Submillimetric localization of microwave diagnostics and modification of objects of various nature

I.N. Bondarenko, Yu.Ye. Gordienko, A.V. Levchenko
Department of Microelectronics, Electronic Devices and Appliances
Kharkiv National University of Radioelectronics
Kharkiv, Ukraine
e-mail: mepu@kture.kharkov.ua

Abstract **– The analysis of the conditions and possibilities of localized electromagnetic fields formation was conducted via coaxial microprobe structures and their use for the diagnosis of electrophysical parameters and local heat influence.**

Keywords – localization; microwave; near-field; coaxial microprobe; converter

I. Introduction

With the design and development of scanning microwave microscopy (SMM) [1, 2] there was an idea of the creating possibility of microwave field sources with a significant concentration of energy in the local area of three-dimensional space. At the same time, there exists almost no radiation in the far field and the energy of the field decreases rapidly as the coordinate increases. Wave processes associated with the presence of standing and traveling waves do not appear. Such sources are called near-field, evanescent. Generated evanescent fields are determined to achieve a high degree of localization of their distribution.

These features of the near-field sources of the microwave field provides an ample opportunities of electrodeless, non-destructive local control of surface and subsurface areas of objects of arbitrary shape. Furthermore, due to its high localization of interaction with the object the reproducibility of measurement results improves significantly. Based on these sources of microwave probing field a wide range of primary measuring converters can be built, which are the basis of microwave sensors.

The resonator measuring converters can get the most widespread by experience of the development of SMM. Unlike SMM, their locality can be varied from a few micrometers up to several millimeters due to the construction and the aperture unit size. Naturally, at the millimeter aperture unit sizes and areas of interaction at sufficiently high operating frequencies it is necessary to consider the possibility of wave processes appearance in the areas of interaction. Such converters are characterized by the fundamental resonant frequency change (Δf / f) and quality factor change (ΔQ / Q) signals under the influence of the object under study. From these signals, the required operating signals are selected by their further processing and conversion and measurement information of microwave sensors are generated.

Provision of high local distribution of the electromagnetic energy also opens up the possibility of an active field and thermal impact on local areas of different objects in order to change their properties.

The analysis of the current processes becomes more complicated with the difficulty of their analytical description therefore for their theoretical and model studies the numerical methods are used.

II. Main Part

In general, the high local resonator measuring converters (RMC) contain a so-called aperture-forming region I (Fig. 1) and the area of the field energy accumulation II. Their influence on the signals $\Delta f/f$ and $\Delta Q/Q$ differs one from another. Aperture-forming region forms a local source of the microwave near field. Therefore, its characteristics define these signals consistently and qualitatively. The design of the aperture-forming region may be different, but by far, the most popular is a coaxial structure, which, along with the convenience of interfacing with accumulative (resonator) area can be made quite tiny, and also has extensive capabilities of variation of geometry and the end part sizes, forming a local field distribution.

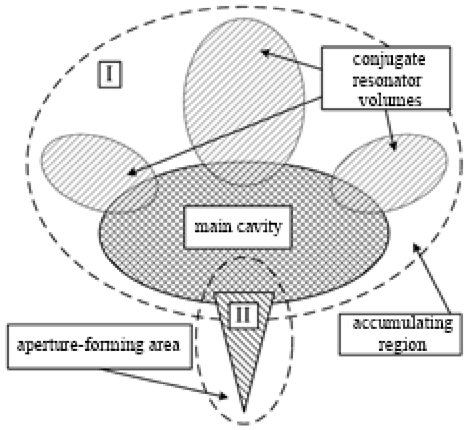

Figure 1 – A generalized schematic illustration of RMC

Accumulative area II defines the quality factor of the original RMC. Therefore, its impact mainly affects the value of $\Delta Q/Q$ signals. In contrast to these signals an increase of the stored in RMC energy reduces $\Delta f/f$ signal. Usually standard or adapted resonant structures are used as accumulative regions when creating the RMC in relation to the current tasks.

The actual design of some RMC are shown in Fig. 2.

