NON-DESTRUCTIVE MATERIAL HOMOGENEITY EVALUATION USING SCANNING NEAR FIELD MILLIMETER WAVE MICROSCOPY

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Millimeter wave bridge technique for non-destructive material homogeneity characterization is described. The idea of this technique is the local excitation of the millimeter waves in the testing material and the measurement of the transmitted (reflected) wave amplitude and phase in different places of it, i.e. the material plate is scanned by the beam of the millimeter waves. Same results of the homogeneity measurements for dielectric wafers are presented. The measurement technique sensitivity is discussed.

Introduction

In many cases, the quality of the fabricated material depends on spatial distribution of electrical, dielectric or mechanical parameters in the whole area of the sample. This is especially important for large area dielectric substrates and thin films used in electronics. Relatively short wavelength of the millimetre wave provides the possibility to utilise them for non-destructive homogeneity characterization of materials [1, 2]. In the present paper new possibilities of the technique based on the scanning of the material by millimeter wave beam and the measurement of transmitted (reflected) amplitude and phase in it different places are discussed.

Theoretical background

It is known that electromagnetic wave transmitted through a dielectric plate demonstrates resonance character. Maximum of transmission is observed at the condition d/λ = 1/2, 1, 3/2, 2,...n/2, where d is a thickness of the plate, λ is a wavelength, n is an integer. This resonance is known as Fabry-Perot resonance. An analysis of electromagnetic wave transmission through the dielectric plate with losses was presented recently [3]. A typical calculated dependences of transmitted wave coefficient and phase for different values of plate conductivity σ are presented in Fig. 1. The conductivity of the plate in the figure is characterized by the dimensionless parameter $\xi = Z_0\sigma d/2$, where Z_0 is an impedance of the free space. When the thickness of the plate contains whole number of half-waves the Fabry-Perot resonance condition is fulfilled and the transmitted wave power reaches its maximum. When σ increases the transmitted wave power decreases. It is important to point out that the influence of the conductivity on the transmitted wave phase is negligible. It is seen from the lower part of the figure where the dependences of the phase for different values of ξ are presented. The largest influence on the transmitted wave phase has a dielectric constant ε of the material under test. Its change causes the strongest shift of the transmitted wave phase at the same Fabry-Perot condition [4]. It means that the largest sensitivity determining inhomogeneities of the dielectric constant and conductivity in semiconductor wafer can be obtained by measuring transmission coefficient and phase distribution at Fabry-Perot resonance conditions. Therefore wishing to determine both dielectric constant and conductivity variation in the wafer area the phase and amplitude views in transmitted wave at a resonance condition should be analysed.

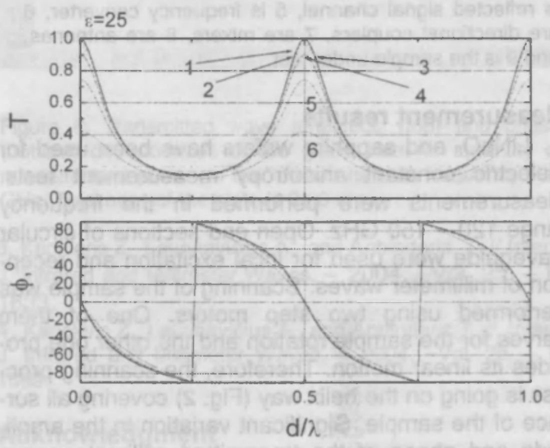

Figure 1. Typical dependences of the transmission coefficient (top) and the phase (bottom) of wave transmitted through the dielectric plate (ε=25) with losses on its thickness normalized to the wavelength of the plate for different values of dimensionless parameter ξ characterizing conductivity of the plate. 1– ξ=0, 2 – ξ=0.01, 3 – ξ=0.03, 4 – ξ=0.1, 5 - ξ=0.3, 6 – ξ=1.0.

Measurement technique

The main idea of the measurement technique operation is the local excitation of millimeter waves in the sample under test and the measurement of transmitted (reflected) wave amplitude and phase at different points of the sample. In essence, we use a millimeter wave bridge consisting of a reference signal and a measuring signal channels (Fig. 2). The tested sample is placed between waveguide probes that provide both local excitation and reception of the low power millimeter wave signals. The sample can be moved relative to the exciting and receiving probes by scanning mechanism. Changes of the electric, dielectric or mechanical parameters in the sample area cause changes in the amplitude and phase of the transmitted (reflected) signal. By probing the sample at different points with the millimeter wave beam, information about the homogeneity of the sample can be obtained. All measurement processes are computer controlled and the measurement results are compiled in the computer. Some examples of the applications of our technique for the measurement of dielectric constant anisotropy distribution in the wafers are presented below.

