Behavioral models and specific design tool for new power integrated devices

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ABSTRACT

The developments of power systems require the use of specific functions offering a higher performance while being more compact and more reliable than existing discrete functions.

To facilitate the design of these new functions, based on the functional integration mode [1] and developed by STMicroelectronics under the name of Application Specific Discrete (A.S.D. ™ [2]), we present a library of basic cells with their related behavioral models.

Keywords: Behavioral models, power integrated devices, design tool.

1 INTRODUCTION

Over the last ten years, numerous examples of monolithic integration have been developed in power electronics for low voltage applications. This type of integration, involving energy sources disconnected from the mains supply, known as Smart power is well suited for automotive electronics.

However, numerous power conversion and protection applications connected to the mains, such as household appliances, can benefit from advantages brought about by new integrated power functions composed of associations of MOS transistors and thyristors based on the functional integration concept. Interactions between semiconductor layers and MOS effects at the top surface allow to achieve new functionality that could not be obtained by the classical integration mode involving devices isolated from each other. In fact, design is based on a generic approach using electrical interactions of elementary cells (as diodes, bipolar and MOS transistors, thyristors,).

To design increasingly complex functions, it is essential to provide the field of these new power integrated devices with design tools as was the case for information and signal processing ICs. The aim is to create an interactive design environment whose philosophy is similar to the one implemented over the last years for Asics, which supports the development of power ICs from basic components.

We propose a design tool allowing to assist designers from the functionality desired to the corresponding integrated structure. This design tool consists in a library referred to as design kit based on functional units [3] and their associated models. As the physical parameters differ from the designer s data, these related models must include the so-called user-friendly electric parameters that are more suited to the designer s known-how. Behavioral modeling, with external electrical parameters, permits to reach this goal.

This design kit allows°to determine the association of functional units and their electrical parameter values leading to the functionality and the latter s electrical performance required.

2 BEHAVIORAL MODELING

The behavioral models approach is only based on the externally characteristic (I (V), C (V) ,). So, functional units are considered as a black box and their modeling requires specific design tools.

This kind of model is simple (to obtain the results quickly) and convenient (for a good representation of the phenomenon). So it is well suited in order to obtain the functional design of new function defined by electrical consideration.

2.1 Behavioral model principle

In a general manner, behavioral modeling is not limited to one field of application only (electrical, mechanical, thermal,) [4]. It is worth recalling that the universal modeling principle can only be used if two types of variables are employed.

The first type accounts for intrinsic quantities such as potential within the context of electrical models. Each kind of variable is linked to a single node. This approach corresponds to the mesh law.

The second type accounts for directional quantities such as current. These types of variables are based on the conservation of energy and yield a zero sum when each variable converges onto a single node (node law).

First type of variables can be noted by T (for through) and represents vector quantities associated with two different nodes (representing an amplitude between two nodes like a voltage).

The second type, noted A (for across), represents a direction through a node (entering or leaving a node for example).

In our case, these models have been described in HDL-A language embedded in the ELDO electrical simulation software. This simulator determines all flows in nodes of a simulated circuit.

For a behavioral model, the simulator does not access the internal equations model. For each stimulus across the terminals, the model sends the information to ELDO simulator. The information sent by the model is then used to solve all differential equations specific to the simulated circuit.

To create a model, we only take into account the device s behavior as seen through its terminals. For this modeling approach, we used the black-box concept.

This black box is fitted with incoming and out going terminals, and their interactions are controlled by some mathematical equations in a predefined validity domain. The electrical characteristics and functionality is then modeled by a succession of curves linked to each other. Thus, the specific I (V) characteristics of the device can be represented using reduced mathematical equations like straight lines, parabolas, hyperbolas, etc ...

The mathematical equations of behavioral models are not based on the knowledge from physic parameters. So, for these models, it is necessary to use experimental electrical characteristics to extract a set of electrical parameters (see Figure 1).

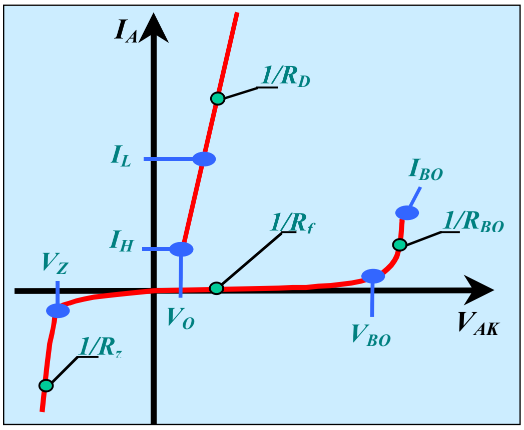

Figure 1: Example of thyristor I (V) characteristic with the associated electrical parameters.

