A Novel Genetic Algorithm Based Method for Measuring Complex Permittivity of Thin Samples in the Compact Radar Frequency Band

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***Abstract* — The growing demand for novel smart and enabling metamaterial designs and semiconductor devices in health, energy, communication, and automatic industries requires designs of material with "thin" features. For broadband complex permittivity measurements using open-ended coaxial probe (OECP), thin sample measurements present significant challenges since a large amount of power may go through the sample making the measured reflection coefficient values unreliable. In this paper, a new approach for accurate measurement of thin material properties is developed. It employs genetic algorithm (GA) and full-wave numerical simulations to find the complex permittivity to match the measured reflection coefficients. The complex permittivity values for several thin samples of known materials are obtained using our approach. Challenges in measuring nanolayers of graphene samples will be described and an effective measurement approach will be discussed.**

***Keywords*— thin sample, OECP, complex permittivity, genetic algorithm, graphene**

I. INTRODUCTION

Open-ended coaxial probe (OECP) has been used for nondestructive broadband dielectric property measurements. It measures the reflection coefficient (S11) from the material under test (MUT) and the complex permittivity of the MUT can then be determined [1]. The Agilent E8364B vector network analyzer (VNA) and Agilent 85070E Dielectric Probe have been used for such tasks. The dielectric property of thick materials in the compact radar frequency band can be measured directly by installing an Agilent Software Package in the network analyzer. However, the MUT must be thick enough to satisfy the "infinite" sample criteria in the calculation procedure [3]. Some efforts to extend OECP measurements to thin *liquid* materials in *millimeters* can be found in Folgero et al [4]. Bringhurst et al developed measurement on several thin solid materials in a *millimeter* range [3].

This paper proposes a new method to extend OECP's complex permittivity measurement capabilities to thin *solid* materials in the range of *micrometers* in the compact radar frequency band. Genetic algorithm (GA) is employed to find the best complex permittivity to match the measured reflection coefficients. For each generation of GA results, full-wave numerical simulations (Ansys High-Frequency Simulation Structure, HFSS) are carried out to obtain their complex reflection coefficients which are compared with the measured one to determine if the best complex permittivity is found.

II. MEASUREMENT SETUP AND SIMULATION MODEL

A. Measurement Setup

To obtain the measured S11, the reference plane needs to be set on the interface between the probe end and the MUT. However, the standard one-port calibration for the network analyzer is performed using calibration kits of short, open, and a matching load. A simple calibration method for OECP using a well-known complex permittivity liquid (distilled water) as a standard in place of a matching load can be found in Kraszewski et al [2]. The measurement setup of the MUT is backed with a known complex permittivity material as shown in Figure 1.

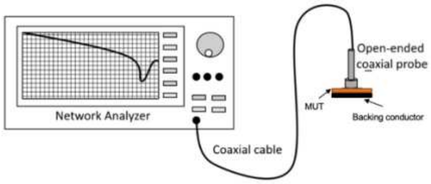

Figure 1. Apparatus Scheme

B. HFSS Design

The HFSS model of the measurement setup is shown in Figure 2. The top surface of dielectric filler is assigned to be a wave port excitation. By using the de-embedding feature of the wave port excitation in HFSS, the simulated S11 can be moved from the top surface of the coaxial cable to the aperture plane.

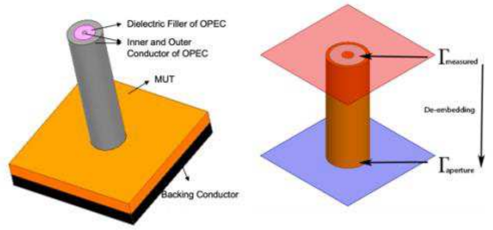

Figure 2. HFSS Design of OPEC placing on the MUT backing with Metal (left), De-embedding (right)

C. *HFSS Design Validation*

The results of the HFSS model design are required to be validated with the VNA measured results. To remove the effects of the air gap, a thick sample of distilled water is used for validation of our HFSS simulation probe model design. Then, the MUT material characteristics in the HFSS design are set to the complex permittivity of distilled water from the Agilent Software Package and the corresponding S11 is simulated. As shown in Figure 3, the S11 results from VNA measurement and HFSS simulation of distilled water are in a good match.

