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Advanced Illumination Tank with Super-hydrophilic Metal Boundary in Microwave Tomography System

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Abstract— **This article presents the advanced illumination tank structure of a microwave tomography system for breast cancer detection. The proposed tank has been implemented with a super-hydrophilic aluminum sheet to realize the upper boundary conditions of the perfect electric conductor with no air gap. In contrast, the previous tank had an air gap layer between the human chest and the matching liquid. A comparison of the results shows that the air gap causes the strong pathing of the transmitted signal when measured near the liquid surface. In the proposed tank, the super-hydrophilic property of micro-to-nano hierarchical structures naturally prevents the forming of air bubbles on the surface, and the shielding property of the aluminum sheet provides stable measurement free from outside interference.**

Index Terms— **microwave tomography system, illumination tank, super-hydrophilic surface, air bubble**

I. INTRODUCTION

In recent years, there has been a significant growth of research involving the use of microwaves to image the human body [1]. Among the many examples of ongoing research, microwave imaging for breast cancer detection has attracted research interest with the prospect of replacing X-ray mammography as the screening tool for early breast cancer detection. To date, several microwave imaging systems have been developed in a number of different countries. Our research group has also studied the development of a precision microwave tomography (MT) system [2–5].

The existing tank structure of the MT system has an air gap over the surface of the microwave matching liquid. The boundary region makes a transmitted microwave signal pass mostly through the air space during the measurement of the scattering signal near the liquid surface. The resulting measurement data is expected to contain very weak information about the dielectric property of the breast interior. The complicated boundary region should also be implemented in the forward solver of the electromagnetic (EM) inversion to reconstruct the precise tomographic image. Those drawbacks make it difficult to find tumors.

In this letter, we present an advanced illumination tank structure designed to obtain stable measurement data even near the liquid surface. The structure has been covered with a super-hydrophilic metal sheet on the tank top surface to achieve the boundary condition of a perfect electric conductor (PEC), which provides the easy implementation of the boundary condition in the EM forward solver. Here, the super-hydrophilic surface made of a micro-to-nano hierarchical structure has a good wetting property, which achieves good performance in removing the air bubble on the metal surface. The following section describes the results in detail.

II. DESIGN AND RESULTS

In this work, we have considered the basic MT system as follows [4]. The patient lies face-down on the bed, and a breast is placed into the illumination tank under the bed. The tank is filled with the microwave matching liquid, 1,3-butylene glycol, which has a low-loss dielectric property ($\varepsilon_r \approx 5$, $\sigma \approx 0.45$ S/m at 3 GHz) and is a nontoxic material. In the tank, the ring-structured array antennas consisting of 16 waveguides [3] is immersed. The aperture size of a waveguide element is 23 mm × 18 mm. To acquire the scattering data, one antenna transmits a microwave signal, and the remaining antennas receive the scattered signal at every layer (at a vertical spacing of 10 mm) from the nearest liquid surface. The antenna position of the nearest liquid surface is 3 mm from the surface, which is considered layer 0.

Fig. 1 shows an illustration and simulated measurement data for both the previous and the proposed tank structures. The previous tank structure (left of Fig. 1a) has an air gap layer (10 mm) and an acrylic layer between the liquid surface and the woman's chest, while the advanced structure (left of Fig. 1b) is fully covered with an aluminum metal sheet, and the matching liquid is full, with no air gap. The illustration notes that the metal part B is opened when the breast is inserted into the tank. To compare the different boundary effect of each tank structure, we conducted an EM simulation using the CST Microwave Studio; the graphs in Fig. 1 show the results at 5 GHz. In the case of the previous structure, we can observe

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the different measurement pattern according to the layers. The amplitude of the electric field is much higher at layer 0 (i.e., the nearest liquid surface). That is because the transmitted microwave almost passes through the air space, and the dominant propagation into the air leads to weak information in the measurement of the breast interior; it is related to poor quality of image reconstruction. However, the proposed structure produces almost identical measurement data patterns for each layer and ensures stability from any unwanted outside EM influence.

