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Scanning Nondestructive Material Homogeneity Mapping Technique

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Millimeter wave bridge technique for non-destructive material homogeneity mapping is described. The concept of this technique is the local excitation of millimeter waves in testing material and the measurement of the transmitted (reflected) signal's amplitude and phase in it different places. Some results of the homogeneity measurements for the dielectric substrates, metallic surfaces and biological objects are also presented.

Keywords: material homogeneity, millimeter waves.

1. INTRODUCTION

There are many papers where millimeter wave application for non-destructive characterization of a vide spectrum of materials were described. Usually the bulk or surface resistance as well as the dielectric permittivity of the material can be measured in this way. In many cases, the quality of the fabricated material depends on spatial distribution of these parameters in the whole area of the sample. This is especially important for large area dielectric substrates and thin films used in electronics. The relatively short wavelength of the millimeter wave makes it possible to utilise such waves for non-destructive characterization of a material's homogeneity. For example, scanning of a material surface by millimeter wave beam and measuring reflected (transmitted) power yields a resistivity map [1]. The probe size and the probe-sample distance determine the spatial resolution of the measurement results. Several designs of the millimeter wave probes based on a narrow resonant slit [1], metal micro-slit [2] and thin-slit aperture in a convex end plate of rectangular waveguide [3] were used. The spatial resolution of the near-field microscopy using such probes is about 100 μm. A non-destructive millimeter wave resonant measurement method based on the open resonator technique for the homogeneity characterization of dielectric [4] high-temperature superconductor wafers [5] was also proposed. Although the sensitivity of this method is very high, its spatial resolution that depends on the millimeter wave beam waist (∅ ~7 mm) is not sufficiently good. In this letter we propose a millimeter wave technique that is capable of solving this problem.

2. EXPERIMENTAL DETAILS

The main idea of the experiment is the local excitation of millimeter waves in the testing sample and the measurement transmitted (reflected) amplitude and phase at different locations. A simplified schematic diagram of the experimental set-up is shown in Fig. 1. In essence, this is millimeter wave bridge consisting of a reference signal channel and a measurement channel. The part of the schematic diagram marked by the dash line corresponds to a bridge making reflectivity measurements.

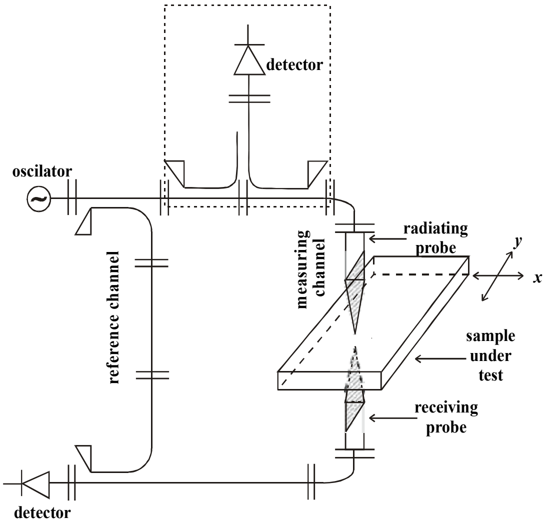

Fig. 1. Schematic diagram of the millimeter wave bridge

In such case, the radiating probe also acts as the receiving antenna for the reflected wave. A testing sample is placed between special dielectric waveguide probes which provide both local excitation and reception of the low power millimeter waves ($f = 120$ GHz). The sample can be moved by the scanning mechanism relative to the exciting and receiving probes in the x-y plane. Changes of the electric or dielectric 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 can be obtained about the homogeneity of the sample. All measurement processes are computer controlled and the measurement results are compiled in the computer.

