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BEM Simulation of Laser Trimmed Hybrid IC Resistors

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Abstract. The capability of hybrid Integrated Circuits (IC) depends on the precision of its own resistors. This is nowadays achieved by laser trimming of film resistors. This process can be highly supported by a robust method of computational electromagnetics. The paper shows how the Boundary Element Method (BEM) is used to simulate important quantities of the process.

Keywords: Boundary Element Method, Hybrid Resistor Design, Laser Trimming

1. Introduction

High precision resistors play an important role in the modern IC production. They are used to compensate any production process variation and ensure circuits functionality and reliability. Further, it is difficult to manufacture a precise resistor and therefore some of them need to be trimmed. This is aspired by laser trimmings afterwards which has become the most effective and popular method. Due to the high trim costs it is highly desirable to optimize resistor size, shape and trim figure. Approximation methods are insufficient for most situations and thus, robust methods of computational electromagnetics can overcome this problem. The paper presents the BEM as best suited method and focusses on the trim sensitivity as the most important property for layout processes of film resistors to be trimmed.

2. Trim procedure and resistance calculation

Electrical film resistors in non-trimmed stage can have a nominal tolerance up to $\pm 30\%$. Fig. 1 (right) shows an example for a resistor shape. By a laser cut of edge Γ_2 the current between Γ_1 and Γ_3 is now reduced, so that resistance changes and can be adjusted. This trimming is achieved by a pulsed laser in a step-by-step movement. Film resistor formula R_{13} (Fig. 1, right) is the 2-dimensional version of the general resistor equation R_{ab} (Fig. 1, left).

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Fig. 1. *Left*: General Resistor; *Right*: Top-Hat film resistor with highly conducting terminals Γ_1 and Γ_3 and laser cut at Γ_2 (called plunge- or P-cut)

$$R_{ab} = \frac{U_{ab}}{I} = \frac{\int_a^b \vec{E}\,\mathrm{d}\vec{s}}{\kappa \int_A \vec{E}\,\mathrm{d}\vec{A}} = \frac{\int_a^b \nabla\varphi\,\mathrm{d}\vec{s}}{\kappa \int_A \nabla\varphi\,\mathrm{d}\vec{A}} \quad\Longrightarrow\quad R_{13} = \frac{\varphi(\Gamma_3) - \varphi(\Gamma_1)}{\kappa z \int_{\Gamma_3} \frac{\partial\varphi}{\partial n}\,\mathrm{d}\Gamma} \tag{1}$$

Latter one takes advantage of choosing for the cross-section area l one of the Dirichlet boundaries: Γ_3. z is the film thickness. The scalar potential φ has to satisfy the Laplacian equation on Ω and homogeneous Neumann boundary conditions on Γ_2 - including the cut pathway - and Γ_4.

3. Trim characteristic, sensitivity and selection of BEM

Basis of trim sensitivity functions is the relative trim characteristic $r(\beta)$, describing how resistance changes relatively to the untrimmed resistance R_0 as a function of trim pathway length β. The relative trim sensitivity $s(\beta)$ itself is the first derivative of the characteristic $r(\beta)$ and expressing the resistance increase over trim pathway increase:

$$r(\beta) = \frac{R(\beta)}{R_0} \quad\Longrightarrow\quad s(\beta) = \frac{\mathrm{d}r(\beta)}{\mathrm{d}\beta} \tag{2}$$

The knowledge of these functions is needed for the resistor and trim pathway design, because the bite size of a trim laser pulse cannot be arbitrary large or small. Hence, the maximum trim sensitivity $s_{Sim} = \max(s(\beta))$ expresses if the used trim figure is able to meet a specified tolerance s_t by any circumstances. This is especially a problem of very small scaled thin film resistors on silicon chips.

It can be shown that the resistance of a shape depends on the edge aspect ratios only and not on the concrete shape size. Thus, a stretch factor $\lambda_1 = s_{Sim}/s_t$ can be introduced for the shape geometry which guarantees the necessary low trim sensitivity for design and trim pathway. Another driving factor of resistor size is the sheet current density J_{max} which must not be exceeded. Thus, the ratio of the simulation current density J_{Sim} to the allowed one J_{max} introduces another stretch factor λ_2. The maximum of both gives the stetch factor λ which is to use for the design. Finally, the comparison of the resized shape with the available real estate on the chip layout reveals if this design is an acceptable one or not.