The determination of electrical parameters of the behavioral model permits to approximate the experimental characteristic. Thus, the validity of the model requires a good method of parameter extraction.

3 FROM THE DESIGN KIT TO THE INTEGRATED STRUCTURE

In the present economic context, a cost effective and time saving approach is essential for design. Hence, we have developed a tool such that designers starting from the functionality and electrical performance desired, can obtain an integrated monolithic structure. In our context of functional integration, the functionality and the electrical characteristics of the integrated structure depend not only on the surface design (layout), but also on electrical interactions between the overlay of different semiconductor layers. In fact, the MOS effect at the top surface can be combined with the bipolar interactions occurring in the bulk. However, we have highlighted that the structure design is based on a generic approach using functional units. Despite the fact that the functional integration mode is based on the interaction between semiconductor layers, the only aid that can be provided to the designer is based on the electrical representation of the different functional units existing in a given specific technological process. So, we have based our design methodology on the use of a functional unit library with their related models.

3.1 Design Kit

The potentialities offered by our power technology are based on a four-layer process combined with MOS technology. The functional units are obtained from (P+, N+) / (P, P- or P+) /N-/ (N) / (P+) semi-conducting layers and from enhanced and depleted NMOS and PMOS transistors. We have drawn up the inventory of these associations in order to define the different functional units. Then, we have developed a behavioral model for each functional unit (diodes, bipolar and MOS transistors and even thyristors) in order to define the design kit. This design kit, based on the ASD3-02 ™ process, consist of two kinds of library.

-the first one including behavioral models with modifiable parameters in a defined validity domain (named open library);

-the second one named ASD3-02 ™ library including behavioral models with extracted parameters from the ASD3-02 ™ process).

Figure 2 shows a schematic representation of the ˙˚Design Kit˚¨ structure.

Each functional unit is described by this electrical representation, the behavioral model and the set of electrical parameters corresponding, and the schematic cross section of the integrated structure.

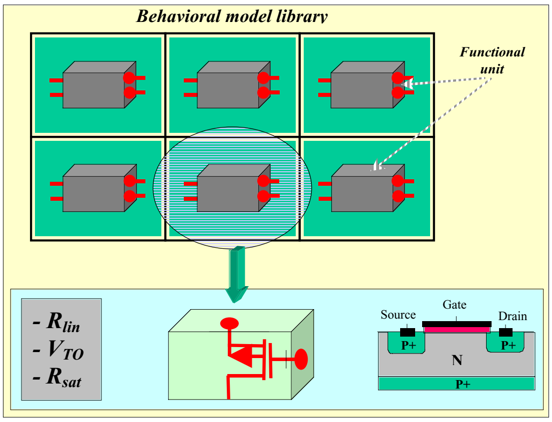

Figure 2: Schematic representation of the design kit.

3.2 Parameter extraction

The model parameters are obtained from the measured electrical characteristics of the device. So, the multichip including the different functional units with different geometrical parameters has been designed and fabricated in order to extract the electrical parameters required by each model of functional units. The important number of electrical characteristics requires the use of automatic and specific mathematical algorithms to determine the best model parameters fitting the measured data. For each functional unit this set of parameters corresponds to the parameter value for the ASD3-02 ™ library and is used to define the validity domain for the open library .

The specific design geometry of functional units in the multichip allows empirical rules to be established linking electrical and geometrical parameters.

3.3 Implementing the method

The electrical characteristics required for the function are not directly linked to the equivalent electrical circuit representation or to this associated schematic topology corresponding to the integrated function.

In order to create new specific functions, the design methodology is based on the design kit including a library of functional units (open library) and the ASD3-02 ™ library linked to the ASD3-02 ™ process (ASD3-02 ™ library). In a first step, according to the functionality requirements, the designer uses the open library and his own know-how to determine the corresponding electrical equivalent circuit. This library permits to study the influence of electrical parameters on functionality. In a second step using the ASD3-02 ™ library the designer determines the template and the electrical performance of the function in the ASD3-02 ™ process environment.

Then the mask designer can refine this approach using specific physical models based on physical and geometrical parameters or 2D simulation tools.

3.4 Example of application

The design of a new power structure providing a circuit breaking type protection function is presented.

Figure 3 shows the schematic electrical characteristics and the specific electrical values, which define I (V) template of the function.

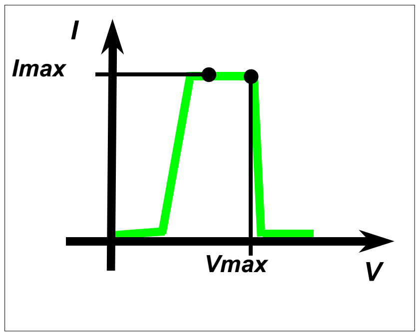

Figure 3: I(V) Typical I(V) electrical characteristic of a circuit breaker.

