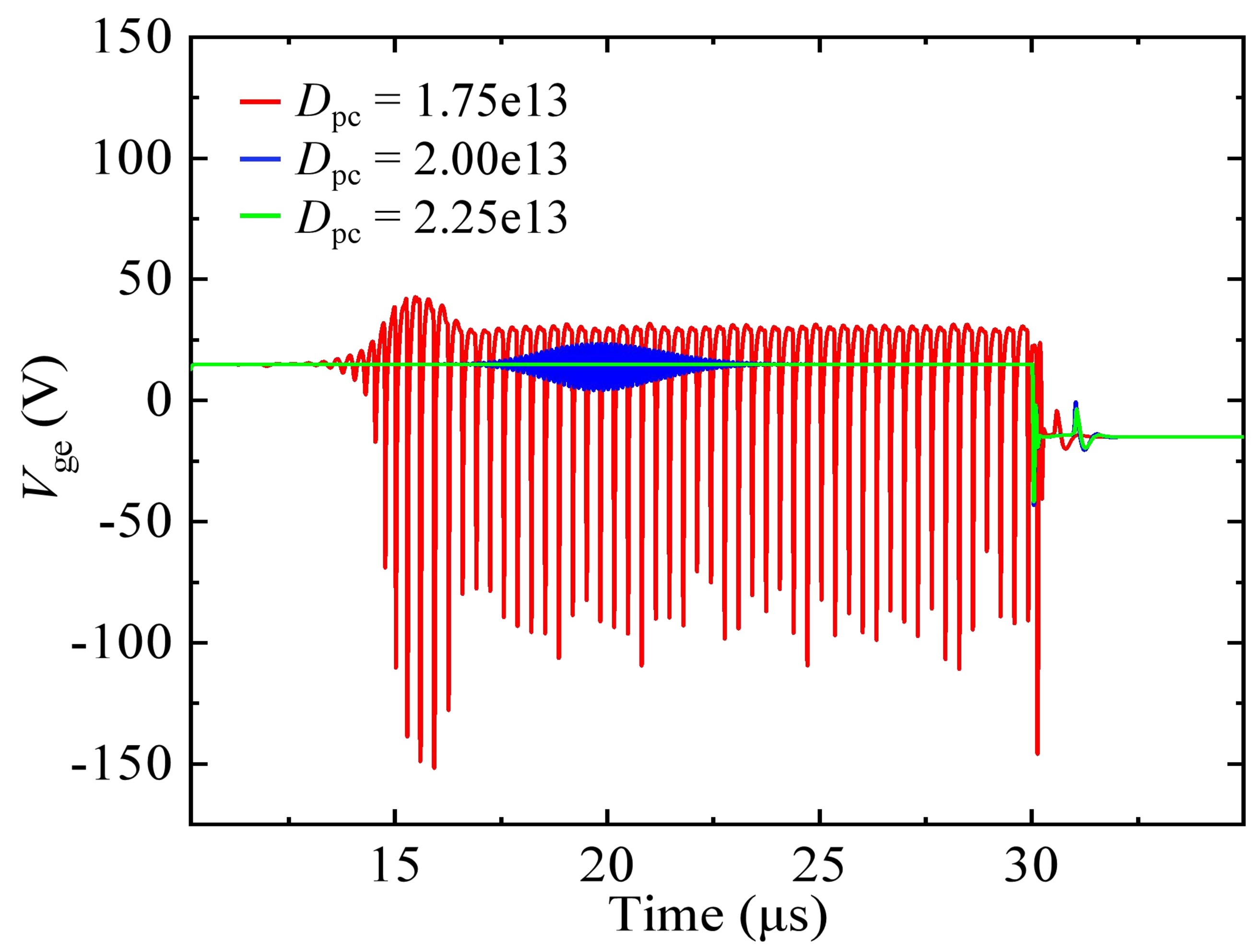

Fig. 5. The effect of the dose of p-collector (D_{pc}) on the short-circuit oscillations.

