

SEQUOIA ESD

Grounded-Gate MOSFET ESD Protection

AppNote 2001ESD01

OVERVIEW

Grounded-gate MOSFETs are widely used for ESD protection of deep submicron integrated circuits. Their advantages include:

- Fast triggering action.
- Easy integration into the VLSI process flow with no additional mask layers or process steps.
- Output buffer transistors can be used in self-protecting schemes with no dedicated protection devices.
- Low on-resistance of MOSFETs after triggering provides for an efficient dissipation of ESD pulse energy.
- Grounded-gate MOSFETs do not trigger a latch-up path, resulting in safer operation than SCR or diode protection schemes.

ESD protection circuits are exposed to high-speed high-voltage stresses. In response, they exhibit complex nonlinear

behavior. Protection circuits must be fast and robust enough to handle pulses ranging from 10ns (Human Body Model) to 1ns and below (Charged Device Model) at voltages of 500-2000V.

rate finite-element descriptions of semiconductor devices, a SPICE-like circuit model to couple multiple devices with other circuit elements, and an intuitive Graphical User Interface.

ESD CIRCUIT

The analysis of an ESD protection scheme begins with establishing a equivalent circuit for the ESD event (Fig. 1). The mixed-mode circuit (finite element models for semiconductor devices, SPICE-type elements for other elements) includes RLC elements needed to accurately model the ESD stress event, protection devices and other linear and nonlinear circuit elements.

CALIBRATED MOSFETS

Protection devices are modeled on the physical finite-element level. Technology options such as silicidation, oxide thickness, threshold adjusts are fully incorporated. Users can expect excellent agreement between simulation and experimental data (Figs. 2, 3) without the need for unphysical parameter adjustments.

NONLINEAR ELEMENTS

Nonlinear elements are an important part of many ESD protection circuits. Such elements are modeled as user-defined analytic models. As an example, element CA0 in the circuit shown in Fig. 1 describes a polysilicon resistor charac-

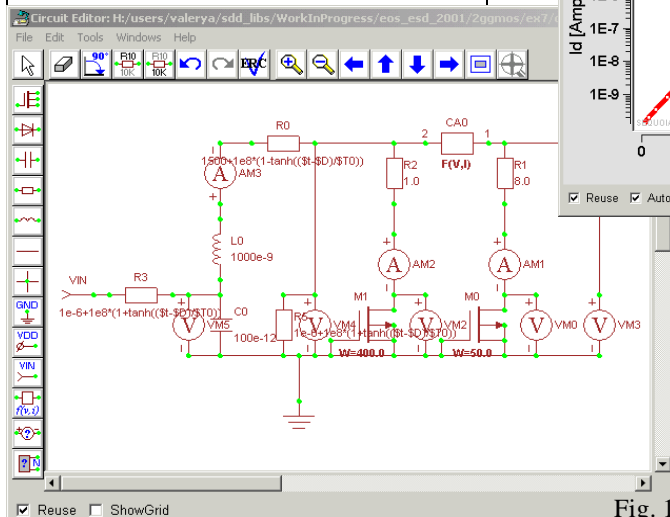


Fig. 1

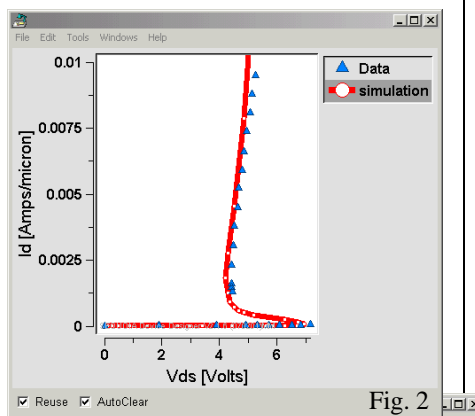


Fig. 2

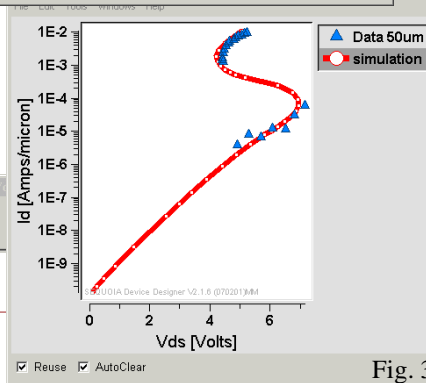


Fig. 3

SEQUOIA Design Systems offers a complete ESD simulation package for physical-level design and optimization of grounded-gate MOSFET ESD protection circuits. The package includes accu-