First, the designer defines a block diagram corresponding to functionality and the fast simulation capability allows him to propose an equivalent electrical circuit based on the functional units (a depleted PMOS transistor and two depletion mode IGBTs) and providing the functionality required (see Figure 4).

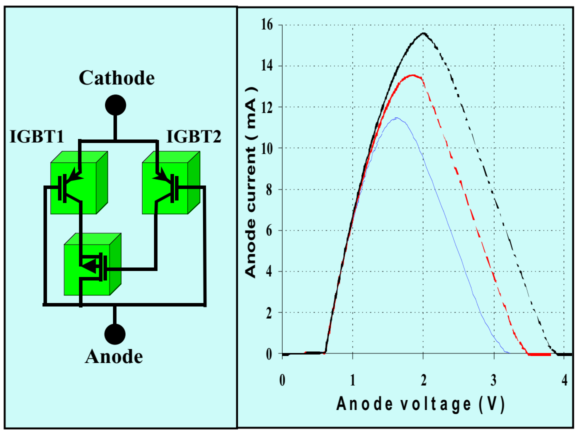

Figure 4: Equivalent electrical circuit of the circuit breaker function and its simulated I (V) electrical characteristic.

The designer can highlight the influence of electrical parameters on the electrical characteristics of the function. In this case the most important parameters are the threshold voltage and the linear resistance value of the IGBT and PMOS transistor. In particular, Figure 4 shows the PMOS threshold voltage impact on the maximum breaking current value.

This approach is then completed using the design kit corresponding to the ASD3-02 ™ process based on electrical parameters linked to this technology. In this case the designer assesses the electrical performances given by the technology available which then sets the threshold voltage of the functional units used in the function.

This in turn allows the designer to define the schematic cross section of the integrated structure (Figure 5). The technological process determines the number and dopings of the different layers. However, a first determination of the most important geometrical parameters can be achieved using empirical relations linking these geometrical parameters to the electrical ones derived from the functional units of the multichip. In this example the gate width (W) can be defined from the linear resistance value.

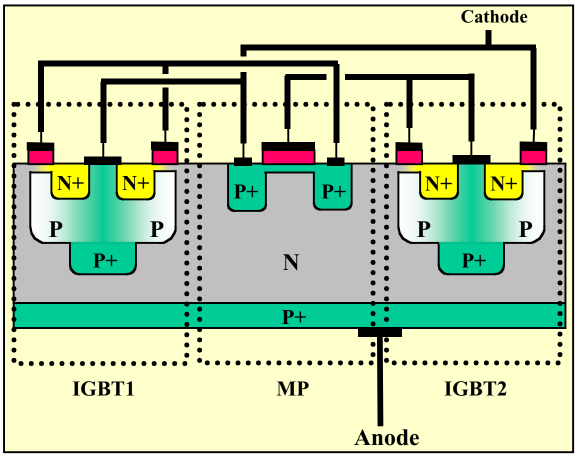

Figure 5: Schematic cross section of the integrated structure.

2D simulations can be employed to assess the overall behavior of the structures and to avoid electrical parasites.

In this manner, interactions (that may be accessed via direct measurements) can be accounted for within the structure.

A more in-depth study of interactions by means of physical simulations will enable us, in the long term, to identify other cells while completing the final design kit.

3.5 Comparison with experimental results

The devices fabricated using the corresponding process allow us to validate these results by simulation (see Figure 6).

This new function defined by the electrical characteristic I (V) and its related electrical parameters can be integrated into the library at the same level of description so as to be used for the design of more complex systems.

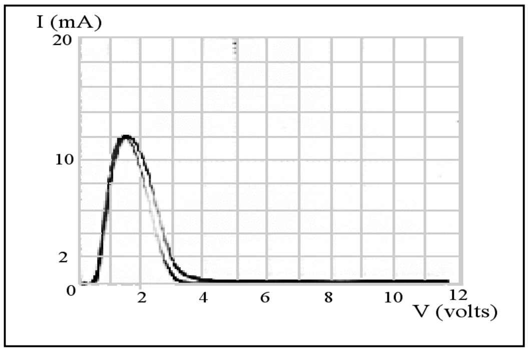

Figure 6: Experimental results.

4 CONCLUDING REMARKS

In this paper, we present the specific features of behavioral models that are well-suited to the design of new power functions based on the functional integration concept and defined by their functionality and their electrical characteristics. The generic approach of this mode of integration is based on the association of electrical functional units. Using the extensive inventory of functional units contained in a power thyristor/ MOS technological process has enable us to set up a library of behavioral models. The use of this library is illustrated by the design of a new integrated power function.

It should be pointed out as well that this behavioral approach supports the addition to the library of new functions, while remaining at the same level of description which allows the design of more complex functions.

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