3. RESULTS

The measured homogeneity of sapphire and $LaAlO_3$ substrates are shown in Fig. 2 and Fig. 3, respectively. Tops and bottoms of the pictures correspond to the

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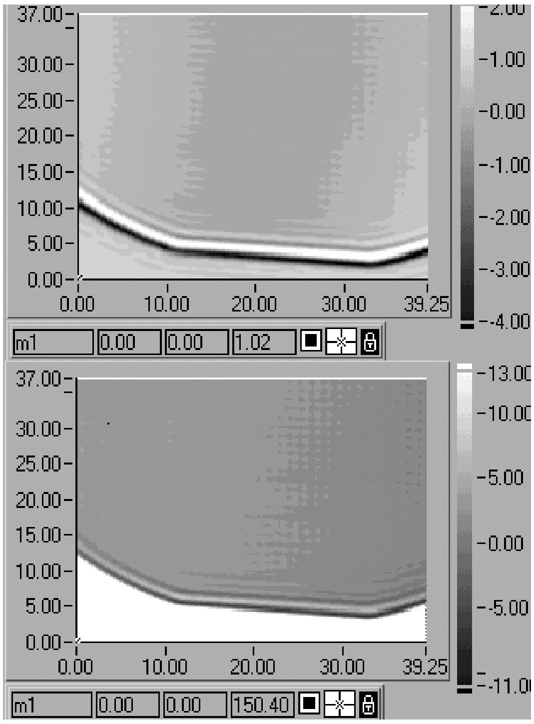

Fig. 2. Transmitted wave amplitude (top) and phase (bottom) images of the sapphire substrate. Thickness of the substrate is 0.43 mm. The scanning area is 37.00 × 39.25 mm^2

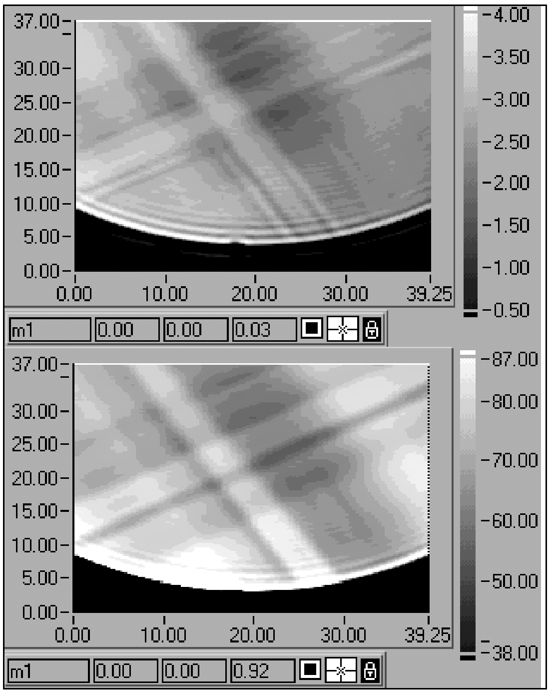

Fig. 3. Transmitted wave amplitude (top) and phase (bottom) images of the $LaAlO_3$ substrate. Thickness of the substrate is 0.50 mm. The scanning area is 37.00 × 39.25 mm^2

transmitted millimeter wave amplitude and phase images of the measured substrates. Both the amplitude and the phase images in the Fig. 2 demonstrate the high homogeneity of the sapphire substrate. But for the $LaAlO_3$ substrate (Fig. 3) the crystal twining associated with lattice structure inhomogeneity is seen very clearly. Besides, millimeter waves have certain advantages over ultrasonic testing of mechanical defects inside dielectrics. Because they have relatively high penetration depth, they can image bulk nonhomogeneities. They have good transmission across solid-air boundaries unlike ultrasound. The observed spot in the millimeter wave image of the SiC substrate (Fig. 4) demonstrate the possibility of application of these waves for detection of mechanical defects inside the crystal. The observed defect is related with wave scattering by microslits in the crystal volume. Dimensions of the microslits are less than 1 mm.

