Reconstruction of Subsurface Dielectric Structure by Microwave Near-Field Measurements

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Scanning near-field microwave microscope for subsurface imaging of samples dielectric inhomogeneities has been built. It includes the small-aperture antenna as a probe, microwave reflectometer, mechanical scanning system and registering device. Special mathematical technique has been developed to achieve super aperture resolution. 3 times increasing of resolution in comparison with initial aperture resolution have been demonstrated.

1. Introduction

Surfaces imaging by near-field microscopy at microwave (MW) frequencies was first demonstrated in [1] and developed further in [2-7]. Corresponding devises have the resolution scale $\sigma<<\lambda$ approximately equal to aperture size $D \approx \sigma = \lambda/n$, where λ is the operating wavelength, $n>>1$. Only the obvious property of near-field measurements to make resolution higher by decreasing D has been considered earlier. For MW near-field microscopes the value of n is typically of about 10^2 - 10^3; the maximum value of $n \approx 10^5$ was reported in [5]. It is necessary to note that increasing of n leads to decreasing of the sounding depth h because the condition $h \sim \sigma$. Thus, a large penetration depth as an important advantage of MW can be lost. In this work we have built a MW near-field system with a low enough space resolution ($n \sim 10^2$) especially for the subsurface sounding of samples. But for all that, a special mathematical procedure of super aperture resolution has been developed to compensate for losses of resolution.

2. Experiment

Fig.1 is a schematic of our 2-D scanning near-field system, and shows a small-aperture antenna used as a probe. Sensitive element of antenna with the size of 5×6 mm^2 have the meander form and is made in contact with a microstrip resonator (resonant frequency $f_0 \approx$

640 MHz, bandwidth $\Delta f \approx$ 15 MHz). The test samples were Al_2O_3 substrates with the deposited Cu films (~ 100 nm) from which the metal-dielectric structures have been formed. Optically opaque dielectric plates with various depths covered the samples. As the probe approaches to the sample, the equivalent impedance of sensitive element changes and the resonant frequency f_0 shifts. Inhomogeneities of the sample dielectric constant lead to variances of f_0. In normal operation, we apply the microwave power at a frequency that is somewhat off the resonant frequency. So, we measure changes of antenna reflection coefficient induced by the sample structure inhomogeneities. To make the sensitivity higher we used the 1 KHz meander modulation of MW radiation on the antenna input and the selective amplification of the reflected signal at the modulation frequency. The 2-D scanning of antenna by stepper motors with the step in x and y-directions of 0.125 mm makes images with the maximal size of observed area 4×4 cm^2. Coordinates of each pixel and corresponding measurement results are stored in a computer.

3. Reconstruction of images

The sample image is 2-D distribution of the measured antenna reflection coefficient R_m, and it can be expressed (at least, approximately) as a function of probe coordinates:

$$R_m(x,y) = \int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} K(x-x', y-y')R(x',y')dx'dy' \quad , \tag{1}$$

where *R(x,y)* is the true image of a sample, *K(x,y)* is the transfer function of antenna. Thus, the initial measured image is the 2-D convolution of the real image and the antenna transfer function. The influence of the antenna transfer function leads to the smoothing of observed image contrasts. For our system *K(x,y)* have been determined by scanning of simple one-dimensional metal – dielectric interface. It was obtained that a good approximation for *K(x,y)* is

$$K(x,y) = \frac{4}{\pi\sigma_x\sigma_y}\exp[-4(\frac{x^2}{\sigma_x^y} + \frac{y^2}{\sigma_y^2})] \tag{2}$$

where parameters σ_x = 2.3 mm, σ_y = 3.6 mm were determined from measurements. These parameters can be considered as the resolution in x and y-direction. For example, using the measured dependence of the metal-dielectric interface (step-function response) in y-direction shown in Fig.2, the value σ_y has been determined.

The reconstruction of images has been done by deconvolution of (1) using the measured image as the left part of (1) and the obtained transfer function (2). It is well known that the solution of integral Fredholm equation of the 1-st kind (1) is an ill-posed inverse problem.