To gain an entire characteristic, the resistance must be computed for any single laser step. Following eq.(1) scalar potential φ of the domain has to be known afore. For the ohmic resistance φ is the potential of a stationary flux field which is described by the Laplacian equation, as mentioned above:

$$\Delta\,\varphi \;=\; 0\,,\ \text{on } \Omega\; \subset \mathbb{R}^2 \text{ and boundary conditions on } \Gamma \;=\; \partial\Omega \tag{3}$$

Following eq.(1) only surface quantities are needed and discretizing of a film resistor's domain for eq.(3) is a very simple 1-dimensional problem. Hence, the BEM is the most appropriate method, see [1].

Method	FDM	FEM	BEM
Nodes / Elements	14,400 Nodes	1,349 Nodes 2,586 Elements	209 Nodes 209 Elements
Net type	equidistant mesh	linear, triangles	constant, linially
Resistance	5.0227 Ω	5.0725 Ω	5.0904 Ω
Lin. equation solver	SOR (1486 steps)	Cholesky	Gaussian column pivot.
Net adaptions	-	10	-
Memory consumption	86,400 Bytes	690,524 Bytes	438,900 Bytes
Global error index	$2.1 \cdot 10^{-3}$	$3.8 \cdot 10^{-3}$	$1.5 \cdot 10^{-4}$
Time consumption	70s	46s	9s

Tab.1 Exemplary comparison of different numerical methods for resistance computations of a 4:1 bar resistor with 70% P-cut at L/4 (computed on 200MHz Pentium; measured resistance 5.1Ω± 0.01Ω)

Moreover it turned out to be faster than FDM and FEM for the same accuracy in trimming, as examplarily shown in Tab.1 (see also [2]). To accompany the trimming process by these computations online in the near future, the fastest and a robust method is even more important.

4. Results

Fig. 2 shows the most frequently used film geometry, the bar resistor and some simulated trim pathways. Investigations of different trim pathways allow designers to choose the most suitable one for the concrete application, e.g. a L-cut because of its low trim sensitivity. The L-cut delivers the highest trim resolution $1/s(\beta)$ here, moreover of mostly constant value over the trim pathway.

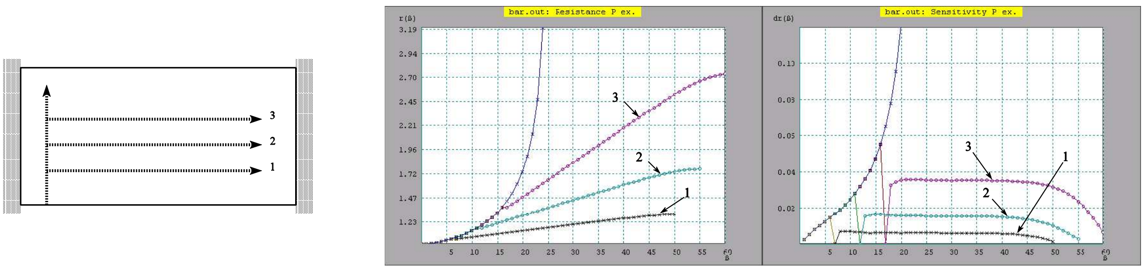

Fig. 2. *Left*: Resistor with P-cut or L-cut 1, 2, 3; *Middle*: Trim characteristic $r(\beta)$; *Right*: Trim sensitivity $s(\beta) = \mathrm{d}r/\mathrm{d}\beta$

Simulator results based on BEM turned out to be very realistic. Fig. 3 shows a comparison plot with measured relative trim characteristics. The Laplacian equation was solved 121 times in approx. 16 minutes on a Pentium 200MHz for that result.

Trim pathways who end up with an infinite resistance by a through cut showing a typical difference between reality and simulation. This illustrates Fig. 4 (right), for example. At such locations physical as well as numerical problems occur who generate these effects. At one hand, the BEM system matrix changes more and more into a singular one. At the other hand, the conductivity right next to the cut path border shows altered properties as the material somewhere else within the domain. These regions, however, are improper for high precision trimmings anyway and thus, these differences are not important for designing.

