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Highly-Accurate Ladder Model of Inductors on a Glass Substrate

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1. Introduction

Recently, the cut-off frequency (f_T) of a poly-silicon thin film transistor (TFT) as high as 6.5 GHz has been demonstrated, enabling the application of TFTs in radio frequency (RF) circuits [1]. TFT-RFIC is fabricated on an insulator, such as a glass substrate. The quality factor (Q) and the self-resonant frequency (f_{SR}) of the on-chip inductors can be improved owing to the smaller substrate loss and substrate capacitance compared to a silicon substrate. However, when the substrate loss and substrate capacitance are small, the characteristics of the inductors will greatly depend on its conductor part. The conventional model of the inductor on a silicon substrate is no longer accurate. Thus, a novel model, which can accurately simulate the skin and proximity effects of the inductors, is indispensable for TFT circuit design.

In this paper, it will be for the first time demonstrated that the ladder model is very effective and three-stage configuration has been found enough for the accurate modeling of inductors on a glass substrate from the experimental measurement.

2. Modeling and Experiments

Figure 1 shows the proposed ladder model for inductors on a glass substrate. This model accurately simulates skin and proximity effect of a conductor by the ladder part [2]. With the frequency increased, the impedances of L_{P1}, L_{P2}, $\cdots$, L_{Pn} are increased. As a result, the resistance is increased and the inductance is decreased. Multi-stage ladder configuration is effective for modeling complicated frequency response of a conductor part. C_S is the capacitance between PORT1 and PORT2. C_{OX1} and C_{OX2} are the substrate capacitances. Since glass is an insulator and conductive substrate effect can be ignored, the substrate effects are simply described by capacitances.

Figure 2 shows cross-sectional view of the inductor on a glass substrate fabricated to evaluate the accuracy of the ladder model. The lower layer of Al with the thickness of 0.3 μm was formed on a glass substrate. The upper layer of Al with the thickness of 1.0 μm is formed on a 0.3 μm-thick insulator.

Figure 3 shows optical microscope image of the fabricated inductor on a glass substrate. Layout parameters are as follows: the number of turns is 3.5, outer-dimension is 300 μm, the line width is 30 μm, and the line space is 5 μm.

3. Results and Discussion

Figure 4 shows the Q and L values of the inductor on a glass substrate obtained by 1/Y11 transformation from measured S-parameter. L_{dc}(inductance value at low frequency) is 2.1 nH, Q is 12.6 at 7.3 GHz as a peak, and f_{SR} is 16 GHz.

Model parameters were extracted from measurement results. First, C_{OX1} and C_{OX2} were directly obtained using Y-parameter π-type equivalent circuit shown in Figure 5, where C_{OX1} corresponded to Y11+Y12, C_{OX2} corresponded to Y22+Y12. Model parameters in the ladder part were extracted by using ADS circuit optimizer, in which linear optimizations on the least-square fitting method was utilized. Note that, using equations $R_{dc}=R_{P1}//R_{P2}//\ldots//R_{Pn}$, $L_{dc}=L_S+L_{ladder}$, the number of parameters can be reduced. L_{ladder} is the inductance of the ladder part. L_{dc} and R_{dc} are measured inductance and resistance at low frequency respectively.

Figure 6 shows the Im[1/Y11] accuracy of the ladder model as a function of the number of ladder stage. The ladder model with the single stage is identical to the conventional model, and the maximum error is 8%, which is too large for practical use. With increasing the ladder stages, the maximum error becomes lower. With the number of three or more stages, the maximum error falls within 2%, which is accurate enough.

Figure 7 shows the Re[1/Y11] accuracy of the ladder model as a function of the number of ladder stage. When increasing the frequency, the error of the single stage model is increased. The maximum error is 60% at 9 GHz, which is too large. With increasing the ladder stages, the maximum error becomes lower. With the number of three or more stages, the maximum error is less than 15%, which is accurate. However, comparing the three-stage with the four-stage, the errors are almost the same, which indicates that the ladder model with the three-stage is the best. This result is the same case of the Im[1/Y11].

Figure 8 shows the comparison of 1/Y11 obtained from the actual measurement with that obtained from the ladder model. This indicates that the ladder model can represent actual characteristics of inductors on a glass substrate with high accuracy.

4. Conclusion

The ladder model has been proposed to accurately model inductors on a glass substrate, in which skin and proximity effects are predominant. The ladder model with three-stage configuration has high accuracy with the maximum Im(1/Y11) error less than 2%, and the maximum Re(1/Y11) error less than 15%. The proposed model is effective for designing RFICs using inductors on a glass substrate.

Reference

[1] Nitz Saputra, Mina Danesh, Alessandro, Baiano, Ryoichi Ishihara, John R. Long, Nobuo Karaki, and Satoshi Inoue: IEEE J.Solid-State Circuits, **43** (2008) 1563.
[2] X.Huo, Philip C. H. Chan, Kevin J.Chen, and Howard C. Luong: IEEE Trans. Electron Devices, **53** (2006) NO. 12, 2942.

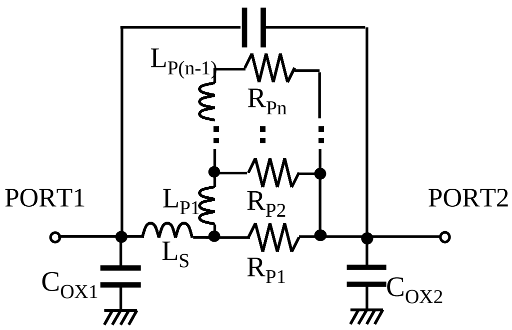

Fig.1 Proposed Ladder Model for inductors on a glass substrate.

