Progress In Electromagnetics Research, PIER 66, 173–178, 2006

MIM CAPACITOR SIMPLE SCALABLE MODEL DETERMINATION FOR MMIC APPLICATION ON GAAS

L. Wang, R. M. Xu, and B. Yan

School of Electronic Engineering
University of Electronic Science and Technology of China
Chengdu, P. R. China

Abstract—An efficient metal-insulator-metal (MIM) capacitor simple scalable model for use in monolithic-microwave integrated circuit (MMIC) design is presented in this paper. This model is based on transmission-line theory. Analytical expressions based on physical parameters have been given in detail. Nine different physical dimension capacitors are fabricated to verify the validity of the proposed model. A good agreement between measured result and simulated data is obtained.

1. INTRODUCTION

MIM capacitors are important components in MMICs. The capacitors are widely used in dc-decoupling, matching and biasing circuits. It is important to accurately predict the performance of such capacitors in order to achieve a first-pass design success of MMIC design. Therefore, accurate and efficient capacitor model is necessary.

Generally, there are two methods for the modeling of MIM capacitors. The first approach is numerical method [1, 2], the other is analytical method. The numerical method is more accurate than the analytical approach, but it is complex and time-consuming. And deeper physical interpretation of the model components can be got from analytical expressions. The analytical method will be used in this paper and the analytical expressions are based on the transmission line theory.

There have been a number of publications on the approximate model of MIM capacitors in the past tens of years [3–7]. However, detailed formulas on equivalent circuit models used in computer-aided design (CAD) programs are rarely disclosed. Mondal [7] presents a couple-line-based distributed model, the two-port impedance-matrix of the capacitor can be derived in terms of line parameters with the boundary conditions [8], but its parameters have been obtained by optimization, which is not ideal in circuit simulation. Mellberg [3] has compared three different models based on microstrip transmission-line models and given an evaluation. Mellberg thinks that the simple line-capacitor-line model is enough accurate in most practical application. However, Mellberg do not give the detailed parameters expressions. In this paper, a lump-based model is developed, and Analytical expressions of model parameters are given in detail. Deeper physical interpretation of the model components can be got from these expressions.

2. CAPACITOR MODEL

The sketch of the MIM capacitor is shown in Fig. 1, and corresponding capacitor equivalent circuit model can be found in Fig. 2. The model bases on the physical parameters of the capacitor, such as length (L), width (W), the thickness of top plate (tt), the thickness of bottom plate (tb), the substrate thickness (h), thickness of the capacitance

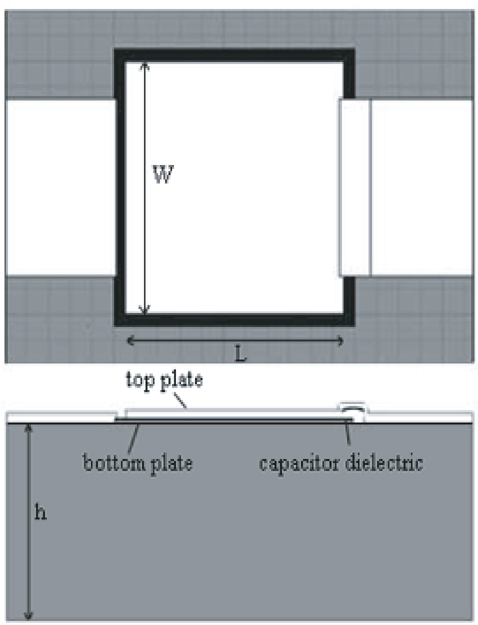


Figure 1. Capacitor structure.

dielectric (t), dielectric constant of substrate (ε_1) and the dielectric constant of capacitance dielectric (ε_2). In this model, the losses due to capacitance dielectric and metal plate have been considered, whereas the mutual inductance coupling between the capacitor plate and the substrate losses have not been accounted for. The proposed model is assumed to be symmetrical and its parameters can be extracted by the following analytical expressions.

