This thesis is about the compact modeling of high-voltage (HV) MOSFETs, usually identified and alternatively known as power MOSFETs. At the beginning, the current status of compact modeling for HV MOSFETs is briefly reviewed. In particular, the HiSIM_HV compact model, now the industry-standardized compact model for HV MOSFETs, is already widely used globally for industrial applications. However, there are remaining issues which have to be addressed. In chapters 3, 4, and 5 of this thesis, the three important remaining issues are investigated.

The first issue addressed in this thesis is the versatility of the compact model regarding device structures. The important thesis contribution in this context is the extension to the class of trench-gate type HV MOSFETs, also known as UMOSFETs. After investigating the current flow in the drift region, usually a lightly doped region which supports a large portion of the applied voltage, a specific feature of this device was identified. Upon this knowledge, the resistance description for the drift region was reformulated to accommodate the electrostatic effects exerted by the trench gate embedded in silicon substrate. With this modification, a development version of HiSIM_HV has successfully captured a geometry-scaled current-voltage relation which was not captured by HiSIM_HV, originally intended for planar devices.

The second issue addressed in this thesis is a widely occurring phenomenon in the presence of high electric fields in the drift region which supports a large portion of the applied voltage. In particular, an occurrence of plateau-like structure in the drain current vs. voltage is identified at larger drain voltages. To clarify this phenomenon, the transport phenomena of high energetic carriers are investigated through device simulation, and high field distribution and carrier generation rate are analyzed. A spatial shift of carrier generation rate distribution was observed in the drift region, according to bias change. A change of potential profile in the
drift region was also identified and ascribed to the presence of impact-ionization-generated holes. An intricate change of the potential distribution was found to withhold the onset of a hard breakdown, resulting in the plateau-like structure in the drain current vs. drain voltage curve. With these findings in mind, a new equation of impact ionization in the drift region was constructed, based on the descriptions of internal potential. This modeling approach is viable in surface-potential-based compact model relying on the descriptions of internal potential.

The third issue addressed in this thesis is an electrostatic effect exerted by the non-uniformity of the dopant concentration in the HV MOSFET's channel region. In laterally-diffused MOSFETs (LDMOS), which are one type of HV MOSFET, the concentration of the dopant species tails off from the source side to the drain side of the channel. This pertinent impurity concentration gradient can add a notable change to the electric characteristics of the HV MOSFET, and this effect was analyzed.

One of notable electric characteristics observed in LDMOS is a capacitance peak in the capacitance-voltage curves. To clarify this effect, a numerical simulation study was performed. Rather than seeking overly complicated analytical approach together with otherwise unnecessary approximations, the author chooses to clarify the precise differences in electric characteristics, as contrasted with uniform dopant settings. For a detailed analysis, a dual approach was used within HiSIM_HV’s Poisson-equation code, one with uniform dopant setting and the other with the non-uniform dopant setting between source- and drain sides. The excess charge pertinent to impurity concentration gradient was extracted between the two codes, following the electrostatic law (Gauss’s theorem), and the capacitance enhancement was deduced. This developed approach was found additionally successful for non-zero drain voltages, which is one of the important achievements in this research. Through analysis, part played by the non-uniform doping for the capacitance enhancement was found modest; larger part is played by the coupling of capacitance and resistance in the drift region, which can be consistently treated within the framework of HiSIM_HV.

In the conclusion, the author summarizes the thesis and addresses future prospect of the remaining research tasks.