Weak fields in strong coupling: a challenge for preconditioners triggered by Lorentz force calculations in PN junctions

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I. Abstract

The singled-out purpose of electrostatic discharge (ESD) devices is that these devices should protect electronic circuitry against fast-transient voltage/current spikes. Although the overall signal variation occurs within a nanosecond, the corresponding currents can ramp up to a multi-Ampere level. Fast varying current patterns give rise to equally fast varying induced magnetic fields being proportional to the time rate of change of the current and as a consequence a substantial part of the electric fields can be attributed to the variation of the induced magnetic fields and the full electromagnetic picture is required for understanding the effects of fast-transient input signals. A similar reasoning can be done for high-power switch devices. Continuing the reasoning along these lines: when the fields are varying sufficiently fast, both the induced magnetic fields and electric fields will ultimately have such large components such that the current flow is controlled by both fields. In particular, in semiconductors, the Hall coefficient is directly related to the carrier mobility and therefore *self-induced* Lorentz force modifications could become appreciable. So far, no simulation tool were available to address these concerns and strictly speaking, without actually computing these effects, we have no clue if it is justified to ignore these subtleties all together or that these effects are really a concern. Recently we have set up the full calculation scheme to address these concerns.

We present an implementation that allows the computation of these self-induced electromagnetic field effects for fast transient phenomena. In particular, the key ingredients are (1) the semiconductor device equations (2) modifications there off to account for the Lorentz force (3) the Maxwell equations to compute the electromagnetic fields. All this is done in the time domain since in the frequency domain the ”small-signal” analysis up front excludes high current/voltage signals at the ports. Furthermore, we apply this setup to compute the response of an ESD protection device, (see Fig. 1) submitted to sub-nanosecond transient signal rising up the several amperes. The system of equations that has to be solved corresponds to determining $\tilde{2}$50K degrees of freedom. While studying the solving process, corresponding to finding these solutions, we observed a remarkable behavior of the solving process. *If* the solution is found *then* we can confirm that the Lorentz force has a negligible impact on the final result. However, the road towards the solutions is tortuous, despite the smallness off the corrections induced by the Lorentz force. A closer look suggests that the linear system structure generates large off-diagonal terms whereas the corresponding variable is close to zero : in other words weak magnetic fields are strongly coupled to the carrier currents through PN junctions. The standard preconditioners and iterative linear solvers can only deal with this transient problem by taking prohibitively (impractical) small time steps.

In this presentation the author will discuss the setup of the equation system, the setup of the transient simulation of the ESD structure and the localization of the solving bottlenecks. The audience is encouraged to participate in finding satisfactory means to elevate the described problem.

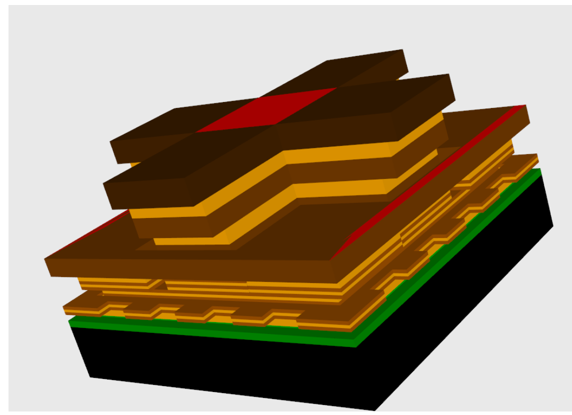

Fig. 1: 3D view of the ESD protection device.

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