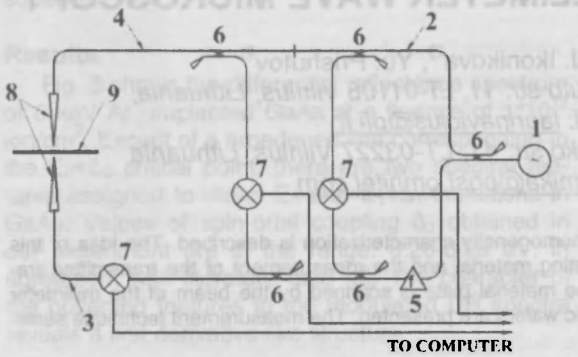

Figure 2. Schematic diagram of the device measuring transmitted and reflected electromagnetic wave amplitude and phase: 1 is millimeter wave oscillator, 2 is reference signal channel, 3 is transmitted signal channel, 4 is reflected signal channel, 5 is frequency converter, 6 are directional couplers, 7 are mixers, 8 are antennas, and 9 is the sample under test.

Measurement results

$LiNbO_3$ and sapphire wafers have been used for dielectric constant anisotropy measurement tests. Measurements were performed in the frequency range 120 – 150 GHz. Open end sections of circular waveguide were used for local excitation and reception of millimeter waves. Scanning of the sample was performed using two step motors. One of them serves for the sample rotation and the other one provides its linear motion. Therefore, the scanning process is going on the helix way (Fig. 2) covering all surface of the sample. Significant variation in the amplitude and phase of the transmitted millimeter wave has been observed in the corresponding images for $LiNbO_3$ wafer (Fig. 3). They are related with dielectric constant anisotropy. Measurement results of the sapphire wafer for two different frequencies are shown in Fig. 4 and Fig. 5. Such amplitude and phase variation data are used for constructing images like this shown in Fig. 3. Comparing curves shown in Fig. 4 and Fig. 5 that are measured at f =122 GHz and f =132 GHz, respectively, one can see that the changes in phase are large at frequency 122 GHz ($\Delta\Phi$ ~ 110°) than at frequency 132 GHz ($\Delta\Phi$ ~ 66°) of the transmitted wave. The point is that for tested wafer fifth order Fabry-Perot resonance condition (d = 5λ/2) is fulfilled at f =122 GHz. As for f =132 GHz, d = 11λ/4 and this frequency is far enough from the resonance condition. These results confirmed in general our earlier predictions that the largest sensitivity of homogeneity mapping can be achieved when the measurements are performed at Fabry-Perot resonance conditions. For comparison corresponding measurement results for glass plate are presented in Fig. 6 what demonstrate good isotropy of this material. It is seen that resolution power in the amplitude is about 2 % and in the phase about 2deg.

Conclusion

Millimeter wave bridge technique for non-destructive material dielectric constant anisotropy characterization is presented. The idea of this tech-

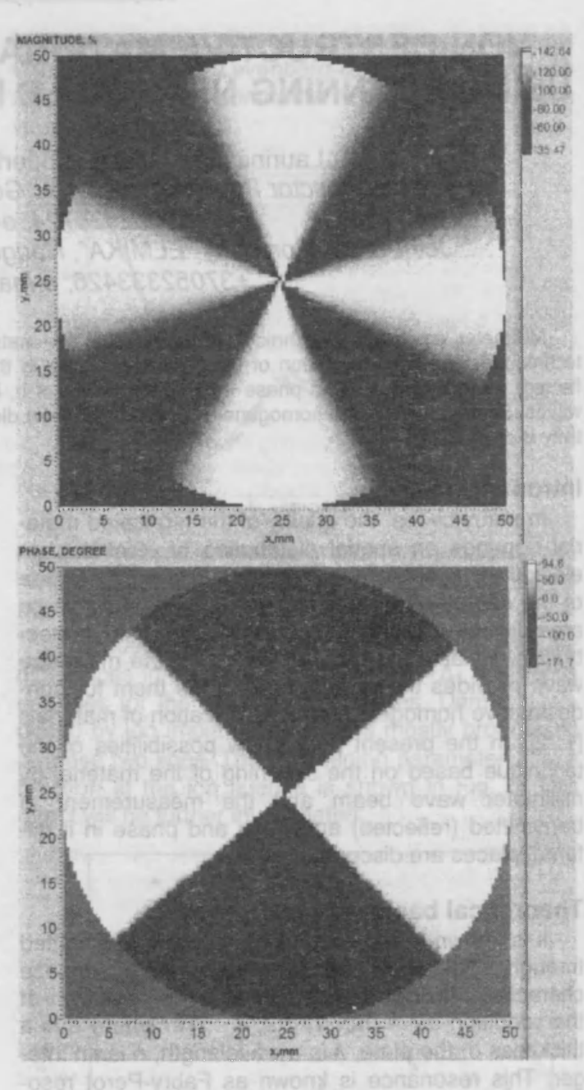

Figure 3. Transmitted millimeter wave amplitude (top) and phase (bottom) images of the $LiNbO_3$ wafer at frequency 130 GHz. Thickness of the wafer is 1,00 mm. Diameter of the scanning area is 50 mm.