Special mathematical technique based on Tikhonov's method of generalized discrepancy [8] has been developed for this purpose.

4. Results

An efficiency of developed technique have been examined by the retrieval of images of samples produced as two parallel dielectric strips carried through metal cower under the dielectric layer. The width of strips *w* and metal cowered distance between them *d* were equal ($w = d$).

In Fig.3 it is clearly seen that the sharpness of the reconstructed image is much better than of the initial one. It is because the space resolution after deconvolution became higher than the initial resolution of antenna. Our calculations gives that new resolution became about 3 times better than the measured resolution $\sigma_{x,y}$ in (2). This estimation is obtained using the retrieved image of the metal-dielectric interface.

5. Conclusion

Thus, in this work the super-aperture resolution for subsurface MW near-field microscope have been achieved.

Acknoweledgements

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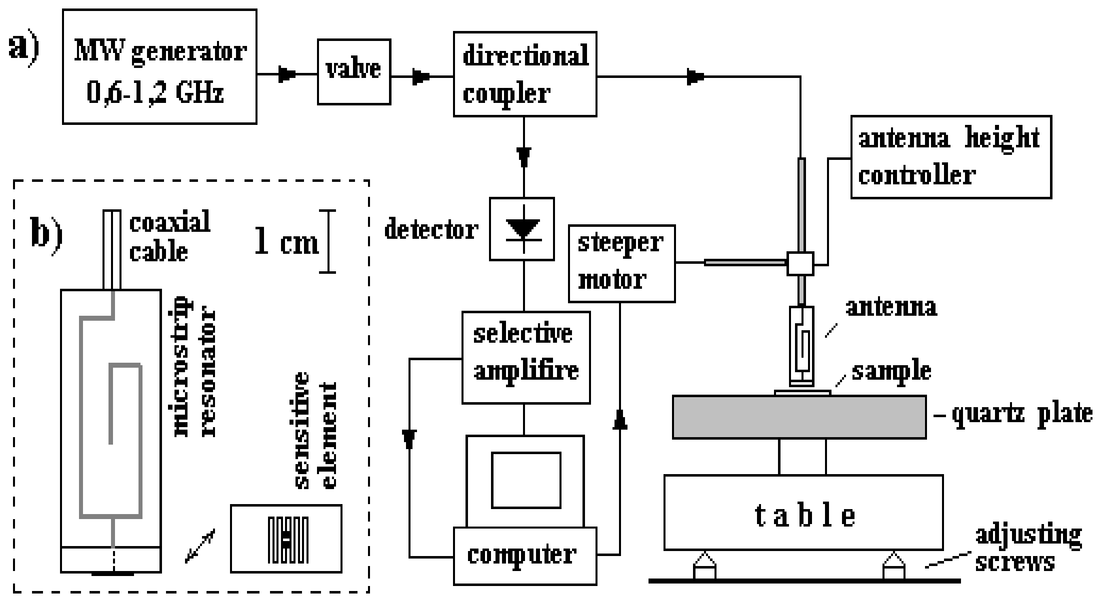
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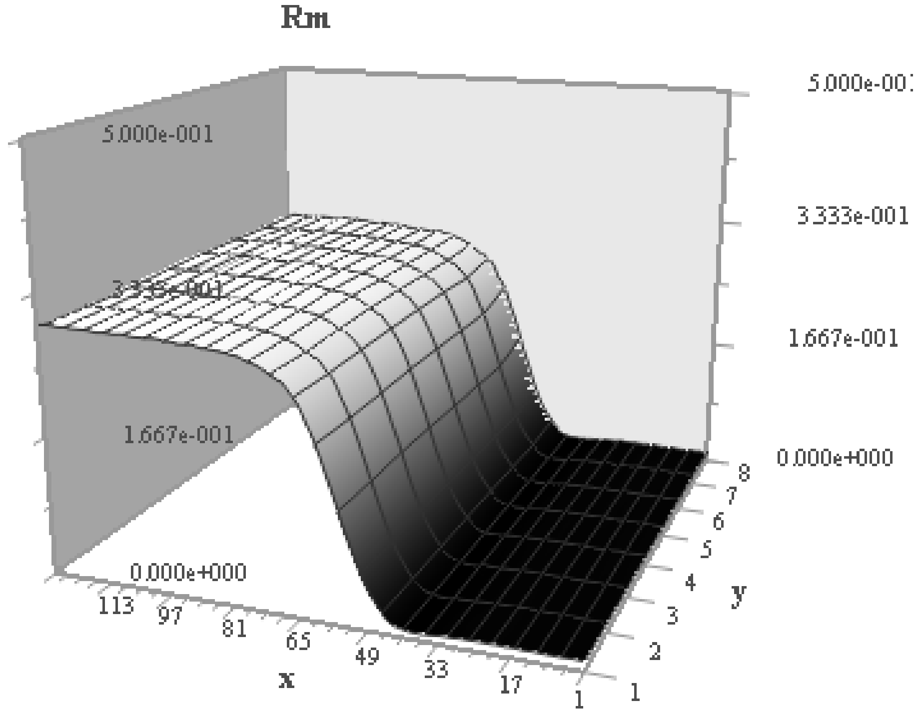
MW generator
0,6-1,2 GHz
valve
directional
coupler
antenna height
controller
b)
coaxial
cable
1 cm
microstrip
resonator
sensitive
element
detector
steeper
motor
antenna
sample
quartz plate
selective
amplifire
table
computer
adjusting
screws