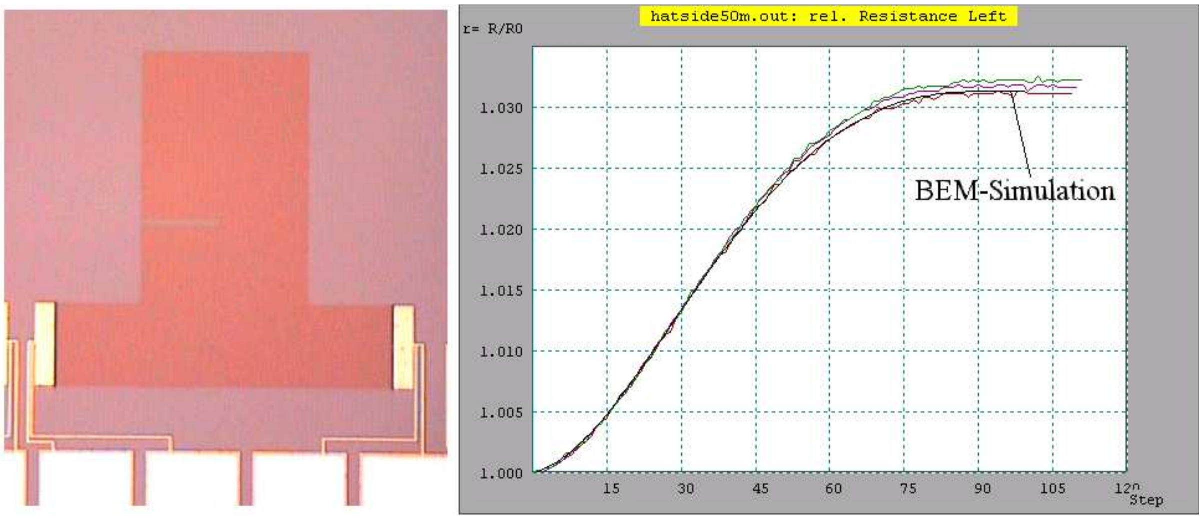

Fig. 3. Three measured trim characteristics of the same top-hat resistor side-cut and the simulator result (left hand side the thin film layout on a silicon chip)

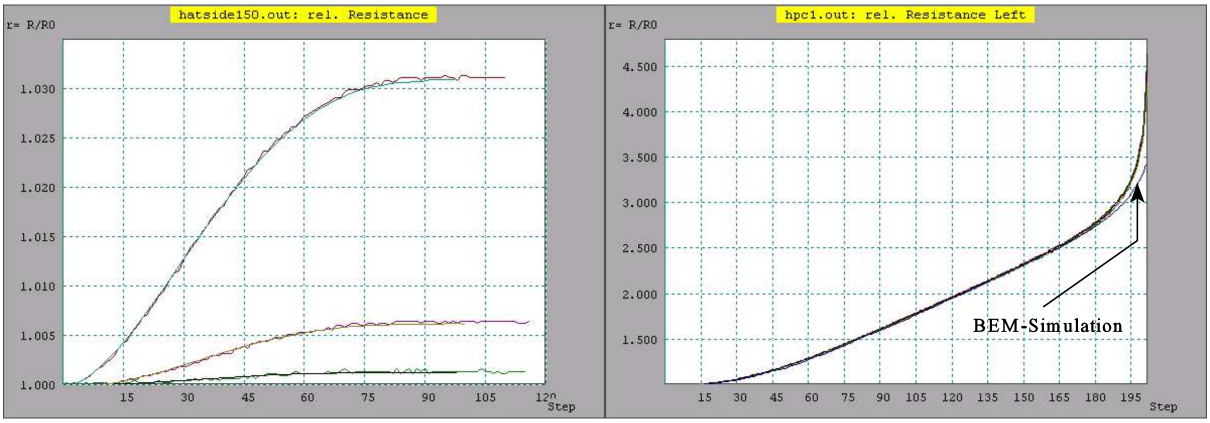

Fig. 4. Measured and simulated relative trim characteristics of three different top-hat resistor side-cuts (*left*) and one central bottom-up cut (*right*)

5. Conclusions

The usefullness of the BEM as a fast, precise and robust method is shown for the computation of highly important functions for the laser resistor trimming. In the near future those computations may accompany the production process online and hereby be of future importance.

References

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