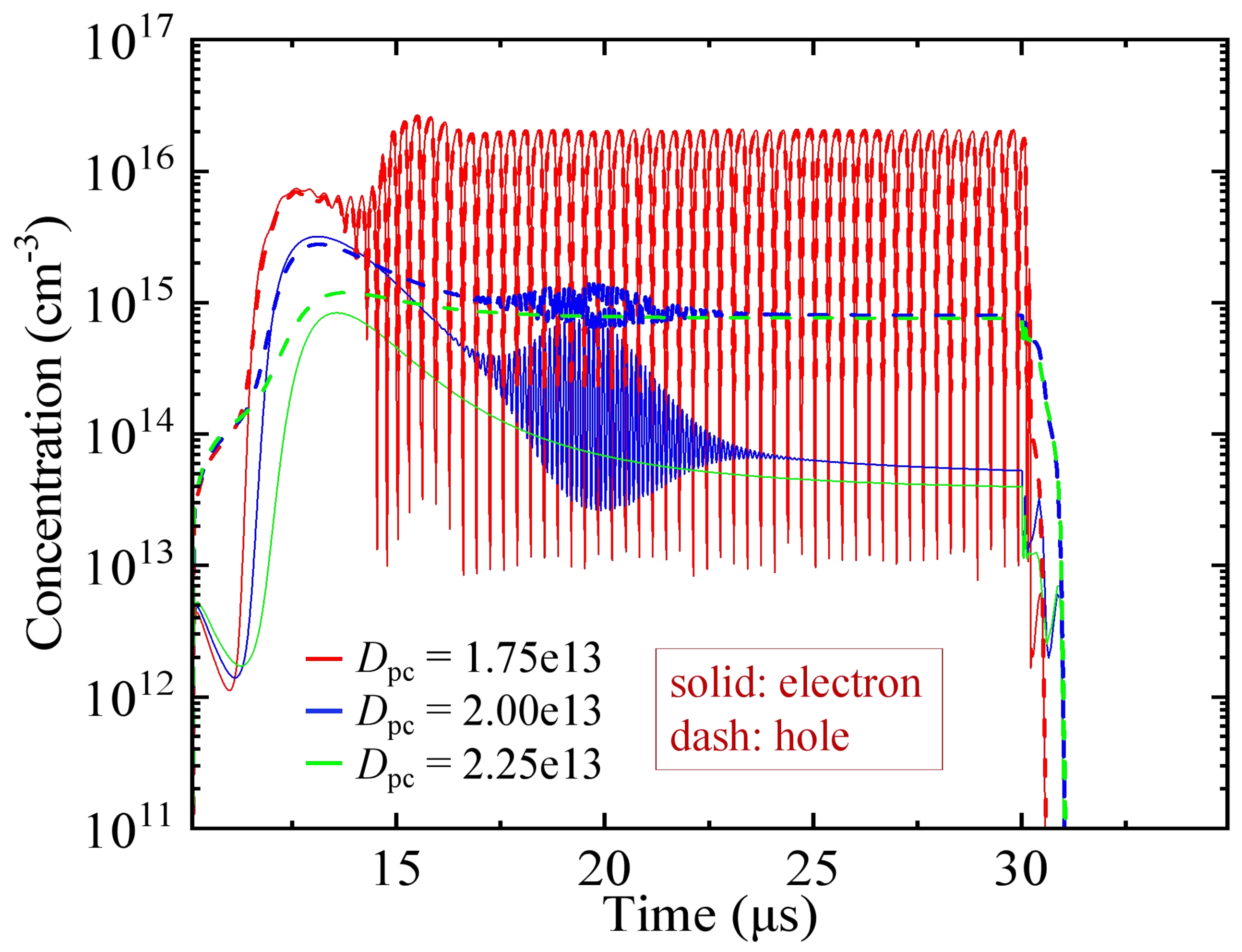

Fig. 6. The distributions of the carrier concentrations at the point A under different D_{pc}.