Fig.1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3.333e-001
1.667e-001
0.000e+000
113
97
81
65
49
33
17
1
x
1
2
3
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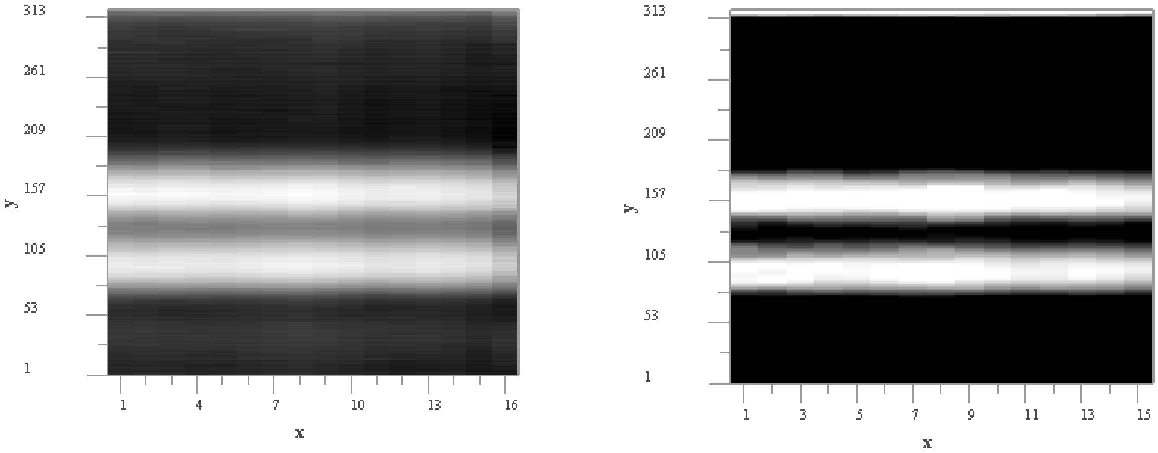
5
6
7
8
y

Fig.2


313
261
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53
1
y
1 4 7 10 13 16
x
313
261
209
157
105
53
1
y
1 3 5 7 9 11 13 15
x

Fig.3

Captures to the figures

Fig.1. Near-field scanning MW system: a) electrical schematic, b) antenna.

Fig.2. Measured one-dimensional scan image of metal-dielectric interface under the dielectric optically non-transparent layer with the depth h = 1.0 mm. Pixel size is 0.125 mm.

Fig.3. Initial (left) and reconstructed (right) image of dielectric strips under optically non-transparent layer with the depth h = 1.3 mm. Pixel size is 0.125 mm; w = d = 4 mm.