RF Measurement of Permittivity of Low-k films on Si

Kouji Isari and Takamaro Kikkawa
Research Center for Nanodevices and Systems, Hiroshima University
Phone: +81-82-424-6265, Fax: +81-82-422-7185, E-mail: isari@sxsys.hiroshima-u.ac.jp

1. Introduction

Various methods for measuring RF characteristics of thin films have been developed by use of planer transmission lines such as a microstrip and coplanar waveguide which incorporate the thin film as part of transmission line [1, 2]. However, those methods have used relatively thick films compared to the substrate thickness; the thickness ratio of film/substrate is around 1/10. Typical thicknesses of thin films used in ULSI are ranging from 100 to 500 nm, and the thickness ratios of film/substrate are less than 1/1000 so that it is difficult to separate the capacitance of the thin films from that of substrate. In this study we have developed a measurement method of the permittivity of very thin films on a Si substrate.

2. Principle

Figures 1 and 2 show a schematic diagram of microstrip and equivalent circuit of this microstrip transmission line. From the frequency dependent propagation constant γ and characteristic impedance Z_0, the distributed capacitance C, conductance G, inductance L, and resistance R per unit length of the microstrip can be calculated from

$$G + j\omega C = \gamma / Z_0 \qquad (1)$$

and

$$R + j\omega C = \gamma Z_0 \qquad (2)$$

These four distributed parameters correspond to the equivalent circuit model for an incremental length of microstrip transmission line shown in Fig. 2. These parameters are also related to the dielectric materials and conductor that make up the microstrip transmission line. For a quasi-TEM mode propagation along a microstrip transmission line made up of dielectric material, C and G are related primarily to the permittivity of material incorporated in the transmission line. While R and L are related to the properties of the transmission line conductor [3]. Thus by using both the propagation constant and characteristic impedance, we are able to separate the properties of the dielectric from the metallic conductors.

3. Results of HFSS Simulation

Circuit parameters were calculated in the frequency range from 1 to 30 GHz, by using "Ansoft HFSS ver. 9.0", where the transmission line widths were changed from 1 to 10 μm. From (1) and (2), the four circuit parameters C, G, R and L for the four microstrip transmission lines were calculated with relative dielectric constant of 4.0. Figure 3 shows C for the circuit. Film dielectric loss is shown in Fig. 4. It is found that as the line width becomes narrower, C and dielectric loss become smaller.

To confirm the effect of thickness on microstrip line structure, we changed relative dielectric constants of thin films from 2 to 5. Figure 5 shows C for the microstrip line, in which are changed the relative dielectric constants of the thin film line widths of 1, 2, 5 and 10 μm. Capacitance becomes smaller as line width becomes narrower as shown Fig. 6. From these simulations, we can also estimate C as a function of a dielectric constant of thin film. Figure 7 shows results of a typical polynomial fit with line width of 1 μm at 1, 5, 10 and 20 GHz. To apply these analyses for measured data, we could estimate relative dielectric constants of thin films on a Si wafer.

4. Summary

Dielectric constants of thin films on a Si wafer can be estimated by using HFSS simulation. To estimate the dielectric constant precisely, it is important to use narrower transmission line width less than 1 μm.

References

[1] J.Baker-Javis, R. Geryer, J. Grosvenor, M. Janezic, C. Jones, B. Riddle, C. Weil, and J. krupka., IEEE Trans. Dielect. Elect. Insulation, vol 5 (1998) pp. 571-577.
[2] G.ponchet., IEEE Trans. Comp., Packag., Manufact. Technol., vol. 21 (1998) pp.171-176.
[3] M.D.Janezic, D.F.Williams, V.Blaschke, A.Karamcheti, and C.S.Chang., IEEE Trans. Microwave Theory Tech., vol 51 (2003) pp.132-136.

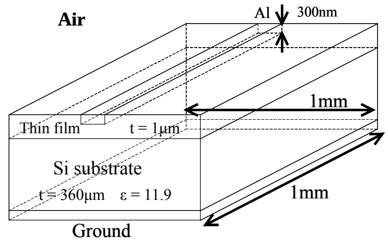

Fig. 1. Schematic diagram of a microstrip line.