Conclusion

The reasons of the short-circuit oscillations are not single, and are closely related to the peripheral circuit and the device design. For the peripheral circuit, reducing the parasitic inductance (L_g and L_c) and increasing the resistance (R_g) can effectively suppress the short circuit oscillations. For the device design, it is necessary to suppress the carrier redistribution (CR) phenomenon from the device design, that is to avoid the positive and negative transition of (p_{PA}-n_{PA}) in the short-circuit process. With the increase of the dose of p-collector (D_{pc}), the hole injection on the back can be increased, and the CR phenomenon inside the device can be effectively suppressed, so as to suppress the short circuit oscillations.

Simulation Results of L_c, L_g and R_g

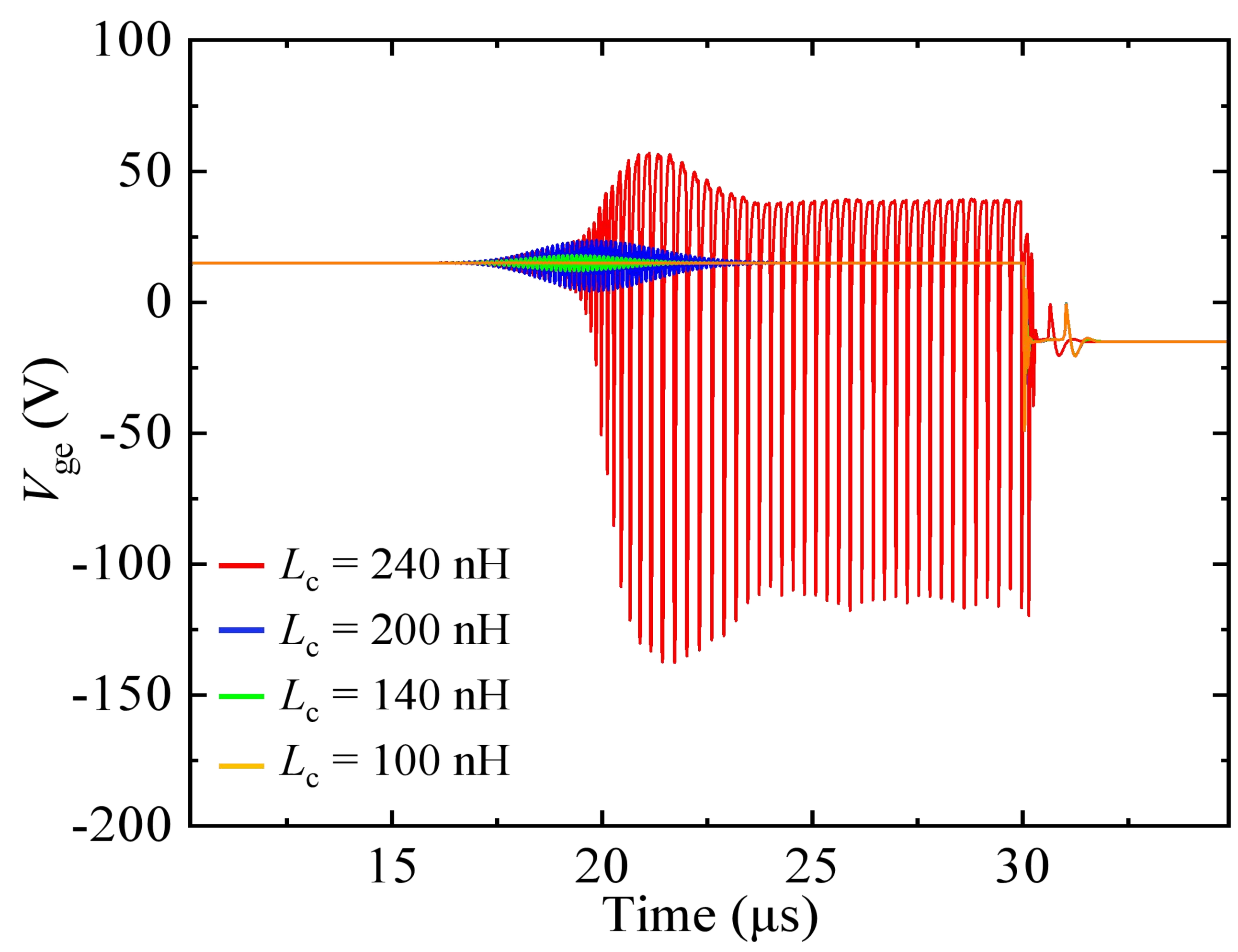

Fig. 7. The effect of the collector inductance (L_c) on the short-circuit oscillations.