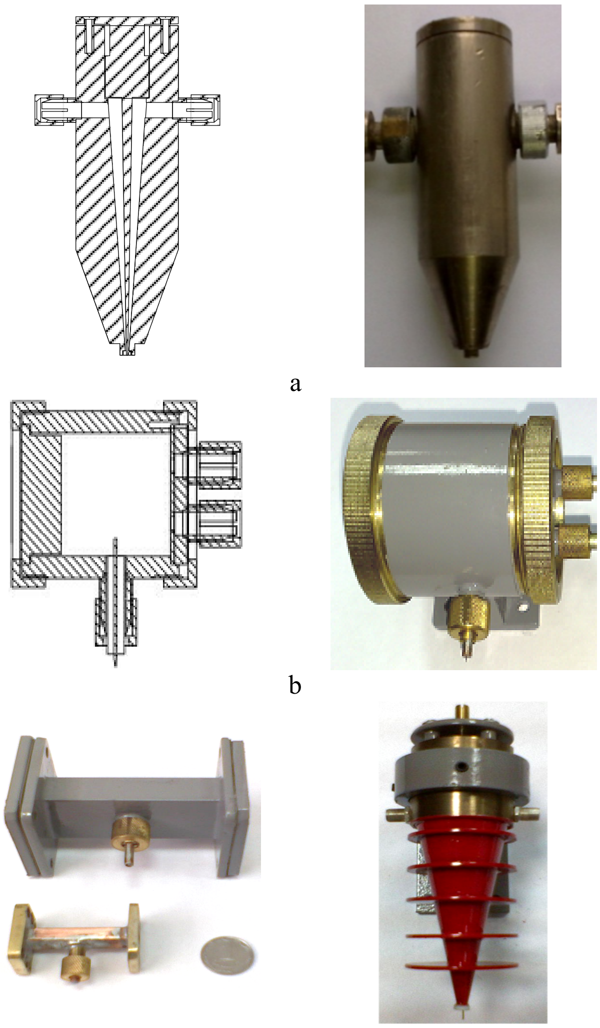

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Figure 2 – RMC constructions: a) conical coax; b) a cylindrical; c) based on the waveguide segments; d) conical coax with the hybrid structure of the field

The idea of a qualitative nature of the interaction between the regions I and II are given in Fig. 3, from which the field distribution in a system with the same area II and different areas I is represented in comparison.

It follows from the above that the effect of electrodynamic structure of accumulative area on electrodynamic probe field structure in the sample is virtually absent. It mainly depends on the geometry of the end part of the probe, the interaction region and electrical characteristics of an object of diagnosis or modification (Fig. 4).

The results of experimental and theoretical studies on the localization of microwave radiation in view of its use in microelectronics technology are brought in [4, 5]. The development of these studies leads to the creation of a new method of formation of micro- and nanostructures based on scanning high local microwave impact on semiconductor and dielectric objects. This approach is similar to the probe technology using scanning tunneling (STM) and atomic force microscopes. Its important advantage is the thermal nature of the impact and applicability to a wide range of materials. In conjunction with the scanning microwave microscopy (SMM) it can create a new trend in microelectronics technology - scanning microwave technology (SMT).

Most of the features of the local microwave heating are shown in the study of the kinetics of establishing temperature at characteristic points of the heated volume. Such points are primarily concerned with the geometry of the microwave probe and are determined by the distribution of the microwave field. In this case, the field distribution depends on the geometry of the probe tip. For spherical shape a microwave field is strongly localized under the center of tip. For conical shape (in frustoconical shape), on the contrary, microwave field is localized under the periphery. Under the center of a tip field tends to zero with an increase of the tip radius. Therefore, for the spherical shape of the edge the characteristic points lie under the center of tip ($r = 0$); for conical shape the processes of heating under the center ($r = 0$) and the periphery ($r = R_{t1}$) should be considered separately. For both species of form of the tip the microwave field penetrates deep into the object at a distance comparable to the radius of the tip. In case of the spherical shape of the probe tip - to a lesser depth.