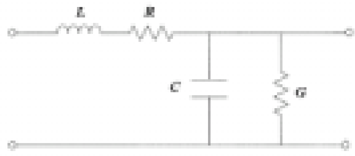

Fig. 2. Transmission line equivalent-circuit model.

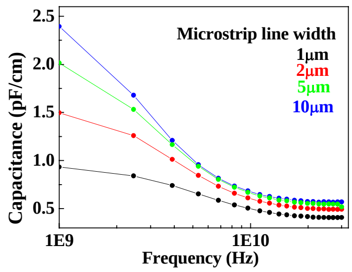

Fig. 3. Capacitances of microstrip lines.

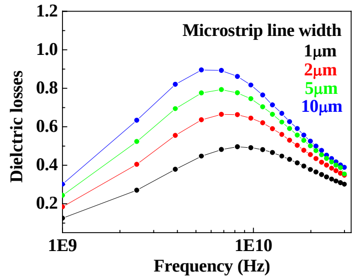

Fig. 4. Dielectric losses of microstrip lines.

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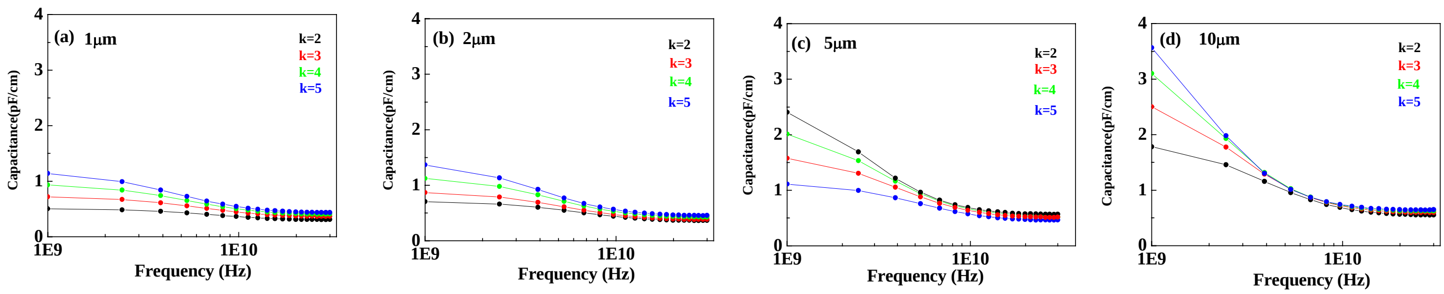

Fig. 5. Capacitances of a microstrip lines fabricated on dielectric thin films. Microstrip line width; (a) 1μm. (b) 2μm. (c) 5μm. and (d) 10μm.

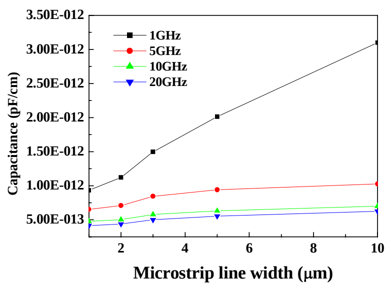

Fig. 6. Dependence of capacitance on microstrip line width.

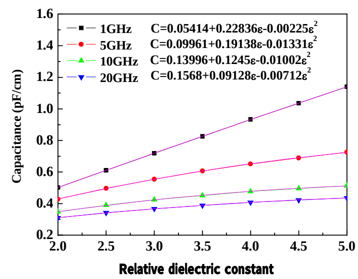

Fig. 7. Capacitance as a function of relative dielectric constants of thin films. The polynominal fit curve is with line width of 1 μm at 1, 5, 10 and 20 GHz.

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Research Center for Nanodevices and Systems, Hiroshima University

1-4-2 Kagamiyama, Higashi-Hiroshima, 739-8527 Japan

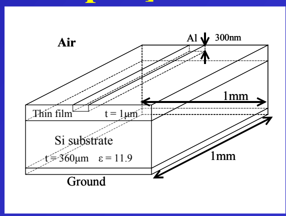
E-mail: {isari, kikkawa}@sxsys.hiroshima-u.ac.jp

RCNS Hiroshima University

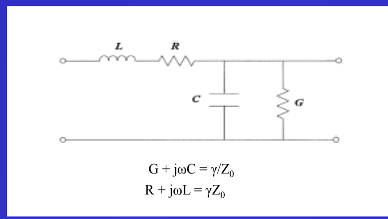
[Introduction]

It is difficult to separate the capacitance of the thin films from that of substrate. We have developed a measurement method of the permittivity of very thin films on a Si substrate.