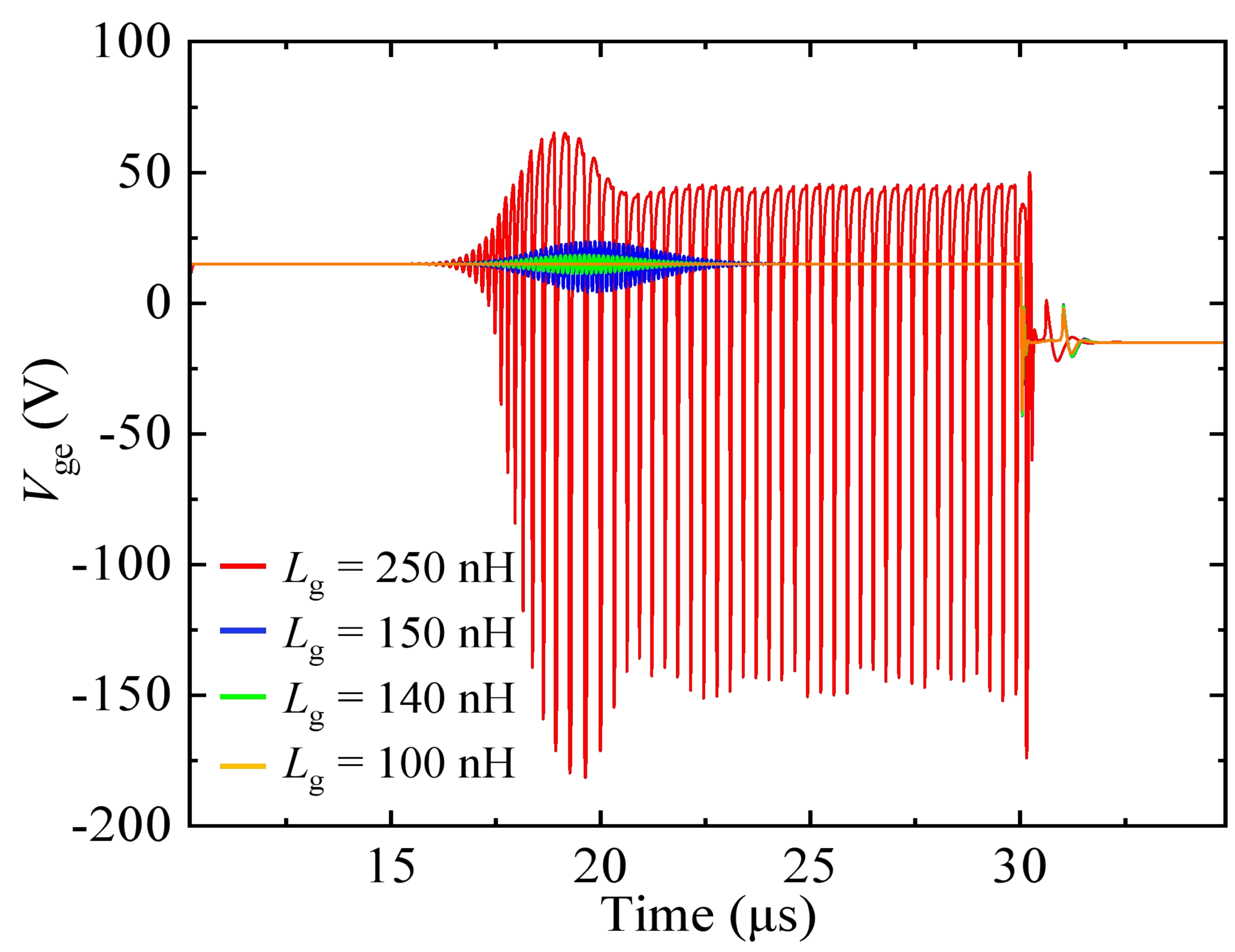

Fig. 8. The effect of the gate inductance (L_g) on the short-circuit oscillations.

