Modeling of Intracell Metallic Elements Using the MRTD Technique

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A new method has been developed which enables the modeling of metallic structures that are placed within the boundaries of a cell in the multiresolution time-domain electromagnetic modeling technique. This technique takes advantage of the unique multiresolution properties of MRTD that are due to the wavelet expansion of the electromagnetic fields. In order to represent a PEC in a time domain simulator the boundary condition of zero electric field on the PEC surface must be met. By setting the coefficients of the wavelets that intersect the metal to zero, an arbitrary size and shape metal structure can be represented in the grid. It is required that the space wavelets used in this technique be finite-domain in nature.

This work was performed using Haar wavelets (T. Dogaru and L. Carin, IEEE Trans. Antennas Prop., 774-784, June, 2002). The Haar scaling (φ) and wavelet (ψ) functions are presented in Fig. 1. Equations (1) and (2) represent the update equations for the scaling functions of the Haar MRTD method in one dimension. In these equations, the scaling functions and wavelets are offset by a factor that depends on the maximum resolution. The coefficients m and m' represent the position of the E and H fields, respectively, where $m'=m+1/2^{(r_{max}+2)}$. The resolution of the wavelets is r; r_{max} is the highest level of wavelet resolution used. The time step is represented by n and n', where n'=n+1/2; the E and H fields are offset by half a time step.

$$ {}_{n'+1}H^{\varphi,\psi}_{m'} = {}_{n'}H^{\varphi,\psi}_{m'} + \frac{\Delta t}{\mu\Delta x}\left({}_{n}E^{\varphi,\psi}_{m+1} - {}_{n}E^{\varphi,\psi}_{m} + \sum_{r=0}^{r_{max}} 2^{r/2}\left({}_{n}E^{\varphi,\psi}_{m+1,r,0} - {}_{n}E^{\varphi,\psi}_{m,r,0}\right)\right) \quad (1) $$

$$ {}_{n+1}E^{\varphi,\psi}_{m} = {}_{n}E^{\varphi,\psi}_{m} + \frac{\Delta t}{\varepsilon\Delta x}\left({}_{n'}H^{\varphi,\psi}_{m'} - {}_{n'}H^{\varphi,\psi}_{m'-1} + \sum_{r=0}^{r_{max}} 2^{r/2}\left({}_{n}H^{\varphi,\psi}_{m'-1,r,2^r-1} - {}_{n}H^{\varphi,\psi}_{m',r,2^r-1}\right)\right) \quad (2) $$

Fig. 2 shows a PEC that intersects a cell. Wavelets that intersect this PEC have their coefficients set to zero. Surrounding wavelets are updated as normal. By increasing the number of wavelets used in the expansion, the metal can be placed at any point in the grid, regardless of the cell boundaries. In addition, by changing the position at which the condition is applied, the PEC can be moved in time during simulation.

This technique can be easily expanded to two or three dimensions. In two dimensions, the wavelet coefficients represent rectangular elements in the grid. By setting their value to zero, any shapes that can be made from these arbitrarily sized elements can be represented. Likewise, in three dimensions the same holds true for rectangular solids. Fig. 3 demonstrates how sections of a grid can be selectively zeroed to represent metal sections. One application of this method is the representation of arrays of vias that often appear in modern multilayer RF circuits.

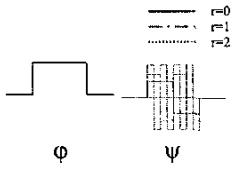

Fig. 1 Haar wavelet and scaling functions

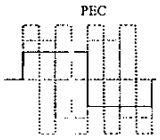

Fig. 2 PEC intersecting MRTD cell

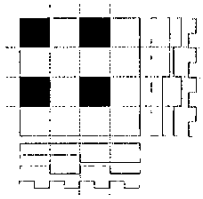

Fig. 3 2D cell with subcell PEC applied

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Multiwavelets in Solving Nonlinear Transport Equations

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1 Introduction

Modeling and simulation of semiconductor devices deal with highly nonlinear equations, such as the drift-diffusion, hydrodynamic, and Boltzmann transport equations. The conventional finite element method (FEM) and Finite difference (FD) schemes always result in oscillatory results, thus fail to work when the cell Reynolds number of the system is large. Several ad hoc schemes were proposed to address the instability issue, including the Scharfetter-Gummel transformation, Petrov-Galerkin method and upwind algorithms, as discussed in an invited paper by Ghione [1]. However, each method suffers from its own defects. We propose a new approach of multiwavelet based finite element method (MWFEM) to solve the semiconductor drift-diffusion system. Due to its ability of tracking the first derivative of the unknown functions, the MWFEM shares the versatility of the conventional FEM while keeps stability in a highly nonlinear system. Comparison with the Scharfetter-Gummel method, upwind FEM, conventional FEM shows the MWFEM performs excellently under circumstances from small to large cell Reynolds numbers. A complete 1D drift-diffusion solver base on the MWFEM is implemented. Numerical results demonstrated high efficiency and accuracy of the new method.

2 Multiwavelet finite element method

Multiwavelets were proposed by Strela and Strang [2]. Basic theory, numerical construction and engineering applications of multiwavelets can be found in [3]. In this section, we use the multiscalets as the basis functions to solve the 1D continuity equation for the electrons with constant drift velocity and zero recombination

$$\frac{d}{dx}\left(n - \frac{1}{R}\frac{dn}{dx}\right) = 0 \tag{1}$$

where $R = v\Delta x/D_n$ is the Reynolds cell number [1], which describes the nonlinearity of the system. The conventional FEM usually produces spurious

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