[Principle]



Schematic diagram of a microstrip line



Equivalent-circuit model

From the frequency dependent propagation constant γ and characteristic impedance Z_0, the distributed capacitance C, conductance G, inductance L, and resistance R per unit length of the microstrip can be calculated.

[Result]

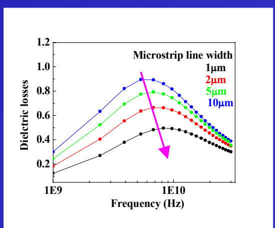
Simulation : Ansort HFSS ver.9.0

Parameter

Frequency range : 1-30 GHz
Microstrip line width : 1,2,5,10 μm
Thin film dielectric constant : 2-5
Substrate conduntance : 0-100 S/m

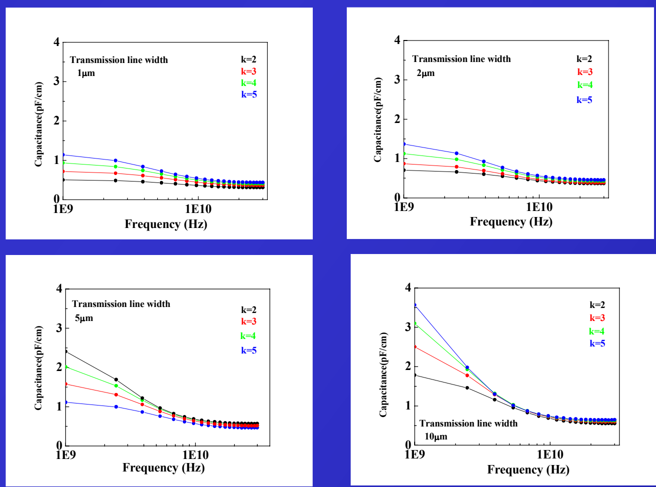
	Thickness	dielectric constant	Conductance
Substrate : Si	360μm	11.9	10 S/m
Thin film : SiO_2	1μm	4.0	0 S/m

Parameter



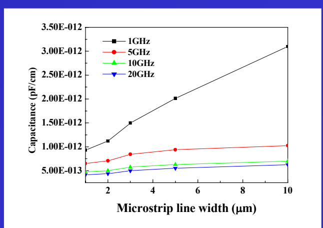
Dielectric losses of microstrip lines

Dielectric loss becomes smaller as line width becomes narrower.



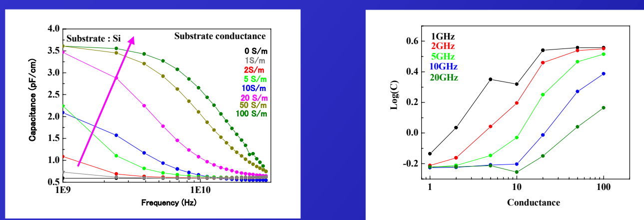
Capacitance of microstrip lines

Capacitance becomes smaller as line width becomes narrower.



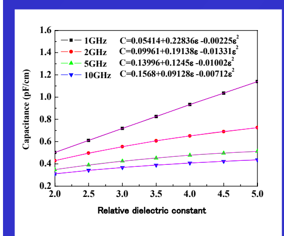
Dependence of capacitance on microstrip line width

Capacitance becomes smaller as line width becomes narrower.



Dependence of capacitance on substrate conductance

Capacitance at low frequency becomes larger as substrate conductance becomes higher.



Capacitance as a function of relative dielectric constants

These plots are simulated the capacitance when the k of thin film is changing, and the results of a typical polynomial fit with line width of 1 μm. To apply these analyses for measured data, we could estimate relative dielectric constants of thin films on a Si wafer.

[Summary]

- It is difficult to estimate the capacitance of thin film whose substrate conductance is higher, because frequency dependence of capacitance is extensive.
- To estimate the dielectric constant precisely, it is important to use narrower transmission line width less than 1 μm.

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