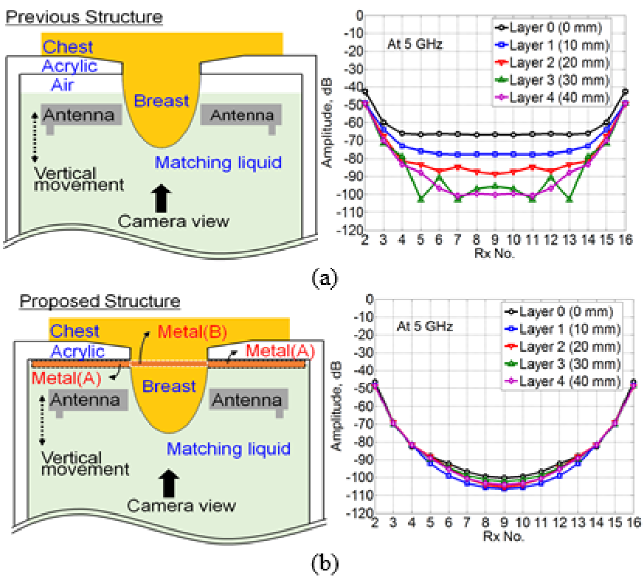

Fig.1. Illumination tank structure (left) and measurement data in the absence of the breast (right) (a) Previous case (air boundary) (b) Proposed case (super-hydrophilic metal boundary)

To perform the experimental test of the proposed boundary condition, we first attached the original aluminum sheet (6061-T6, 2 mm thickness) on the top surface of the tank, as shown in Fig. 1(b), and then pumped up the matching liquid until the tank was full. However, an unexpected air bubble randomly stuck onto the metal surface (see Fig. 2b). To investigate the influence of the generated air bubble, we compared the actual measurement data with the reference data at layer 0. The reference data was measured after the air bubble was removed by force, as shown in Fig. 2(a). The amplitude and phase difference of the two cases is shown in Fig. 2(c); in the operating frequency of 3 to 5.8 GHz, the peak-to-peak deviation of the difference is about 31.52 dB and 207.95 degrees, and the standard deviation is about 3.09 dB and 28.71 degrees. The result shows that the measurement data is strongly influenced by the unwanted air bubble formed on the upper boundary surface.

To remove the air bubble formed on the upper boundary surface, we next considered the aluminum surface to be super-hydrophilic; the super-hydrophilic surface has a good wetting property (i.e., the contact angle of the liquid is almost 0 degrees). The surface was fabricated to be dual scale hierarchical structures combining both the micro- and nano-structure (see [6]). The original aluminum sheet was first degreased in a 1-mol/dm3 sodium hydroxide solution for 30 sec at 27 °C. To fabricate micro structures on the surface, the sheet was etched in a 1-mol/dm3 hydrochloric acid solution for 90 sec at 80 °C. Then, the sheet was dipped into 1-mol/dm3 sodium hydroxide solution to form aluminum hydroxide gels. The sheet was immersed in boiling deionized water for 120 sec after sodium hydroxide treatment to fabricate crystalline aluminum hydroxides.

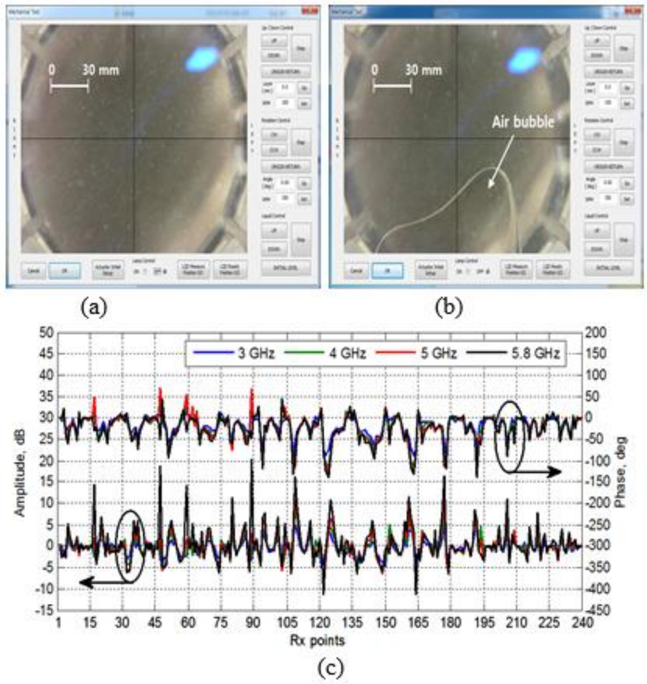

Fig.2. Experimental results under the proposed tank structure having original metal boundary (a) Reference case (air bubble was forcibly removed) (b) Actual case (air bubble was naturally formed) (c) Amplitude and phase difference between the two cases