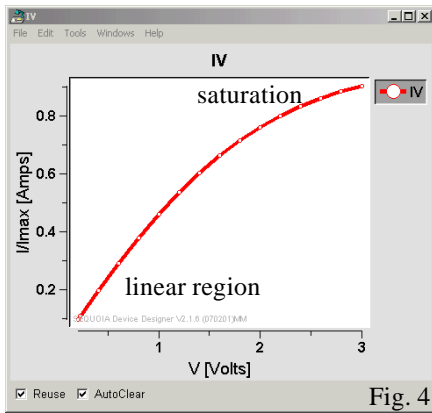


Fig. 4

terized by strongly nonlinear saturation behavior (Fig. 4). This effect is exploited to protect the small and fragile output buffer transistor M0 by causing the larger primary ESD protection device M1 to trigger when M0 reaches its maximum current level.

TRANSIENT RESPONSE

After setting up the circuit and calibrating MOSFETs to match experimental data, a transient ESD simulation is carried out. Figures 5-7 show results for a 2000V Human Body Model (HBM) simulation.

Current flows in the protection circuit show the desired behavior: the small ($L=0.18\mu\text{m}$, $W=50\mu\text{m}$) output buffer device M0 turns on first and carries current up to the limit of 0.2A set by the nonlinear polysilicon resistor CA0. At this point the poly resistor saturates and causes the voltage on the primary protection device M1 to build up to breakdown. As a result, the current shifts entirely to

the larger device M1 ($L=0.2\mu\text{m}$, $W=400\mu\text{m}$), which then absorbs most of the discharge. Current shifts between MOSFETs are indicated by vertical arrows (Fig. 5).

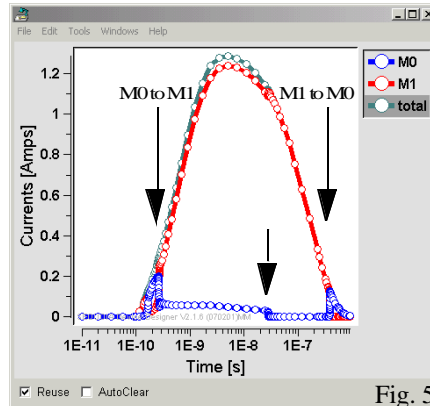


Fig. 5

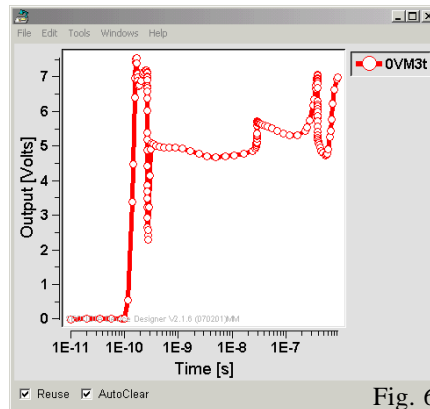


Fig. 6

The complex current flow in the protection circuit results in the output voltage waveform shown in Fig. 6. Abrupt changes in current flow are reflected in the output voltage. The circuit overall shows good ESD protection capabilities clamping the 2000V HBM pulse to under 8V.

HEATING EFFECTS

An HBM pulse is slow enough for self-heating to be of concern during the transient discharge. Heating effects can impact the circuit's ESD protection capabilities and in extreme cases lead to permanent damage to the protection devices. In our example, a check of peak temperatures in both devices shows no serious problems.

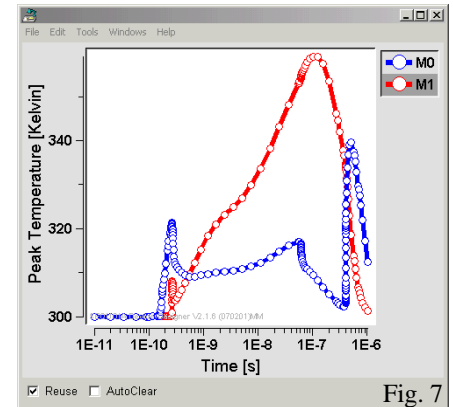


Fig. 7

Transient temperature distributions are calculated for each finite-element device during the simulation and can be viewed to gain insights into circuit behavior.

SUMMARY

SEQUOIA ESD is a complete integrated software solution for the analysis and design of ESD protection circuits. Physical accuracy and ease-of-use are combined in a uniquely powerful package. For more information, please contact SEQUOIA Design Systems.

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