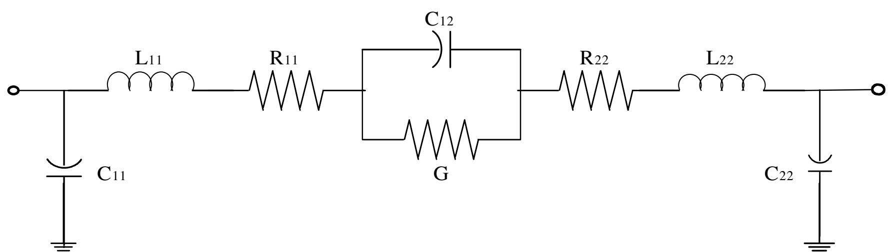


Figure 2. MIM capacitor equivalent circuit.

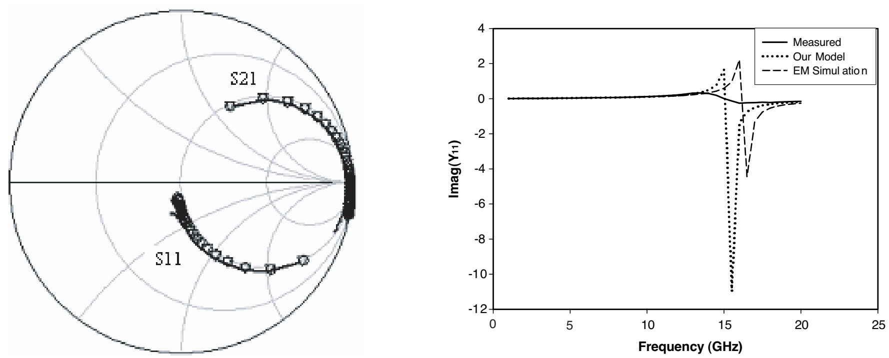
3. VERIFICATION

To verify the validity of the presented equivalent circuit model, nine different sizes MIM capacitors corresponding to capacitance values between 0.4–15 pF are fabricated on GaAs substrate. S-parameters measurement between 1 GHz and 20 GHz is made using a network analyzer and on-wafer probe station. A thru-reflect-line (TRL) method is used for calibration. Measurements of two capacitors shown in Fig. 3 and 4 are compared with simulation data using proposed model in this paper and EM simulation results. Tables 1–2 show the relative mean different between measured S_{11}, S_{21} and Y_{11} and simulation data. The two tables clearly show that the proposed equivalent circuit model and analytic expressions can accurately predict the performance of different-size MIM capacitors.

4. FORMULATIONS

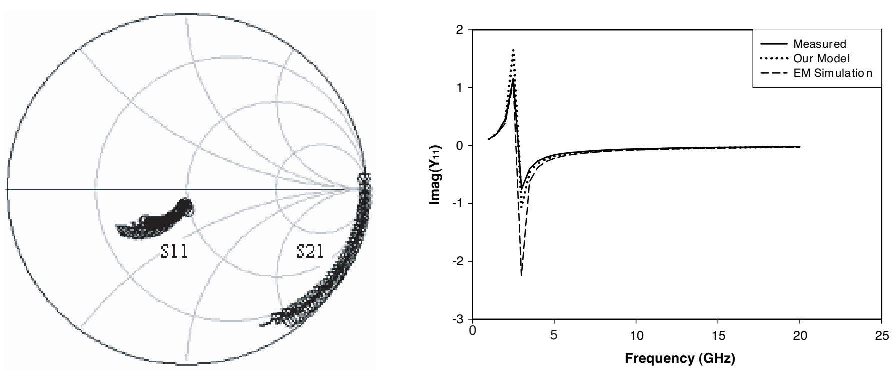
The main parameter of the model, C_{12}, is calculated by parallel-plate capacitance formula,

$$C_{12} = \frac{\varepsilon_0 \varepsilon_2 W L}{t} \tag{1}$$



(a) (b)

Figure 3. Comparison results for $121 \times 53\,\mu$m capacitor. Frequency is from 1 GHz to 20 GHz. (a) S-parameters for measurement (line), proposed model (circle) and EM simulation (triangle), (b) Comparison of imaginary part of Y_{11}.



(a) (b)

Figure 4. Comparison results for $200 \times 484\,\mu$m capacitor. Frequency is from 1 GHz to 20 GHz. (a) S-parameters for measurement (line), proposed model (circle) and EM simulation (triangle), (b) Comparison of imaginary part of Y_{11}.