Fig. 3 shows the mechanism of the air bubble formation and removal for the cases of the original and the super-hydrophilic surfaces. The original metal surface (see Fig. 3a) induces surface tension. Because of this, the air bubble easily clings to the surface. In contrast, the super-hydrophilic surface gets wet and then releases the surface tension. This prevents the formation of air bubbles on the surface.

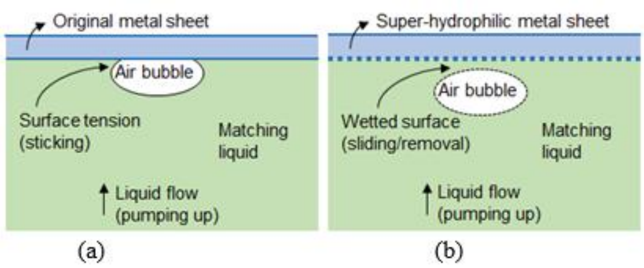

Fig.3. Mechanism of air bubble formation and removal (a) Case of original metal boundary (b) Case of super-hydrophilic metal boundary

Finally, we implemented the super-hydrophilic aluminum sheet on the top of the illumination tank in the MT system (as shown in Fig. 1b). The experimental result is shown in Fig. 4. According to the test, the air bubble was naturally removed (or slipped out) when the matching liquid touched the super-hydrophilic surface (see Fig. 4b). To compare the result with the case of the original surface having no air bubble (reference case; Fig. 4a), we obtained the amplitude and phase differences between the two cases at layer 0 (see Fig. 4c).

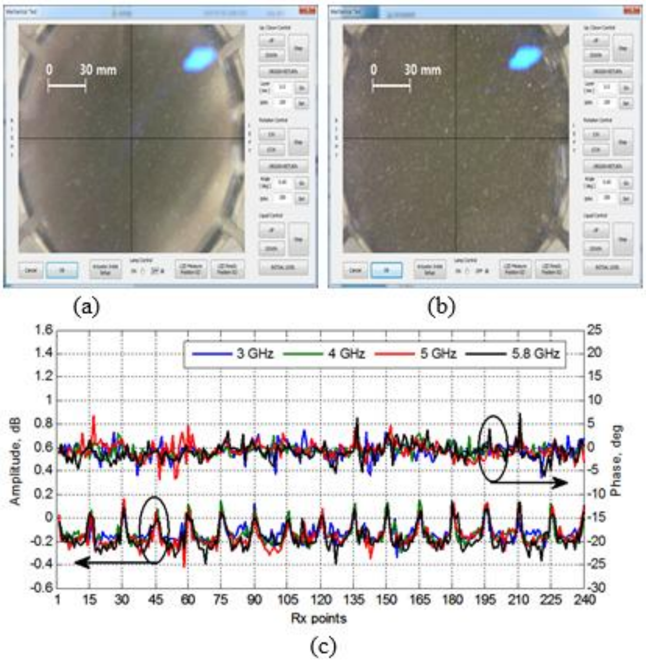

Fig.4. Experimental results under the proposed tank structure having super-hydrophilic metal boundary (a) Reference case (air bubble was forcibly removed) (b) Actual case (air bubble was naturally removed) (c) Amplitude and phase difference between the two cases

The peak-to-peak deviation of the difference is about 0.58 dB and 14.11 degrees, and the standard deviation is about 0.09 dB and 1.59 degrees. The result is within the range of measurement uncertainty of the inherent transceiver. We thus confirmed that a super-hydrophilic surface performs the PEC condition in which no air space is formed on the upper boundary surface of the illumination tank.

III. Conclusion

We presented an advanced illumination tank structure covered with a super-hydrophilic aluminum sheet in a microwave tomography system. The implementation achieved a good PEC boundary condition and the effective removal of air bubbles on the boundary surface. The measurement data was found to be quite stable with identical patterns at every layer, even near the liquid surface. This information will be helpful in reconstructing a precision MT image.

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