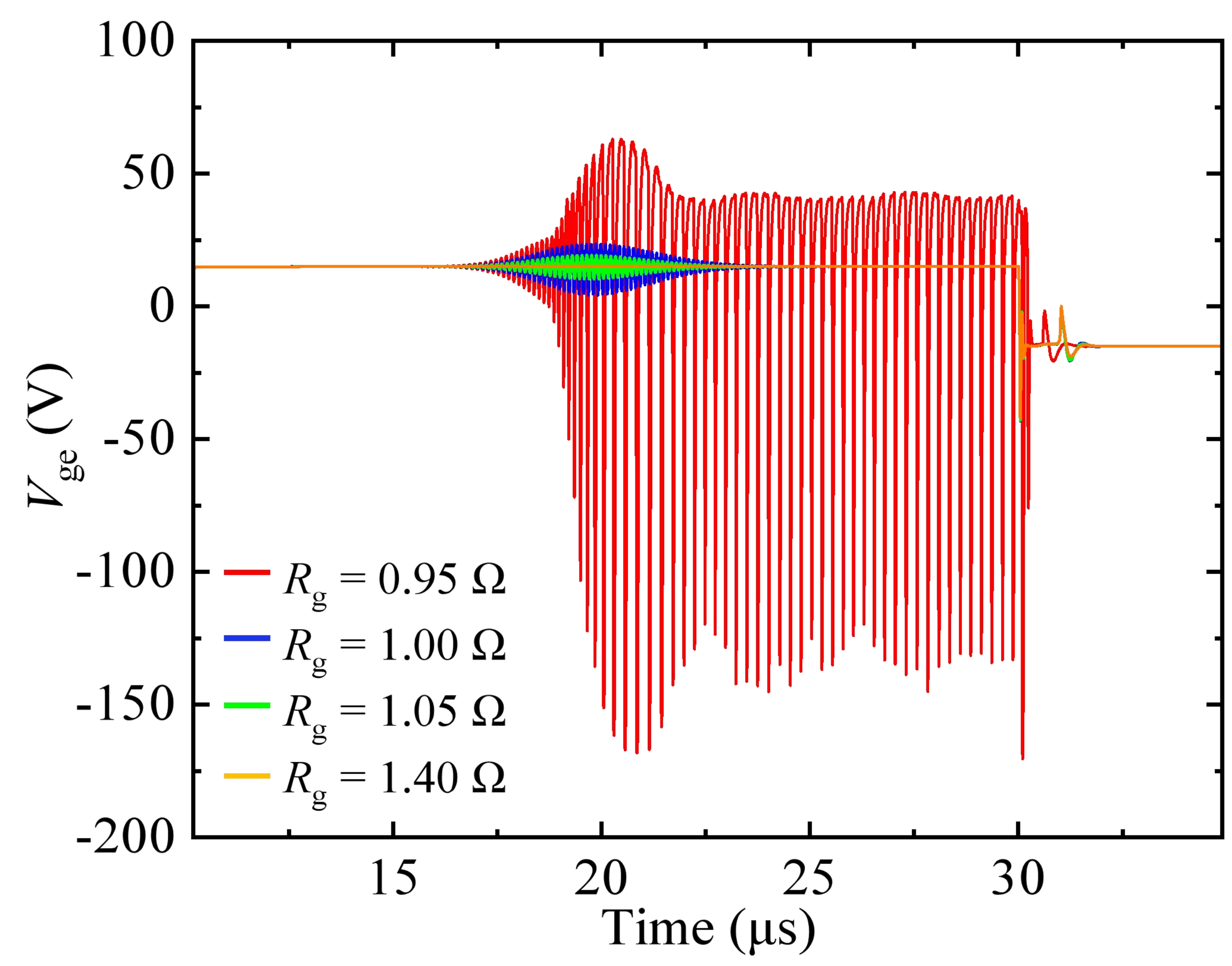

Fig. 9. The effect of the gate resistance (R_g) on the short-circuit oscillations.