Abstract—Robustness performance is one of the most important concerns in the design of ESD (Electro-Static Discharge) protection devices, and this quality plays a more and more important role in NEMS protection devices. Improvement of robustness requires not only experience but also TCAD (Technology Computer Aided Design) methodology to evaluate ESD protection devices in NEMS. A novel TCAD methodology for robustness evaluation is presented and developed here. This methodology is based on mix-mode transient circuit simulation, and this simulation method depicts ESD events better. Through analyse of the time effect on power accumulation, an important key parameter, named as robustness coefficient, is provided to characterize and evaluate robustness performance of ESD protection devices quantificationally. Based on analyse of this robustness coefficient of different ESD devices under different ESD models and levels, the results show that this TCAD methodology has a good ability of convergence, and can be used to evaluate robustness performance of ESD protection devices objectively.

Keywords-NEMS; ESD; robustness; evaluation; TCAD

I. INTRODUCTION

Reliability of NMES (Nano-Electromechanical System) is always challenged by ESD-induced damage. [1] This reliability issue is mainly due to lack of methodology to evaluate ESD protection devices’ robustness performance in NMES before designing to ensure that internal circuits of NMES will be protected against ESD damage effectively.[5]-[11] There are three main methods to simulate the I-V characteristic of the ESD protection device based on TCAD tools. a). DC simulation, that is, to put an increasing DC voltage on the two ends of the ESD protection device, and inspect the DC currents under different voltages; or instill DC current to the device and inspect the voltages between two ends of the device. b). TLP simulation, that is, to take advance of the circuit analysis modular in the TCAD tools to imitate the TLP rectangle wave to simulate the I-V characteristic of the device. c). Half-wave sine function current simulation, that is, to instill the current pulse of a half-wave sine function to the ESD protection device, and inspect the voltages under different currents. [13]-[18] In the practice, there are mainly three difficulties in device’s robustness evaluations using existing methods. 1) A transient high current will go through the protection device during an ESD event, and therefore a normal SPICE model cannot realize the device’s robustness simulation. [2] 2) As intense change in the currents and voltages will occur on the “snapback” region, this makes convergent problem occurs very frequently during the simulation with existing TCAD methods. [3] 3) Even if the convergent problem can be avoided fortunately, the I-V characteristic obtained in the existing methods can’t evaluate the robustness performance of the devices with different dimensions under different ESD models and levels quantificationally. [4] The above problems make it difficult to evaluate ESD protection devices through simulations, and therefore raise the blindness and risk of the design. Against these problems, a novel TCAD methodology to predict robustness performance of ESD protection objectively will be presented.

II. SETUP OF TCAD SIMULATION

It is necessary to choose right physic and math models in ESD transient simulation using TCAD, in order to reflect the right conditions of the devices under instantaneous high current. Both the internal thermal transportation and the current led by the temperature difference should be taken into account. It is also necessary to choose right mobility and impact ionization model. The mobility on zero bias may choose Caughey-Thomas experiential model, and the transient solution should choose high field FLDMOB model and carrier temperature based TMPMOB model. Impact ionization model should choose IMPACT.I model, which use Chynoweth expression, and II.TEMP model, which use temperature controlled model instead of field controlled impact ionization. Based on the technology of HHNEC EE180, the device structure as shown in Fig. 1 is obtained in Tsuprem4 processing simulation tools, as well as optimized mesh (Fig. 2a). Then, the device is connected in the equivalent circuit model of ESD (Fig. 2b).

![Fig. 1 SCR-based protection device](image-url)
III. METHODOLOGY OF ROBUSTNESS EVALUATION

A. Rectangular box heat source

Modified D.F.C. model, named as rectangular box heat source model, which is provided by Ajith Amerasekera, is used to evaluate the robustness of the SCR protection device. [2][9]

In this modified model, on the assumption that all the power is concentrated in a cuboid with the three side lengths of a b c respectively, as shown in Fig.3. “a” is the width of ESD protection device, “c” is the depth of the N+ implant region, and “b” is the lateral dimension of the N+ region embedded in the PWELL. This cubic region is the most vulnerable during ESD event, considering the extremely high power density. In this way, failure to power in different devices is given. The relations between power to failure and time in different devices are provided in Fig. 4. We can observe that, as the applying time increased, power to failure decreases quickly, which is due to the power accumulation effect. And, given different device dimensions, the relationships between power to failure and time are different a lot.

