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ABSTRACT DELLA TESI DI DOTTORATO

Characterization, Modeling and Simulation of 4H-SiC Power Diodes

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Abstract

Exploring the attractive electrical properties of the Silicon Carbide (SiC) for power devices, the characterization and the analysis of 4H-SiC pin diodes is the main topic of this Ph.D. document. In particular, the thesis concerns the development of an auto consistent, analytical, physics based model, created for accurately replicating the power diodes behavior, including both on-state and transient conditions.

At the present, the fabrication of SiC devices with the given performances is not completely obvious because of the lack of knowledge still existing in the physical properties of the material, especially of those related to carrier transport and of their dependences on process parameters. Among these, one can cite the degree of doping activation, the carrier lifetime into epitaxial layers that will be employed and the sensitivity of some physical parameters to temperature changes. Therefore, a set of investigative tools, designed especially for SiC devices, cannot be regarded as secondary objective. It will be useful both for process monitoring, becoming essential to the tuning of technological processes used for the implementation of the final devices, and for a proper diagnostics of the realized devices. Following this need, in our research activity firstly a predictive, static analytical model, including temperature dependence, is developed. It is able to explain the carrier transport in diffused regions as function of the injection level and turns also useful for better understanding the influence of physical parameters, which depend in a significant way from the processed material, on device performances. The model solves the continuity equation in double carrier conditions, taking into account the effects due to varying doping profile of the junction, the spatial dependence of physical parameters on both doping and injection level and the modification of the electric field of the region with the injection regime. The model includes also the device characterization at high temperatures to analyze the influence of thermal issues on the overall behavior up to temperature of 250°C. The accuracy of the static model has been extensively demonstrated by numerous comparisons with numerical results obtained by the SILVACO commercial simulator.

Secondly, with the aim to properly account for the dynamic electrical behavior of a diode with generic structure, the static model has been incorporated in a more general, self-consistent model, allowing the analysis of the device behavior when it is switched from an arbitrary forward-bias condition. In particular, the attention is focused on an abrupt variation of diode voltage due to an instantaneous interruption of the conduction current: although this situation is notably interesting for the study of the switching behavior of diodes, the voltage transitory is also traditionally used in different techniques of investigation to extract more information about the mean carrier lifetime. This occurs, for example, in the conventional *Open Circuit Voltage Decay* (*OCVD*) technique, where the voltage decay due to the current interruption is useful for an indirect measure of minority carrier lifetime in the epitaxial layer.

Because of its heavy dependence on processes, the carrier lifetime is an important parameter to be monitored, especially in the case of bipolar devices, and it cannot be neglected. Due to the existent uncertainty about this parameter in SiC epi-layers, the OCVD method reveals itself a practical way to overcoming this limit.

In detail, by using our self-consistent model, that exploits an improved method of the traditional OCVD technique, it is possible to characterize the carrier lifetime into 4H-SiC epitaxial layer of a generic diode under test, obtaining the spatial distributions of the minority carrier concentration and carrier lifetime at any injection regime. The overall model performances are compared to both device simulations and experimental results performed on Si and 4H-SiC rectifier structures with various physical and electrical characteristics. From the comparisons, the model results to have good predictive capabilities for describing the spatial–temporal variation of carriers and currents along the whole epi-layer, proving contextually the validity of the used approximations and allowing also to resolve some ambiguities reported in the literature, such as the stated inapplicability of the OCVD method on thick epitaxial layers, the reasons of the observed non linear decay of the voltage with time, and the effects of junction properties on voltage transient.

Finally, with the imposition of right boundary conditions, it is possible to use the versatility of the developed model for extending the analysis and obtaining a physical insight of any arbitrary switching condition of 4H-SiC power diodes.