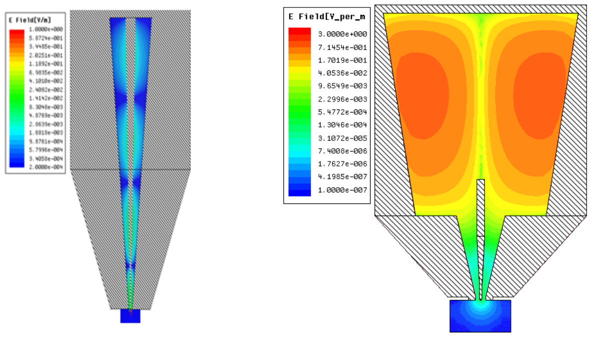

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Figure 3 – Diagrams of the electric field for the RMC with different accumulative area: a) conical coax; b) volumetric RMC with a coaxial output

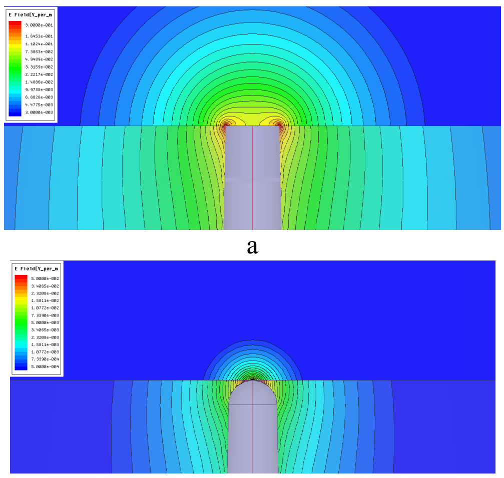

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Figure 4 – Diagrams of the electric field in the aperture of the conical coaxial RMC with different tip shape: a) flat; b) spherical

The work [6] shows that the microprobe with the edge in shape of hemisphere is most effective in the localization of the microwave electric field. Fig. 5 shows graphs of the distribution of the microwave field along the surface and in depth of the object, depending on its electrophysical parameters.

The graphs show that by using the flat edge of the probe the electric field will have a "pipe" character, and concentrate in the periphery of the tip. Usage of the tip of the probe in the form of a hemisphere allows to provide greater localization of the microwave electric field, and further heating, under the edge of the microprobe.

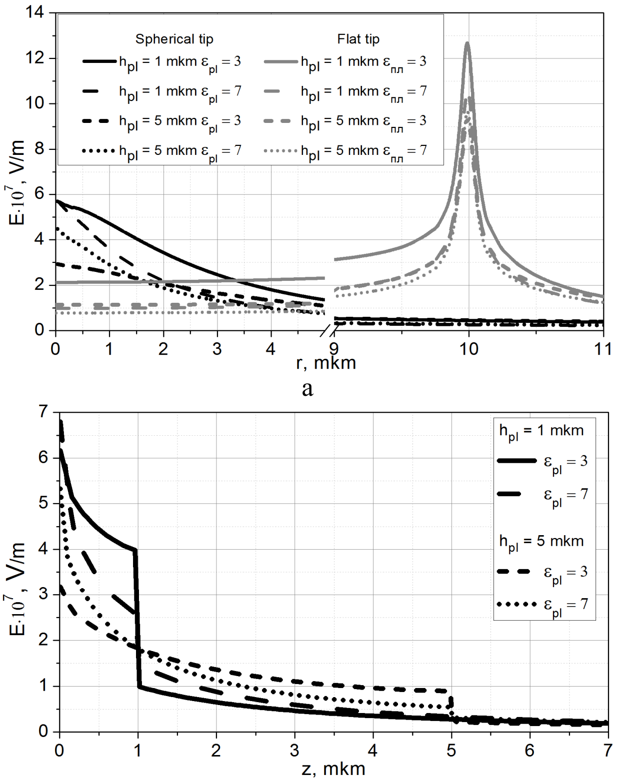

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Figure 5 − The distribution of the microwave electric field along the surface (a) and the depth of the object (б)

III. CONCLUSION

The independence of the local distribution of the microwave field generated by a coaxial microprobe structures on the species, type and operating frequency range and mating with them non-resonant and resonant elements are shown.

The structure of the local field distribution is determined by the shape and size of the aperture of the probe, the interaction zone with the object and its electro-physical parameters.

Local microwave fields of various configurations can be used as for diagnosis as for modifying the thermal effects on objects of various nature.

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