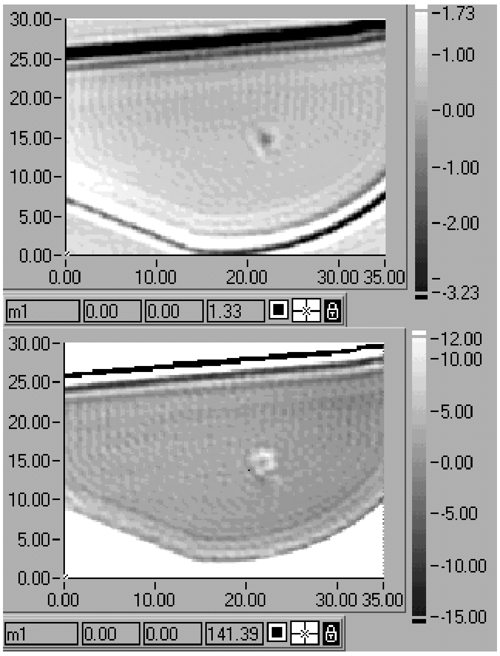

Fig. 4. Millimeter wave amplitude (top) and phase (bottom) image of the mechanical defect in the SiC substrate volume. Thickness of the substrate is 0.50 mm. The scanning area is 30.00 × 35.00 mm^2

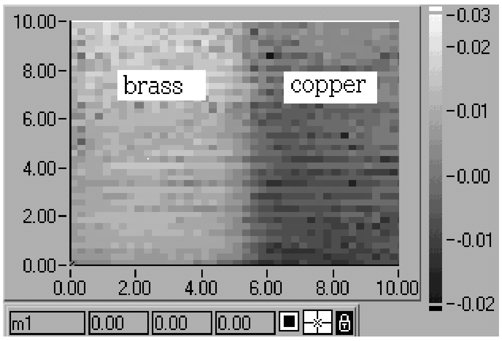

Fig. 5. Reflected wave amplitude image of the mirror made of two different metals (copper and brass*)*. The scanning area is 10 × 10 mm^2

The reflection of electromagnetic waves from conducting surfaces is determined by their resistivity. Thus, measurements of the reflected wave amplitude produce a resistivity map. This can be seen very clearly in Fig. 5, where a metal mirror surface with different resistivity was scanned by a millimeter wave beam and corresponding changes of the reflection were detected. Besides, millimeter waves can be used for investigation of the biological

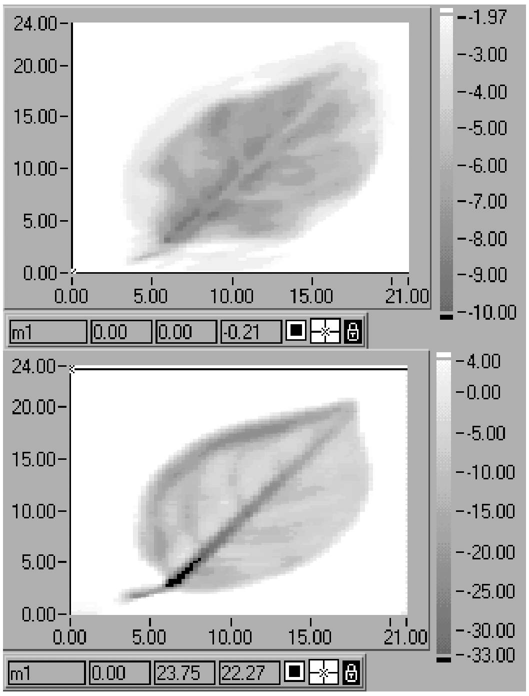

Fig. 6. Transmitted wave amplitude (top) and phase (bottom) images of the plant leaf. The scanning area is 21 × 24 mm^2

objects. For example, images of a leaf of plant at millimeter waves are shown in Fig. 6. Darker places in the picture (top) correspond to the higher level of the moisture content in the leaf.

4. COCLUSION

In this paper we present a millimeter wave homogeneity mapping technique useable for very wide spectrum of large area materials, including dielectrics, semiconductors, metals and biological objects. A spatial resolution of this technique is 0.5 mm^2.

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