B. Robustness coefficient

Since the relations between power to failure and critical dimensions of ESD protection device in NEMS have been given above, and now it is time to calculate the actual effective powers in the device, and evaluate the robustness performance quantificationally based on some parameter. Relations between applied power of the device and time (PA-t), equivalent max power and time (PM-t) are obtained in Fig. 5. “PA(t)” refers to the applied power in the device at the time point “t”, and “PM(t)” refers to the power dissipated in the rectangular box heat source calculated by the max power density “Pmax(t)” in
(1), where $P_{\text{max}}(t)$ is the max power density in ESD protection device at time “t” during ESD event. In order to present time-considered power effect, both $P_A(t)$ and $P_M(t)$ are integrate-normalized in (2) and (3), and $P_{\text{AI}}$ and $P_{\text{MI}}$ are induced respectively. We can observe that, although the curves of $P_A(t)$ and $P_M(t)$ vary largely, the integrate-normalized curves, $P_{\text{AI}}$ and $P_{\text{MI}}$ are quite coherent with each other. The relation between effective power “$P_{\text{EFF}}$” dissipated in the rectangular box heat source and time is depicted in Fig. 6. $P_{\text{EFF}}(t)$ is defined as follows: The effect of ESD on the protection device is equivalent to that the power $P_{\text{EFF}}(t)$ applied to the device for time “t”. Obviously, larger values of integrate-normalized applied power $P_{\text{AI}}$ will induce larger value of $P_{\text{EFF}}$, and in the same way, larger integrate-normalized equivalent max power $P_{\text{MI}}$ will make larger $P_{\text{EFF}}$ in (4). $P_{\text{EFF}}$ is an important parameter, it represents the true effective power in the device with the external power ($P_{\text{AI}}$) and internal distribution ($P_{\text{MI}}$) taken into account in the same time. This critical power will be compared to power to failure in the ESD protection device to evaluate the robustness performance.

\[
P_{\text{AI}}(t) = \frac{\int_{t=0}^{\tau=0} P_A(t) \, dt}{t} \quad (2)
\]

\[
P_{\text{MI}}(t) = \frac{\int_{t=0}^{\tau=0} P_M(t) \, dt}{t} \quad (3)
\]

\[
P_{\text{EFF}}(t) = C_A \cdot P_{\text{AI}}(t) + C_M \cdot P_{\text{MI}}(t) \quad (4)
\]

In TABLE I and Fig. 7, effective powers of the devices with different dimensions under different ESD levels are presented, from which we can observe that higher ESD levels and larger dimensions of D4 and D5 will cause larger values of $P_{\text{EFF}}$, and the effect of ESD levels on the effective powers plays a predominant role.

<table>
<thead>
<tr>
<th>Devices with different dimensions (in microns) under different ESD models and levels</th>
</tr>
</thead>
</table>

---

Fig. 5 a)Applied power and integrate-normalized applied power  b) Equivalent max power and integrate-normalized equivalent max power

Fig. 6 Comparison of integrate-normalized applied power, integrate-normalized equivalent max power and effective power

Fig. 7 Effective powers in four cases
Finally, robustness coefficient $\text{Coer}(t)$ is defined and presented in Fig.8 and equation (5). This coefficient makes great sense in the robustness evaluations. Its definition tells us that robustness performance is relevant to not only the effective power “$P_{\text{EFF}}$” dissipated in the protection device but also the threshold power “$P_{t}$” this device can undergo without being damaged. According to the value of Coer, we can conveniently evaluate robustness performance of different devices under different ESD models and levels quantificationally, that is, the larger Coer is, the more robust the device performs, and this coefficient should exceed unit to ensure that this device won’t be damaged by ESD overstress in such case. In this way we can obtain the order of the four cases shown in Table 1 by their robustness performance from Fig. 8. The order is C4, C3, C1, C2. The order is obtained based on the quantificationally evaluated TCAD results.

$$C_{\text{Coer}}(t) = \frac{P_t(t)}{P_{\text{EFF}}(t)}$$

(5)

![Fig. 8 Robustness coefficients (in watt/watt) in four cases](image)

**IV. SUMMARY**

A novel TCAD methodology for robustness evaluation is presented in this paper. Analyse of the time effect on power accumulation is taken into account, and an important key parameter, named as robustness coefficient, is provided to characterize and evaluate robustness performance of ESD protection devices quantificationally. With this parameter, robustness performance of different devices under different ESD models and levels can be evaluated quantificationally. This TCAD methodology has a good ability of convergence, and can be used to evaluate robustness performance of ESD protection devices objectively.