The loss conductance due to the capacitance dielectric can be obtained by,

$$G = \omega C_{12} \tan \delta_d \tag{2}$$

The metal plate losses resistance R_{11} and R_{22} can be computed

Table 1. Relative mean errors between S_{11} for measurements and proposed model.

$\mathrm{W} * \mathrm{L}\,(\mu\mathrm{m}^2)$	$80 * 32$	$51 * 51$	$121 * 53$	$100 * 194$
RME	0.1113	0.1412	0.2713	0.3280
$170 * 171$	$120 * 108$	$200 * 258$	$200 * 484$	$194 * 100$
0.3203	0.3217	0.3512	0.2077	0.3002

Table 2. Relative mean errors between S_{21} for measurements and proposed model.

$\mathrm{W} * \mathrm{L}\,(\mu\mathrm{m}^2)$	$80 * 32$	$51 * 51$	$121 * 53$	$100 * 194$
RME	0.0901	0.0872	0.0829	0.0759
$170 * 171$	$120 * 108$	$200 * 258$	$200 * 484$	$194 * 100$
0.0725	0.0545	0.1107	0.1142	0.0906

by skin-depth resistance formula,

$$R_{11} = R_{22} = \frac{\rho \cdot L}{W\delta(1 - \exp(-t_p/\delta))} \tag{3}$$

If the metal thickness is smaller than the skin-depth, the resistance must be obtained from the body resistance formula,

$$R = \frac{\rho \cdot L}{W \cdot t_p} \tag{4}$$

where t_p denotes the thickness top plate (tt) or the thickness of bottom plate (tb) correspondingly.

The metal plate inductance can be computed based on microstrip transmission line approach [9].

$$L_{11} = L_{22} = \frac{0.4545 Z_0 L}{c} \tag{5}$$

C_{11} and C_{22} are capacitances with respect to ground of the top plate and bottom plate respectively.

$$C_{11} = C_{22} = \frac{0.5\varepsilon_{eff} L}{c Z_0} \tag{6}$$

5. CONCLUSION

The simplified equivalent circuit of MIM capacitor is studied, and to accurately extract the capacitor parameters, analytical expressions based on physical parameter are presented. The presented model shows good agreement to equivalent circuit model, EM simulation and measured data. It is concluded that the proposed model in this paper can easily be used in CAD programs and it will be helpful to control and improve the process procedure.

REFERENCES

1. Qian, Z. H., R. S. Chen, K. W. Leung, and H. W. Yang, "FDTD analysis of microstrip patch antenna covered by plasma sheath," *Progress In Electromagnetics Research*, PIER 52, 173–183, 2005.
2. Chew, W. C. and L. J. Jiang, "A complete variational method for capacitance extractions," *Progress In Electromagnetics Research*, PIER 56, 19–32, 2006.
3. Mellberg, A. and J. Stenarson, "An evaluation of three simple scalable MIM capacitor model," *IEEE, MTT-S*, Vol. 54, No. 1, 169–172, Jan. 2006.
4. Lombard, P., J. D. Arnould, O. Exshaw, H. Eusebe, P. Benech, A. Farcy, and J. Torres, "MIM capacitors model determination and analysis of parameter influence," *IEEE ISIE*, 1129–1132, June 20–23, 2005.
5. Song, S. S., S. W. Lee, J. Gil, and H. Shin, "Simple wide-band Metal-Insulator-Metal (MIM) capacitor model for RF applications and effect of substrate grounded shields," *Japanese Journal of Applied Physics*, Vol. 43, No. 4B, 1746–1751, 2004.
6. Yin, W. Y., B. Wu, M. Miao, L. B. Ooi, L. W. Li, and P. S. Kooi, "Experimental characterisation and modelling of on-chip capacitors and resistors on GaAs substrate," *IEE Proc. MAP*, Vol. 149, No. 1, February 2002.
7. Mondal, J., "An experimental verification of a simple distributed model of MIM capacitors for MMIC applications," *IEEE MTT-S*, Vol. 34, No. 4, 403–408, April 1987.
8. Tripathi, V. K., "Asymmetric coupled transmission lines in an inhomogeneous medium," *IEEE MTTs*, Vol. 23, No. 9, 734–739, September 1975.
9. Ladbrooke, P. H., *MMIC Design: GaAs FETs and HEMTs*, Artech House, 1989.