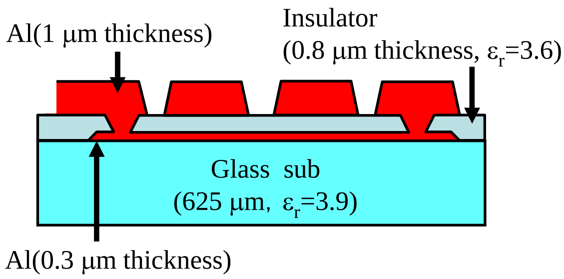

Fig.2 Cross-sectional view of the inductor on a glass substrate.

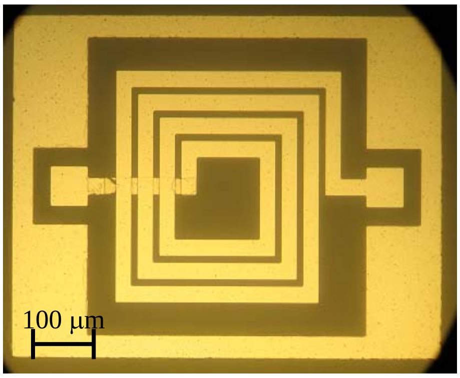

Fig.3 the optical microscope image of the inductor on a glass substrate.

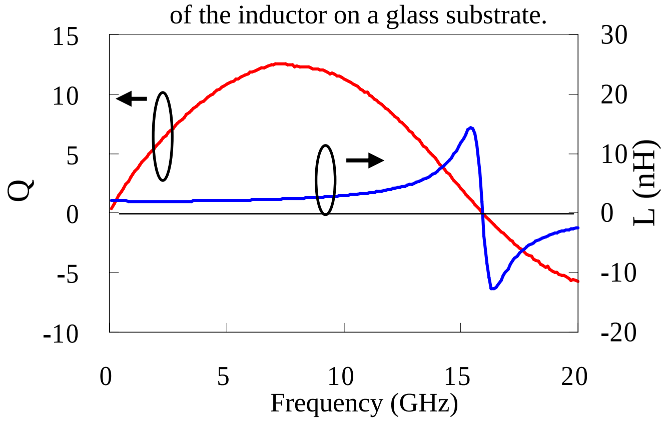

Fig.4 Q and L of inductors on a glass substrate by Y11 transferred from the measured S-parameter.

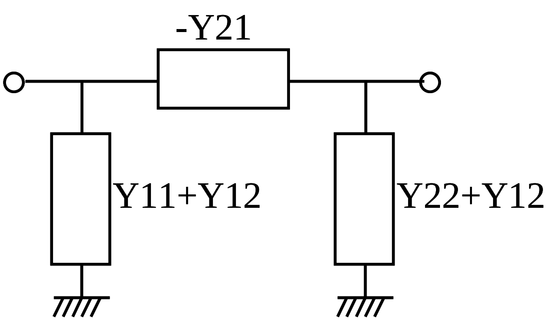

Fig.5 Y-parameter π-type equivalent circuit.

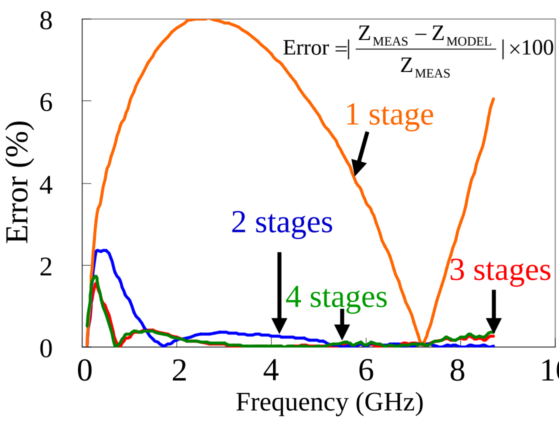

Fig.6 Im(1/Y11) error as a function of the frequency and the number of ladder stages

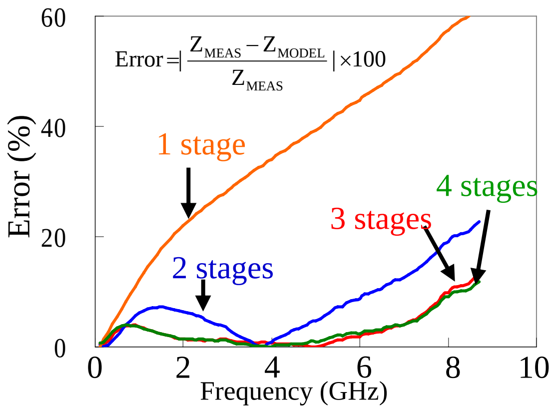

Fig.7 Re(1/Y11) error as a function of the frequency and the number of ladder stages

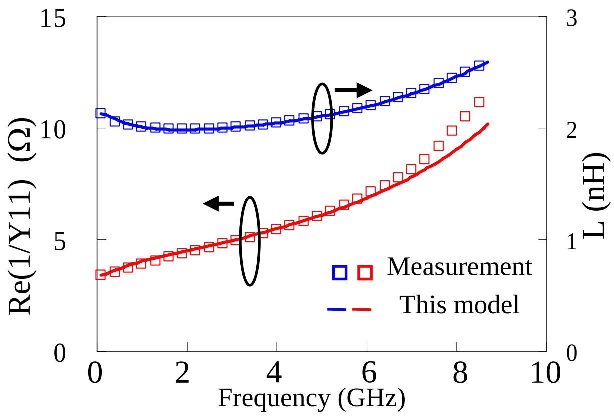

Fig.8 Comparison of 1/y11 obtained by the actual measurement and the simulation of Ladder Model.