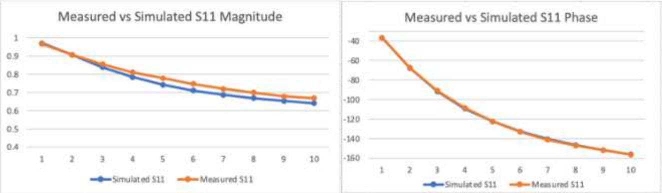

Figure 3. Measurement and Simulation Comparison of S11 Magnitude (left) and S11 Phase (right)

III. METHOD

Genetic Algorithm in MATLAB is employed to generate the desired complex permittivity (relative permittivity and loss tangent) of the MUT. Using the sets of complex permittivity that are initially assumed within a range of relative permittivity and loss tangent, GA will generate an initial population of sets of parameters. These sets will be simulated in HFSS and evaluated a fitness value. The fitness value F is defined as:

$$F=100\,|\Delta S_{11mag}| + |\Delta S_{11phase}| \tag{1}$$

where $|\Delta S_{11mag}|$ and $|\Delta S_{11phase}|$ are the difference of S11 magnitude and phase (in degree) of HFSS simulated result and VNA measured result.

GA will choose the best performing (lowest fitness value) complex permittivity parameters from the initial population and invoke mutations creating the next set to be simulated. This process of simulation and evaluation will continue until the fitness value satisfies the termination criteria or converges. Figure 4 shows the flow chart of GA using HFSS script to obtain the complex permittivity of the unknown MUT. This way of finding the minimum fitness value is called Zero-Finding Technique [5].

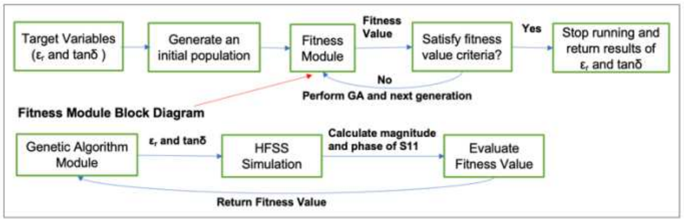

Figure 4. Flow Chart of GA Setup Environment

IV. ERROR ANALYSIS

As mentioned earlier, a small air gap between the probe end and the MUT creates significant errors in the measurement [3]. However, the errors created by the air gap can be modeled in the HFSS design by adding an air gap layer between the coaxial cable end and the MUT. The estimated air gap is around 0-3 µm, then in cases of air gaps of 0µm and 3µm, the GA results of the two cases can be established to be the lower and upper limit of the complex permittivity of the MUT. Other unexpected small errors may occur, such as inaccurate measurement of thinness, the surface roughness of MUT, OECP calibration error, instrument error, and test set error.

V. RESULT

Multiple samples with different thinness of 500µm alumina and 25µm polyimide are used for verifications. The corresponding air gaps are around 2-3µm and 0-1µm for the alumina sample and polyimide sample. The two materials have theoretical relative permittivity of 9.8 and 3.3 in a broadband frequency range. The GA results with error analysis are shown in Figure 5. Since they are all low-loss materials, the loss tangents of the two materials are around 0.001 to 0.01. The complex permittivity of these two samples matches their theoretical results.

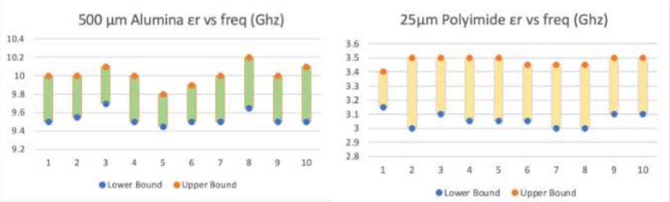

Figure 5. GA results of upper / lower bound of 500µm Alumina (left) and 25µm Polyimide (right) with error analysis

VI. CONCLUSION

We have developed a new approach to obtaining the complex permittivity of thin solid materials (in micrometers) using OECP measurement results in compact radar frequency band based on Genetic Algorithm and full-wave numerical simulations. Our method can obtain excellent results compared with theoretical values. Future development may include complex permittivity measurement of multi-layered, lossy, and ultrathin materials such as graphene on polyimide.

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