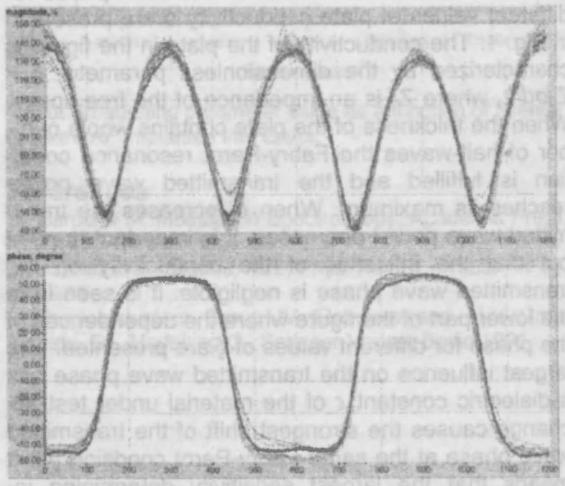

Figure 4. Transmitted wave amplitude (top) and phase (bottom) dependences of the sapphire wafer on quantity of measurement points on the rotation helix at frequency 122 GHz. Thickness of the wafer is 1,85 mm.

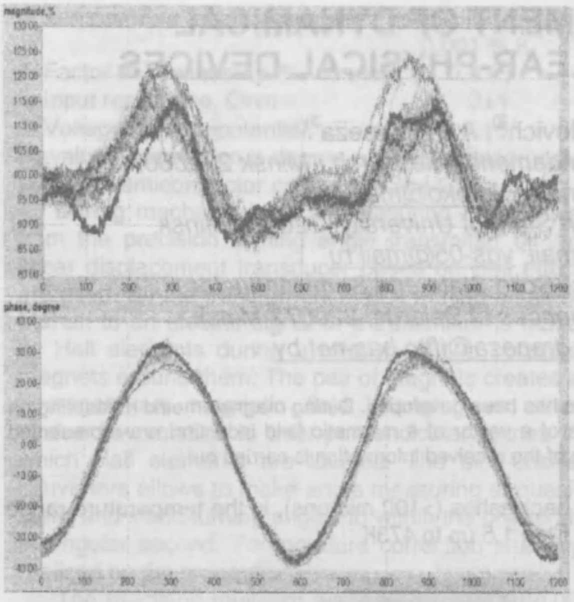

Figure 5. Transmitted wave amplitude (top) and phase (bottom) dependences of the sapphire wafer on quantity of measurement points on the rotation helix at frequency 132 GHz. Thickness of the wafer is 1,85 mm.

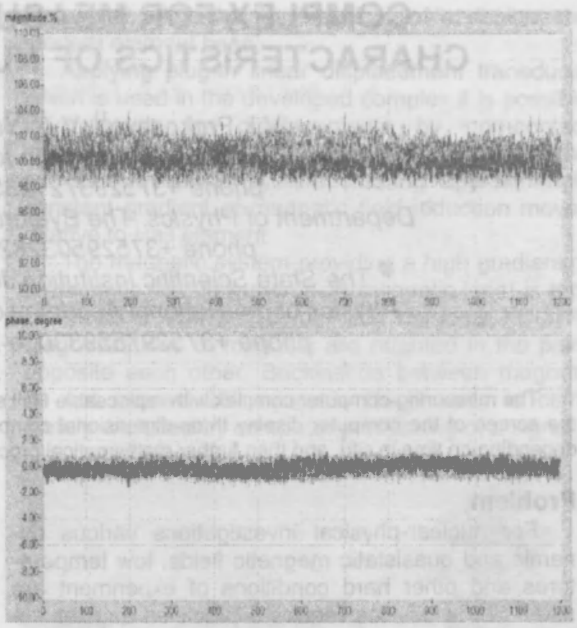

Figure 6. Transmitted wave amplitude (top) and phase (bottom) dependences of the glass plate on quantity of measurement points on the rotation helix at frequency 132 GHz. Thickness of the plate is 2,00 mm.

nique is the local excitation of the millimeter waves in the wafer under test and the measurement of the transmitted wave amplitude and phase in the different places of the sample. Measurement results of the anisotropy measurements for some dielectric wafers are presented. The space resolution is about 1 mm^2. The measurement technique sensitivity is discussed.

References

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